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SECOND INTERNATIONAL CONGRESS OF THE INTERNATIONAL RADIATION PROTECTION ASSOCIATION

3-8 May 1970, at the Metropole Hotel, Brighton, England

Abstracts of papers presented at the Congress

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MONITORING OF WORKERS I

1 Oral presentation. Radiological protection of workers exposed to airborne plutonium particulate.
B. HOLLIDAY, UKAEA Health and Safety Branch, Harwell (UK).

The general aims of monitoring for plutonium are to determine deleterious changes in the working environment, to identify workers at risk, to estimate plutonium retention of the bodies of workers and, if possible, to identify causes so that the release of plutonium may be reduced in future by changes in design or operation, or by personal protection. There are two basic types of monitoring, environmental and individual.

The design and interpretation of an environmental programme are difficult because plutonium is released into the working areas in chemical and physical forms which may not be well established, and at one or more of the very many possible positions which may often be closer to the operator than the monitoring instrument. It is against this extremely complex background that a system of environmental monitoring has to be designed. The techniques that can be employed are briefly discussed.

Interpretation of individual monitoring is also difficult, as the monitoring procedures are carried out at infrequent intervals and the measurements made are only indirectly related to retention. The roles played by urine and faecal sampling and direct counting over the chest, of L X-rays and low-energy γ rays from deposited plutonium, are briefly discussed and reference made to the lung model assumed for interpreting the data.

The main aim of the paper is to stress that the scale of the monitoring programmes needs to be related in some way to the quantity of plutonium being handled or to conditions in the working areas. It is demonstrated how experience of environmental monitoring in the working areas and of individual monitoring can be used to define a single, integrated programme to determine plutonium retention in the body and to give early indications of individuals who have been at risk.

2 Read in title. Calcul du degré de solubilité des radionucléides dans les liquides organiques, d'après la variation de leurs excréctions urinaires en fonction du temps. M. DELPLA et R. SCHAEFFER, Electricité de France, Paris (France).

Quelle que soit voie d'introduction, la connaissance du coefficient de solubilité des radionucléides dans les liquides organiques est nécessaire pour déterminer quels sont les organes les plus atteints et les doses correspondantes.

La classification, à cet égard, des radionucléides en trois classes [Task Group on Lung Dynamics, Chairman P. E. MORROW; *Health Phys.* **12**, 173-207 (1966)] fournit des valeurs moyennes tirées de l'étude de quelques cas de contamination humaine ou d'expériences sur animaux, mais ne saurait tenir compte des conditions particulières à chaque contamination, ni des variations individuelles.

La variation, en fonction du temps, de l'excrétion urinaire d'un radionucléide diffère selon que celui-ci est passé rapidement dans le sang ou, au contraire, n'est libéré que progressivement par les poumons: de l'allure de la courbe qui représente cette variation, nous déduisons le degré de solubilité qui a réellement présidé au métabolisme du radionucléide chez l'individu considéré.

La méthode est appliquée au cas de cinq sujets récemment contaminés par inhalation de ^{60}Co . Les valeurs trouvées pour le degré de solubilité sont très faibles: les deux organes les plus atteints sont donc les poumons et le gros intestin inférieur, et les doses absorbées par l'organisme entier peuvent être négligées.

Calculation of the degree of solubility of radionuclides in organic liquids from the variation of their urinary excretion as a function of time.

Whatever the rate of intake, a knowledge of the coefficient of solubility of radionuclides in organic liquids is necessary to decide which are the most affected organs and the corresponding doses.

The classification in this respect of radionuclides in three classes (Task Group on Lung Dynamics,

Chairman P. E. MORROW; *Health Phys.* **12**, 173-207 (1966)) provides average values drawn from the study of several cases of human contamination or from experiments on animals, but cannot take account of the particular conditions of each contamination or individual variations.

The variation as a function of time of the urinary excretion of a radionuclide depends on whether it is transferred rapidly into the blood or, by contrast, is liberated only progressively from the lungs: from the appearance of the curve which represents this variation, we deduced the degree of solubility which actually governs the metabolism of the radionuclide in the individual concerned.

The method is applied in the case of five subjects recently contaminated by inhaling ^{60}Co . The values found for the degree of solubility are very small: the two organs most affected are thus the lungs and the lower large intestine, and the doses absorbed by the whole body can be ignored.

3 *Read in title. Operational experience with the personal centripeter, with particular reference to nose-blow sampling.* W. A. LANGMEAD, UKAEA Health and Safety Branch, Harwell, and R. T. BRUNSKILL, UKAEA, Windscale Works, Sellafield (UK).

The personal centripeter has been used operationally to measure the activity concentrations and the aerodynamic diameters of plutonium aerosols in the working areas of a nuclear chemical plant. This instrument, which samples at 2 l./min, separates coarse dust from the finer particles which are collected separately on different parts of a high efficiency, glass fibre filter paper suitable for direct radiation counting. The collection characteristics of the instrument are such that the activity associated with unit density spherical particles greater than $5\ \mu\text{m}$ dia. is collected in the central area of the paper, the remaining particles being deposited on the outer annular ring of paper.

The instrument has been calibrated against a static cascade centripeter and a personal air sampler, the three instruments being positioned together in various plutonium areas. Subsequently the personal centripeter was worn on the coat lapel by an operator throughout shift workings over several months. At the end of each shift, two "nose-blows" were obtained from the operator and the plutonium activity determined by alpha counting of the ashed tissues.

Relationships between the nose-blow activities and the large particle fractions of the personal centripeter readings are reported and the validity

of the nose-blow as an operational monitoring technique has been assessed. The value of the personal centripeter as a particle size selective sampler for routine use in the measurement of radioactive aerosols has also been determined.

4 *Read in title. A size-selective dust sampler which conforms to the lung model proposed by the ICRP Task Group on Lung Dynamics.* J. STEPHENSON, Health Physics and Medical Division, AERE, Harwell (UK).

This paper describes a size selective dust sampler used to obtain an estimate of the total dust concentration, and the fraction which would penetrate to the pulmonary compartment of the lung. The results obtained from the samples may be used in conjunction with the curves given in the report of the ICRP Task Group II (1966) to obtain an estimate of the fraction of the dust retained in the nasopharyngeal and tracheobronchial compartments of the respiratory system.

The design of the sampler allows a considerable amount of flexibility in the choice of separation characteristics and it is believed that a sampler of similar design could be made to conform to any future changes in the lung model deposition curves.

5 *Oral presentation. Problems in the interpretation of data from the measurements of ^{239}Pu in vivo.* D. RAMSDEN, M. E. BAINS, R. A. PIKE and C. O. PEADODY, AEE Winfrith (UK).

The importance of such parameters as the body build of the subject and the isotopic composition of a contaminant are discussed in relation to the accurate determination of the amount of insoluble ^{239}Pu in the human lung using equipment previously described by the authors. This is illustrated by reference to an incident in which an individual inhaled some insoluble plutonium oxide resulting in an initial lung burden of about 20 nCi. The lung contents were measured on several occasions during the next two years and compared with the faecal and urine excretion data accumulated after the incident. The results from this incident suggest that urine monitoring is not a reliable guide to the amount of PuO_2 in the lung.

This paper also discusses the need to match calibration factors to the exposed individual's body build in order that full advantage can be taken of the sensitivity of the detection system.

Whole Body Counting

Rapporteur Presentation

- 6 External counting of low-energy emitters in lung: chest attenuation measurements using inhaled radioactive aerosols.** B. T. TAYLOR and D. V. BOOKER, Health Physics and Medical Division, AERE, Harwell (UK).

The results are given of experiments designed to yield realistic calibration data for the external counting of the uranium L X-rays from ^{239}Pu in the human lung. In the first experiment, seven volunteer subjects inhaled polystyrene particles labelled with the 20 keV X-ray emitter ^{103}Pd and the 323 keV gamma-ray emitter ^{51}Cr . The data have been analysed to determine an effective tissue thickness for each of the subjects. The values ranged from 3.6 cm to 6.5 cm, and the correlation with body weight, height and chest circumference is discussed. The thickness values are of general application, and enable calibration data to be derived for other nuclides and detector systems.

In more direct simulation of ^{239}Pu , a group of subjects inhaled particles labelled with ^{233}Pa , a 27-day β emitter which also emits uranium K and L X-rays and 312 keV gamma-rays.

- 7 Escape of characteristic X-rays from Xe-filled proportional counters and its effect on *in vivo* measurements of Pu-Am.*** S. S. YANIV, A. BROOSKY and D. SASHIN, Department of Radiation Health, Graduate School of Public Health, University of Pittsburgh (USA).

We have developed a method that permits, in principle, the evaluation of *in vivo* plutonium and americium, utilizing spectral measurements of the X- and gamma-radiations emitted by these isotopes without necessarily requiring the *a priori* knowledge of the Pu-Am ratio or phantom calibration in each case. For this purpose xenon-filled proportional counters were used. Analysis of Pu-Am spectra indicated that many counts observed in the plutonium and americium L X-ray region were actually due to absorption by the detector of higher-energy photons followed by the escape of xenon characteristic X-rays. The higher-energy photons originate mainly in americium (Compton-scattered 59.6 keV gammas), and to a smaller degree also in plutonium. Quantita-

tive assessment of *in vivo* Pu-Am thus requires correction of the count-rate in the L X-ray region for these contributions from higher-energy photons. This correction is particularly important in cases where the contaminant is located deep within the body, since the L X-rays are attenuated faster than the higher-energy photons. The relative importance of this correction thus depends upon the Pu-Am ratio, the thickness and type of absorber, and the particular detector used. In practice, an approximate correction factor for each case has been obtained from spectra in the 35-55 keV region obtained simultaneously with the corresponding spectra in the L X-ray region. The contribution of these higher-energy photons to count rates observed in the L X-ray region severely limits the practical usefulness of xenon-filled proportional counters for quantitative evaluation of plutonium and americium body burdens.

- 8 Détermination du plutonium *in vivo*.** M. KUNZLE-LUTZ, H. METIVIER, D. NOÛBE, M. GANCE et M. A. BEUVE, Commissariat à l'Energie Atomique, Paris (France).

La nécessité de déterminer dans un organisme vivant contaminé par du plutonium la charge pulmonaire nous a amené à utiliser un compteur proportionnel sensible aux rayons X associés à la désintégration du ^{239}Pu dont le rayonnement alpha ne peut être mesuré.

L'appareillage utilisé est composé de trois parties: un détecteur formé de deux compteurs proportionnels xénon-méthane branchés en anticoincidence, un ensemble analyseur électronique associé, et une enceinte blindée dans laquelle le détecteur est positionné de façon variable et reproductible par rapport aux animaux dont le système de contention permet le repérage.

Le spectre obtenu sur un animal vivant et correspondant à la bande d'énergie 2-26 keV, est perturbé par l'absorption du rayonnement due au passage à travers les tissus. Nous avons donc été amené à rechercher la déformation des spectres, et à relier le rendement de détection à la variation des aires de chaque pic. Les aires sont déterminées en approximant le spectre par une somme de gaussiennes. Le calcul de l'activité de même que les calculs intermédiaires ont donné lieu à l'écriture d'un programme complet.

Ces méthodes de mesure et de calcul ont été testées sur le rat, le lapin et le singe empoussiérés par l'oxyde de plutonium, et sont maintenant utilisées couramment dans les expériences de contamination respiratoire de singes.

* Supported in part by a US Public Health Service Research Grant from the Environmental Control Administration.

Determination of plutonium *in vivo*.

Because of the need to measure the lung burden of a living organism contaminated with plutonium, we have used a proportional counter sensitive to the X-rays associated with the ^{239}Pu disintegration, since the alpha radiation cannot be measured.

The equipment used is made up of three sections: a detector comprising two xenon-methane proportional counters connected in anticoincidence, an associated electronic analyser and a shielded enclosure in which the detector is placed in a variable but reproducible way, with respect to the animals, so that the system of measurement allows the location of the activity to be determined.

The spectrum in the energy range 2–26 keV obtained from a living animal, is modified by the absorption of radiation in the tissues. We have therefore studied the distortion of the spectra and have related the efficiency of detection to the variation of area of each peak. The areas have been measured by approximating the spectra by a series of Gaussian distributions. The calculation of the activity and the intermediate calculations have been achieved by the preparation of a complete programme.

These methods of measurement and calculation have been tested on the rat, rabbit and monkey, insufflated with plutonium oxide, and are currently being used in respiratory contamination experiments on monkeys.

9 Calculations concerning the calibration characteristics of a whole body counter. A. ANDRÁSI and G. KÖTEL, Central Research Institute for Physics, Budapest (Hungary).

The absolute photopeak efficiency of a 6 in. \times 4 in. NaI/Tl/crystal detector was evaluated from experimental data and for point source an explicit analytic expression was obtained in terms of the position and the quantum energy of the source which permits to calculate the photopeak efficiency to $\pm 10\%$ accuracy at energies from 0.1 to 2.0 MeV.

Using this equation the relative counting efficiency of a whole body counter as a function of the tilting chair, arc and scanning-bed geometry parameters for point source was evaluated on computer by the aid of a mathematical model by which the attenuation effect was also taken into account. The influence of the various scanning parameters on the counting efficiency was established and the optimum possible scanning parameters could be assessed.

Sufficiently uniform and even relatively high counting efficiency can be achieved by using a "scanning end-stop method" with a scanning length of 126 cm, a bed-detector centre distance of 50 cm,

and a relative duration of the scanning end point operation, i.e. $t_{\text{end}}/t_{\text{scan}}$ ratio of 0.14. With these parameter values the variation of the relative photopeak efficiency can be kept less than 10% in the longitudinal direction within about 100 cm length in the environment of the scanning centre in the range of total linear attenuation coefficients from 0.000–0.160 cm^{-1} .

The reliability of the mathematical model and of the computed values were confirmed by measurements.

Some further possible applications of the absolute photopeak efficiency equation are briefly discussed.

10 A procedure to indicate persons with internal radioactive contamination at a low level. J. G. ACKERS, Health Protection Division, Reactor Centrum Nederland, Petten (Netherlands).

When a large group of possibly contaminated persons should be measured with a whole-body counter, there is a need for a quick procedure in order to select with a reasonable high degree of probability the contaminated persons from the others at a fairly low level for further investigation.

At many institutes a one-channel analyser is used measuring the countrate of gamma-radiation from say 0.1 to 2.0 MeV. By the use of the ratio in countrate of two channels measuring gamma's from 0.1 to 0.6 MeV and from 0.6 to 2.0 MeV the influence of bodysize and of background fluctuation can be strongly reduced. In this manner the detection limit can be lowered considerably compared with the one channel method using the same counter set up.

The merits of this system will be discussed.

It will be pointed out that for determination of some nuclides this method would be of important profit at low costs.

11 Contrôle de contaminations au moyen d'un "whole body counter" 4π à usage clinique. P. A. DELWAIDE, Service de Chimie Médicale, Toxicologie et Hygiène, Université de Liège (Belgium).

Le "Whole Body Counter" de l'Université de Liège, à destination principalement clinique, est constitué d'un détecteur en plastifluor de géométrie 4π , de 18 photomultiplicateurs et d'un spectromètre à 3 canaux. La résolution en est relativement faible, mais le rendement très élevé. Tenant compte de ces caractéristiques, les possibilités d'un appareil de ce genre pour le contrôle des contaminations radioactives sont discutées. L'identification précise des radionuclides incorporés ne

peut être effectuée, mais l'appareil peut rendre des services pour la surveillance de la teneur en ^{137}Cs dans la population, et aussi en cas de contamination en milieu hospitalier et universitaire, où l'isotope responsable est en principe connu. Les activités décelables sont généralement de l'ordre de 10^{-4} de la "charge corporelle maximum tolérée" pour les principaux radioéléments à utilisation médicale; la précision et la reproductibilité sont satisfaisantes et le facteur de géométrie n'exerce qu'une influence réduite. La technique d'étalonnage pour le ^{137}Cs , requise par la faible sélectivité, est décrite. Les valeurs des "charges corporelles" en ^{137}Cs pour des échantillons de la population liégeoise sont rapportées; des corrélations ont été recherchées entre la teneur en ^{137}Cs et l'état du métabolisme potassique. Les résultats d'une surveillance du personnel hospitalier et scientifique sont également indiqués, ainsi que les méthodes de calibration pour les divers isotopes mesurés. Les données recueillies attirent l'attention sur l'importance du problème des contaminations fréquentes par ^{131}I en milieu médical.

The monitoring of contamination by a 4π whole body counter intended for clinical use.

The whole-body counter of Liège University, intended principally for clinical applications, consists of a 4π plastic scintillator with eighteen photomultipliers in a three-channel spectrometer. The resolution is fairly low but the sensitivity very high. The potentialities of an apparatus of this type for monitoring radioactive contamination is discussed, taking into account all these characteristics. It is not possible to make precise identification of radionuclides in the body, but the equipment can be used for the surveillance of the level of ^{137}Cs in the population or in the event of contamination of the environment of the hospital and the University by an isotope which is otherwise identified. The detectable activity is generally of the order of 10^{-4} of the maximum permissible body burden of the main radioelements used in medicine. The accuracy and the precision are satisfactory and the geometrical factor has only a minor influence. The special calibration technique for ^{137}Cs is necessitated by the low resolution and this technique is described. The body burdens of ^{137}Cs in samples of the Liège population are reported. Correlations have been set between the level of ^{137}Cs and the state of potassium metabolism. The results of monitoring of hospital and scientific personnel are reported, as well as methods of calibration for the different isotopes measured. The results draw attention to the importance of the frequent contamination by ^{131}I in the medical environment.

12 Programme pour le calcul systématique des doses à partir des mesures périodiques de la radioactivité incorporée. P. GUILLOT, Service Protection, CCR, Ispra (EURATOM).

Par suite de l'emploi toujours plus répandu des radioisotopes, et du nombre croissant de personnes contaminées de façon chronique, il devient souhaitable de convertir systématiquement en doses les diverses mesures périodiques de radiotoxicologie ou des anthropogammamètres. En l'absence d'incidents au cours de ces mesures de routine, on peut admettre les hypothèses suivantes:

- pendant le temps passé en zone contaminée, l'activité interne d'une personne professionnellement exposée augmente d'une quantité constante par unité de temps.
- pendant une durée de 24 hr, la rétention du radioélément dans l'organisme est une fonction linéaire du temps $R = 1 - \lambda t$
- les mesures périodiques se font à des instants répartis de façon aléatoire dans la journée.

Dans ces conditions, le calcul montre que la dose absorbée dans l'intervalle entre deux mesures est une fonction linéaire des activités incorporées mesurées au début et à la fin de cet intervalle A_1 et A_2

$$D = K_1 A_1 + K_2 A_2$$

K_1 et K_2 sont des coefficients dont la valeur dépend de l'intervalle de temps, des caractéristiques physiques et métaboliques du radioisotope. Un programme, écrit en FORTRAN IV, a été mis au point pour le calcul systématique des doses de façon à pouvoir additionner les risques dus à tous les radioéléments incorporés.

A programme for the systematic calculation of the doses from regular measurements of the radioactivity taken up by the body.

Following the ever-expanding use of radioisotopes and the increasing number of people chronically contaminated, it would be desirable to convert the various regular measurements of radiotoxicology and body γ emission into dose. In the absence of incidents between routine measurements the following hypotheses might be accepted: the internal radioactivity of a worker increases at a constant rate with time during the time spent in the contaminated area; over a period of 24 hr, the retention of a radioelement in the body is a linear function of time, $R = 1 - \lambda t$; the periodic measurements are made at random(?) times during the day.

In these conditions, calculation shows that the absorbed dose in the interval between two measurements is a linear function of the activities A_1 and A_2

measured in the body at the beginning and the end of the interval.

$$D = K_1 A_1 + K_2 A_2$$

K_1 and K_2 being coefficients whose values depend on the interval of time and the physical and metabolic characteristics of the radioisotope. A programme in FORTRAN IV has been applied to the systematic calculation of doses in order to sum the risks from all the radioactive elements taken up in the body.

13 Read in title. Whole body counting of occupational workers. R. K. HUKKOO and D. S. KATOCH, Health Physics Division, Bhabha Atomic Research Centre, Bombay (India).

As part of the personnel monitoring programme a shadow-shield whole body counter is used to carry out routine measurements of total body activity of uranium miners and occupational workers at Trombay. The shield is designed to use a minimum of shield material and background counting rates comparable with steel room monitors have been obtained. Data are presented on the performance characteristics of the counter. The counter has been used in single-crystal multiple-position counting geometry to study the pattern of distribution of radon daughter products along the mid-axis of a control subject exposed to uranium mine atmosphere.

Results of body burden measurements on more than 300 subjects are presented. These involve the workers at the Jaduguda Uranium Mine and Mill and workers from the processing plant and reactors at Trombay.

14 Read in title. A low background, underground whole body counting facility.* R. V. GRIFFITH, A. L. ANDERSON and C. L. LINDEKEN, Lawrence Radiation Laboratory, Livermore, Calif. (USA).

A whole body counting facility has been built which features an underground monitoring room with a volume of 20.5 m³. The 1.5 m thick shielding material is crushed serpentine rock. Entrance to the room through a single bend corridor eliminates the need for a massive door.

Serpentine rock was selected for the shield because it was found to have a specific activity which is equivalent to commercially available steel or lead. Construction of a compacted rock shield around a

thin steel shell is simpler and less expensive than fabrication and placement of a massive metal room. During construction more than 300 samples of serpentine, steel, wall coverings, floor material, adhesives and many other items were analyzed for radioactivity content. Sample measurements were made using two 20.3 × 10.2 cm NaI(Tl) crystals in a low background steel-lead cave. Counting was done with a 256 channel pulse height analyzer.

The facility is located near a research reactor, so that the presence of ⁴¹Ar together with ingress of natural ²²²Rn and radon daughter products, combined to create a background instability. Methods of eliminating these instabilities include a ventilation system which can be used either to recirculate the monitoring room air through a charcoal bed and absolute filter, or to flush the room with filtered air from the outside.

Personnel are counted on a motorized table, 2 m long, that passes under ceiling-mounted detectors. The detectors available include two large sodium iodide crystals for measurement of gamma rays having energies in excess of 0.1 MeV. Low energy gamma and X-ray measurements are made with a pair of thin NaI crystals which are attached to the faces of 5 cm thick CsI crystals. Discrimination of the pulse shape from the CsI compared to that of the NaI provides means for background suppression.

A pleasant atmosphere in the monitoring room is developed by covering the walls with a vinyl wall material and use of a high fidelity sound system which plays music from FM radio. A television monitor and intercommunication system are used to communicate between the monitoring room and operator's console located in the reception room.

The 0.1–2.0 MeV gamma background in the room is less than 0.30 counts/min/cm³ of crystal volume using a 29.2 × 10.2 cm sodium iodide crystal. The low energy background from 10–100 keV is less than 3.0 counts/min using a 15.2 cm × 0.3 cm NaI crystal with background suppression.

15 Oral presentation. Neue Methode für den Inhalationsnachweis von ²³⁹Pu durch Ausmessen des Bronchialsekrets. H. BRUNNER und R. LEIMGRUBER, FIR, Würenlingen, und H. HERZOG, Medizinischen Universitätsklinik, Basel (Switzerland).

Die bisher bekannten Methoden zum Nachweis einer Pu-Inhalation durch Direktmessung der Lunge oder durch Ausscheidungsanalysen sind alle sehr zeitraubend und ziemlich unempfindlich. Nach einem Inhalationszwischenfall bestehen Aussichten auf eine wirksame Therapie, sofern diese innert

* Work performed under the auspices of the US Atomic Energy Commission.

etwa 2-4 Stunden einsetzen kann. Dies bedingt, dass innert 1-2 Stunden eine qualitative Ja-Nein-Aussage über das tatsächliche Vorliegen einer Inhalation gemacht werden kann. In Zusammenarbeit zwischen dem EIR und dem Leiter der Abt. für Atemungskrankheiten der Medizinischen Universitätsklinik in Basel konnte eine für den raschen Nachweis geeignete Methode gefunden werden. Nach einem Inhalationszwischenfall wird sogleich mit Hilfe eines automatischen Respirators mit der Inhalation einer hypertonen Kochsalzlösung begonnen, die, kombiniert mit einem Expektorans, die Schleimproduktion in den Bronchien und die Ausscheidung des Schleims mittels gesteigerter Tätigkeit des Flimmerepithels soweit erhöht, dass nach etwa einer Viertelstunde genügend Schleim produziert und durch Auspucken gesammelt werden kann. Eine Schnellanalyse auf das Vorhandensein von Plutonium wird dann ausgeführt, sodass etwa 1 bis 1½ Stunden nach dem Zwischenfall entschieden werden kann, ob die vorgesehene Therapie durch Lungenspülung in der Basler Klinik durchgeführt werden soll, was innert 3-4 Stunden nach dem Zwischenfall jederzeit möglich wäre. Durch genauere Analysen der Schleimprobe mittels Halbleiter- α -Spektrometer und dünnem Szintillator kann z.B. auch das Verhältnis $^{239}\text{Pu} : ^{241}\text{Am}$ ermittelt werden, was dann bei der weiteren Überwachung des Falles mittels Direktmessung der Lunge die Verwendung der härteren 60 keV- γ -Strahlung des ^{241}Am an Stelle der schwierig nachzuweisenden 17 keV-Röntgenstrahlung des ^{239}Pu erlaubt. Weitere Untersuchungen sollen zeigen, ob die Inhalationsmethode ausser qualitativen auch quantitative Rückschlüsse auf die eingeatmete Aktivität erlaubt, und ob die Methode selbst schon eine wesentliche therapeutische Wirkung aufweist.

New methods for indicating ^{239}Pu inhalation by measurement of bronchial secretion.

Up to the present, the methods used indicating plutonium inhalation by direct measurement of the lungs or by secretion analysis are all very time consuming and not very sensitive. After an intake by inhalation, there are now prospects of an effective therapy, provided that it can be applied within 2-4 hr. This means that within 1-2 hr it should be possible to make a qualitative yes/no statement about the actual occurrence of inhalation. The EIR, in conjunction with the Head of the Department for Respiratory Diseases at the University of Basle Clinic, have discovered a suitable method for a quick proof. After an inhalation intake, inhalation of a hypertonic common salt solution is started with the

aid of a respiratory machine which, combined with an expectorant, increases the mucus production in the bronchi by means of increased activity of the Flimmerepithelia, to such an extent that after about ¼ hr enough mucus has been produced and can be collected by spitting out. A quick test for the presence of plutonium will then be carried out. Thus, 1-1½ hr after the intake, it will be determined whether the method of therapy used in the Basle Clinic should be continued. This usually takes 3-4 hr after an intake. By more detailed analyses of the mucus experiment by means of an α spectrometer and a thin scintillator, the ratio of ^{239}Pu to ^{241}Am , for example, can be ascertained; this then permits the use of the harder 60 keV γ -radiation, under further supervision of the case by direct measurement of the lungs, instead of the 17 keV X-rays of ^{239}Pu which are difficult to measure. Further examinations should show whether the sputum method allows quantitative as well as qualitative conclusions about the inhaled activity and whether the method itself produces any material therapeutic effect.

RADIATION PROTECTION POLICY AND ADMINISTRATION I

16 Oral presentation. The application of appraisal techniques to radiation protection activities. J. R. HORAN, USAEC, National Reactor Testing Station, Idaho Falls, Idaho (USA).

The management of any nuclear facility is responsible to judge independently the quality of its performance in all activities through the collection of pertinent information and the deliberate evaluation of the overall results, efficiency and effectiveness, against appropriate criteria. Without the use of some method of evaluation and follow-up, it is only a matter of time for an effective program to deteriorate into obsolescence and the waste of resources.

The need for internal appraisal is greatest in the more rapidly changing areas of technology such as radiation protection. This is one of the most challenging activities for the professional health physicist. It is his task to perform an objective review and evaluation of existing activities and procedures, to report formally on the conditions found and, whenever necessary, to recommend any action for management consideration.

The criteria and techniques employed to improve operating health physics programs by greater efficiency and economy will be presented based on twelve years of experience at the National Reactor Testing Station.

17 Oral presentation. Regulatory inspection of by-product material licensees in the United States.

H. E. BOOK, USAEC Division of Compliance, Berkeley, California (USA).

The uses of most radioactive materials in the United States are licensed and regulated by the United States Atomic Energy Commission. After a license is issued, the Division of Compliance performs regular inspections of the licensee's operations to evaluate safety and to determine compliance with regulations and with conditions of the license. The Division also takes appropriate enforcement action against those licensees where an unsafe condition or noncompliance exists. This paper describes the organization of the Division of Compliance, including the number of people involved and their professional specialties. The education, training and experience of the typical health physics inspector in the organization are described. Salary ranges are discussed. The significant aspects of a typical radiological safety inspection are described, including frequency of inspections, physical inspection of equipment and facilities, observation of work in progress, review of procedures and records, independent measurements, and discussions with actual isotope users and with company management. The types of inspection reports and typical enforcement actions are discussed. The paper concludes with a brief description of the program for transfer of some of these regulatory functions from Federal control to the jurisdiction of individual states.

18 Oral presentation. A mental health problem in the Japanese nuclear industry. Y. KUROKAWA, Power Reactor and Nuclear Fuel Corporation, Y. MINAGAWA, Toshiba Company Central Laboratory for Radiological Protection, and M. SUZUKI, National Institute of Radiological Sciences, Chiba (Japan).

Because of the direct catastrophe of two atomic bomb explosions in August 1945 and of the indirect disaster from the atomic bomb test in the Pacific, the so-called disaster of "deadly ashes" on the Lucky-Dragon Fishermen in March 1954, Japanese people have been very sensitive and emotional about the words "atomic power" or "radioactivity".

This has caused great difficulty in the proper development of nuclear industries in Japan where the people are strongly dependent upon marine products and sources, because of the narrowness of arable land and of dense population, in spite of the fact that the nation had decided the advent of developing the nuclear industries already 15 yr ago.

Since WHO had indicated the importance of mental health aspects for the development of nuclear industries more than 10 yr ago, the authors have been conducting some survey and analysis on mental health problems associated with the development of nuclear industries of the country, by making a survey on the mental health status of workers in the industry, by investigating the mental health tendency of workers through some psychiatric tests or inquiries, and by pursuing the changing pattern of emotional reaction of people on atomic energy matters through some surveys conducted by some organizations, although there was, in general, an unfavorable circumstance for such investigations.

Results of the investigations and studies on the mental health aspects for development of nuclear industries in the country will be reported and discussed by us, together with general aspects of the problem to be considered.

19 Oral presentation. Experience in the control of radiation dose in United Kingdom civil nuclear power stations. B. W. EMMERSON, CEGB, Bradwell Power Station, E. P. GOLDFINCH, CEGB, Dungeness Power Station, and B. W. SKELCHER, CEGB, Sizewell Power Station (UK).

This paper is based on the operational experience gained during the past seven years at the three civil power stations operated by the South Eastern Region of the Central Electricity Generating Board. These stations, Bradwell, Dungeness and Sizewell, were commissioned between 1962 and 1965 and are similar in type, each having two gas cooled graphite moderated reactors, fuelled with natural uranium, and are operated on base load generation at high load factors. The stations are staffed as self contained units each employing its own maintenance and services staff, in addition to plant operators.

The paper examines the accrued radiation doses received at each station since commissioning. Details are given of the accumulated dose to various groups of workers, and the range and variation in environmental dose rates is discussed. These doses are contrasted with the current ICRP recommendations for classified and non-classified persons and it is shown that there is no difficulty in meeting these requirements for whole body, extremity and internal doses. It goes on to illustrate the methods of radiation control adopted at the stations and quotes typical dose rates and contamination levels found in practise.

In conclusion, it is shown that on the basis of accrued annual dose, the number of classified persons who have exceeded 1.5 rems per year is less than 5%

of the total staff employed, and arguments are stated for and against the need for classifying more than the minimal number of employees.

20 Oral presentation. How much health physics? A preliminary analysis of a world-wide survey of the strengths of health physics services. B. A. J. LISTER, DERF, Thurso, and N. G. STEWART, Health Physics and Medical Division, AERE, Harwell (UK).

At the end of 1968 a questionnaire was sent to senior health physicists of major atomic energy establishments in Europe (18), N. America (8), UK (7) and other countries (4) requesting information on the professional and non-professional strengths of their health physics services (direct operations, operations support, decontamination and waste disposal, radiation dosimetry, bioassay, spectrometry etc.). Nearly all the establishments contacted have co-operated wholeheartedly in this survey.

This paper analyses the results as a function of the establishment population associated with active areas and the general nature of the establishment. The present analysis is necessarily preliminary, as many factors which influence the strength of an individual service organisation cannot be quantitatively assessed without a more detailed study of its historical growth, the nature of the operations covered, and the underlying philosophy.

SYMPOSIUM ON PLUTONIUM PROBLEMS

21 Invited paper. Biological problems posed by plutonium. G. W. DOLPHIN, UKAEA Health and Safety Branch, Harwell (UK).

Plutonium is a most valuable source of energy and industrial nations cannot afford to ignore its use. It is also a very toxic material due to its alpha decay, long half life and almost permanent retention once absorbed into the body. In order to appreciate the biological problems posed by plutonium, in its use in the atomic energy industry, it is necessary to give a brief review of our knowledge of plutonium metabolism and toxicity.

There are many practical problems which stem from the complex metabolism of plutonium in the body. First there is the problem of determining how much plutonium has entered a worker's body. This may be done from environmental measurements, from chest monitoring, from wound monitoring, or from excreta monitoring. Secondly, there is the problem of treatment to reduce absorption or retention of plutonium following a large accidental intake.

This treatment may be by removal of plutonium from the site of intake or by means of a chelating agent to prevent systemic deposition. A third practical problem concerns the collection of more human data from analysis of human organs and tissues obtained at post mortem. Serious consideration must also be given to the possibility of carrying out more human experiments, similar to those conducted by WRIGHT LANGHAM and his associates, because a better knowledge of the relationship between retention and excretion in humans is urgently required for routine control of the exposure of workers.

There has been a tendency over the last few years to seize on every opportunity to suggest reductions in the values of MPC and MPBB. If man is to benefit from plutonium as a cheap source of energy, then the choice of values for these parameters deserves careful consideration.

22 Invited paper. Experimental animal studies of inhaled plutonium.* W. J. BAIR, Biology Department, Battelle Memorial Institute, Richland, Washington (USA).

Because of the toxicity of the more available plutonium isotopes, knowledge of its behavior in humans is limited to that derived from cases of accidental exposure. Animal studies have, therefore, been the major source of information on the biological behavior and effects of inhaled plutonium.

In extensive studies with rodents and dogs, comparisons were made of the deposition and subsequent disposition of several inhaled plutonium compounds— PuO_2 , $\text{Pu}(\text{NO}_3)_4$, PuF_4 —including several types of PuO_2 and PuO_2 aerosols of several different particle size distributions. PuO_2 calcined at 1000°C showed maximum retention, while $\text{Pu}(\text{NO}_3)_4$ was cleared most rapidly from the lung, although even in the latter case 40–50% of the alveolar deposited plutonium was retained in the lung after 3 months. Of the PuO_2 aerosols studied, those composed of the smallest sized particles showed the greatest rate of clearance from the lung. Except for $\text{Pu}(\text{NO}_3)_4$ which translocated principally to bone and liver, the tracheobronchial lymph nodes accumulated the major fraction of plutonium translocated from the lung—amounting to 40% of alveolar deposited PuO_2 . Data from nearly 100 dogs, some followed for as long as 9 yr, were used to develop a mathematical model for inhaled PuO_2 in dogs. The half-time for pulmonary retention of alveolar deposited plutonium was about 1000 days. Excretion was principally via the feces.

* This paper is based on work performed under contract to the US Atomic Energy Commission.

Lymphopenia was the most consistent clinical observation in animals with lung burdens. Long-term effects included pulmonary neoplasia which occurred in 18 of 26 dogs that survived more than 3 yr after deposition of about a microcurie or more. Studies have also been made of the phagocytosis of PuO_2 , of biochemical changes in irradiated lung tissue, and of therapeutic procedures for removing inhaled plutonium. Dogs with plutonium lung burdens have been useful in evaluating *in vivo* counting techniques including the feasibility of ^{241}Am as a tracer for plutonium.

23 Invited paper. Large-scale processing of plutonium: radiation protection under commercial conditions. R. CALDWELL and T. POTTER, Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania (USA).

NUMEC established the world's first commercial plutonium laboratory in 1960. The original plant evolved from research laboratories, handling hundred-gram quantities, to expanded production facilities in which fuel contracts as large as 2200 kg of plutonium have been processed. This paper presents the considerable experience we have accumulated over this 10 yr period.

Our methods of exposure evaluation evolved along with the facilities. Early reliance on surface contamination measurements, stationary air sampling and urinalysis lessened, as we learned that personal air sampling, fecal analysis and body counting gave truer (and much higher) indications of exposure to airborne plutonium. This improved evaluation also revealed a greater incidence of chronic exposure than has been suspected. We will present a summary of several hundred minor exposures.

Fuel cycle plutonium has a greater abundance of the higher isotopes of plutonium and consequently greater neutron and gamma emission. This gave us many evaluation and control problems. We overcame the gamma energy dependence of film by routinely using lithium fluoride TLD. However, neutron personnel dosimetry remains an incompletely solved problem.

Large-scale plutonium production generates control problems not encountered nor envisioned in laboratory-scale operations. Americium accumulation in melt furnaces and ion exchange columns, deterioration of gloves, bags and box windows in corrosive environments, valve and piping leaks and shortage of trained personnel are among the difficulties which beset the commercial plutonium industry. We will discuss our current solutions to these problems,

as well as the controls we think future plutonium facilities should have.

Finally, several unusual accidents have occurred at our plutonium plant which resulted in extensive facility contamination and acute personnel exposure. We will relate these experiences and what we have learned about radiation emergencies in an industrial plutonium plant.

24 Invited paper. Traitement des contaminations par le plutonium. J. LAFUMA, Centre d'Etudes Nucleaires, Fontenay-aux-Roses (France).

La possibilité d'améliorer le traitement des contaminations internes par le plutonium dépend de la connaissance plus approfondie de son métabolisme et d'expérimentations orientées vers la recherche de modalités thérapeutiques nouvelles.

Nous avons dans ce but depuis plus de 7 ans, effectué des recherches qui ont porté sur plus de 1000 rats. Pour tous ces animaux une autopsie systématique et le prélèvement quotidien des excréments ont fourni les données métaboliques de base. Quatre voies d'administration ont été utilisées. En plus du plutonium, trois terres rares, le curium, l'americium dont le métabolisme sont très comparables, ont été administrés sous une dizaine de formes chimiques et de nombreux schémas thérapeutiques ont été testés.

Les résultats obtenus permettent une vision valable du métabolisme du plutonium suivant ses modalités d'administration; ainsi que de la thérapeutique à mettre en oeuvre.

Cette thérapeutique doit toujours être aussi précoce que possible. Elle devrait a priori comporter toujours deux aspects: le nettoyage de la porte d'entrée ce qui est plus facile à faire pour une blessure que pour un poumon, et un traitement par chélateur. Pour avoir une efficacité maximale ce traitement devrait être poursuivi pendant le maximum de temps possible.

Les expériences montrent l'efficacité de cette thérapeutique chronique sur la diminution de la contamination des poumons, des plaies, du foie et même aussi du squelette.

Un cas humain où le traitement a été poursuivi pendant trois ans confirme les données expérimentales et montre bien l'intérêt d'un traitement prolongé.

The treatment of plutonium contamination.

The possibility of improving the treatment of internal plutonium contamination depends on a more profound understanding of plutonium metabolism and on experimental programmes aimed at investigating new therapeutic techniques.

With this aim, we have undertaken studies in the last 7 yr which have involved more than 1000 rats. Systematic autopsy and the daily collection of excreta on all of these animals have given the basic metabolic data. Four routes of administration have been used. In addition to plutonium, three rare earths, curium and americium, in all of which the metabolism is very comparable, have been administered in about ten chemical forms and many therapeutic procedures have been tested.

The results give a valid picture of the metabolism of plutonium following these routes of administration, and also of the therapy to be applied.

This therapy must always be as early as possible. First of all, it must always comprise two aspects: the cleaning of the route of entry, which is easier to do for a wound than for the lung, and treatment by a chelating agent. For maximum effectiveness, the treatment should be continued for as long as possible.

The experiments show the effectiveness of this chronic therapy on the reduction of the contamination of lungs, wounds, liver, and even of the skeleton.

One human case where the treatment was continued for 3 years confirms the experimental data and shows clearly the value of prolonged treatment.

RELEASE OF ACTIVITY INTO THE ENVIRONMENT I

25 Oral presentation. Current policy in radioactive waste disposal and environmental monitoring in the UKAEA. F. MORLEY, UKAEA Health and Safety Branch, Harwell (UK).

The basic radiological protection objectives of radioactive waste control and the variety of disposal methods in use have now remained substantially unchanged for more than a decade. The regulated use of the environment for the dilution and dispersion of low activity wastes and the use of long-term storage for materials of higher activity have proved to be both practicable and safe in a heavily populated country committed to a large nuclear energy programme. Over the same period there has been a progressive improvement in the methods used to demonstrate that protection standards are met. Comprehensive hazard assessments are required for new large-scale disposal operations but when environmental effects are sufficiently well understood the policy is to introduce effective but economical monitoring programmes which are confined to critical radiation exposure pathways and capable of interpretation in terms of dose to man. When discharges of radioactive material are small, it is often possible to demonstrate safety without the need for environmental measurements.

26 Oral presentation. Liquid radioactive waste disposal and related environmental concentrations at Brookhaven National Laboratory.* A. P. HULL, Health Physics Division, Brookhaven National Laboratory, Upton, N.Y. (USA).

Almost two decades of data relating to the disposal of radioactive wastes into a sanitary sewer and their passage through a conventional treatment facility have been obtained. During the first decade, most of the released activity was aged fission products, principally ^{90}Sr and ^{137}Cs , in amounts ranging from 100 to 500 mCi/yr. Although fission product activity has declined steadily since 1960, about 100 mCi of activation nuclides have been released and the wastes now include about 20 Ci of ^3H /yr.

A retrospective assessment indicates that about 25% of the fission product activity released at the Laboratory complex was retained in the sewage system enroute to the treatment plant. Another 25% was removed by solids settling treatment. Of the activity reaching the secondary sand filter bed treatment, less than 25% passed immediately through the beds and into the Peconic River. Declining inputs have revealed that the retention by the beds is transient, in that 60% of the ^{90}Sr input passed through the beds within a year and 65% of the ^{137}Cs within 3 yr. About 90% of ^3H released from the Laboratory complex reached the treatment facility. Of this, 75% was recovered in the filter bed effluent.

Recent river surveillance data indicate that its flow was diminished by 50% and that a comparable fraction of effluent activity was retained between 0.8 km and 2.1 km downstream from the effluent outfall. In the mid-1960's, concentrations of ^{137}Cs and ^{60}Co between 5-30 pCi/g were found in aquatic media in this zone. More recently, these have declined to less than 5 pCi/g. Ranges of concentration factors have been established for ^{60}Co , ^{65}Zn and ^{137}Cs in plants and animals found in this zone. Laboratory effluent nuclides have not been detectable beyond 11 km downstream.

27 Oral presentation. On a model for the establishment of liquid radioactive wastes discharge formulae. G. BRANCA, F. BREUER and A. CIGNA, CSN, Casaccia (Italy), and R. AMAVIS, Commission des Communautés Européennes, Luxembourg (EURATOM).

The problem of the evaluation of the maximum amount of radioactive wastes that can be introduced at a given rate into a receiving environment is a

* Research carried out at Brookhaven National Laboratory under contract with the US Atomic Energy Commission.

rather difficult one. Many factors contribute to such an evaluation and they cannot often be easily expressed by mathematical quantities.

Furthermore these factors are very different according to each environment and they are subject to change with time. The first aim of the present paper was to choose a model representative of the environment as well suitable for a mathematical treatment. This model can be considered as a compromise between a complete description of the environment and the necessity to obtain simple solutions to the problem. Under these assumptions the system of the receiving environment was described as composed of a primary (aquatic) subsystem (where the radioactive wastes are directly disposed of) and of a secondary (terrestrial) subsystem. The latter is divided into two partial subsystems: the vegetable and the animal ones. Within each subsystem principal components were isolated for the identification of the possible exposure pathways to man. Successively a mathematical method based on the compartments theory was developed for the establishment of the critical pathways and, therefore, of the maximum rate of discharge (discharge formula).

28 Oral presentation. Some particular aspects of the problem of radioactive waste in large accelerator installations. M. HÖFERT and J. BAARLI, European Organization for Nuclear Research, Geneva (CERN).

Handling and disposal of radioactive waste has grown in importance as more and more nuclear power stations are built and come into operation. This problem has been extensively discussed in the past in many conferences devoted to this subject.

At CERN, disposal of highly radioactive waste, like targets used in the accelerators, is carried out according to the well-established procedures. Nevertheless, large quantities of material like magnets, vacuum chambers, supports, cables and counting devices located near to target areas or near to points where particle losses occur, become radioactive as they are hit by the secondaries of high energy particles. These items are, however, of rather low specific activity (1000-100,000 pCi/g) but, because of their mass, their total activity amounts to several curies. Waste material of this kind is stored at CERN in a special area and kept for more than a year to allow for the decay of short-lived isotopes; after this period the γ -emitters found in the metal parts are: ^{60}Co , ^{22}Na , ^{54}Mn , ^{57}Co , ^{58}Co , ^{59}Fe and ^{51}Cr (in decreasing order of half-lives).

As the normal way for disposing of low specific activity waste is expensive and time consuming,

a semi-automatic procedure was developed at CERN for sorting out all items whose total specific γ -activity has dropped to below 1000 pCi/g. For units of higher activity estimates of the time when the limiting value will be reached are made. Items of less than 1000 pCi/g specific activity level are regarded as inactive and in this way most of the valuable material, such as copper and stainless steel, is recuperated.

29 Oral presentation. A boiling water reactor nuclear power plant as a source of environmental radioactivity. C. L. WEAVER, B. KAHN and G. E. STIGALL, Division of Environmental Radiation, US Department of Health, Education and Welfare, Rockville, Maryland (USA).

The Division of Environmental Radiation of the Bureau of Radiological Health conducted a 1-yr study at the Dresden Nuclear Power Station, Morris, Illinois, with the objective of characterizing a boiling water reactor (BWR) nuclear power plant as a source of environmental radioactivity. This paper delineates the radioactivity transport pathways from the plant through the environment and evaluates transfer coefficients from the source of man. This involved sample collection and radiochemical analysis of the primary coolant, the fuel storage pool, the neutralizer waste, the laundry waste, the containment and turbine ventilating air, the gaseous waste delay line, both the intake and discharge canal, and the stack discharges.

A discussion is presented of the techniques for measuring external doses in the plant's environs using TLD's and NaI(Tl) monitors plus a Shonka vibrating quartz-fiber electrometer. This paper summarizes the results of the data obtained from this special study.

OPERATIONAL HEALTH PHYSICS I

30 Oral presentation. Comparison of the radiation dose to the wrists and fingers of workers engaged on radiochemical processing. W. D. CHISWELL, Radiochemical Centre, Amersham, and W. B. GILROY, Radiation Unit, University of Surrey, Guildford (UK).

It is general practice at most establishments where radioactive materials are handled, to use film badges worn on the wrists for measurement of radiation doses received by the hands of the various operators. Such measurements are needed to satisfy the regulations for control of radiation doses. Much work has been published in recent years, particularly since the introduction of compact thermoluminescent

dosemeters, showing that in many cases, especially where small radioactive sources are manipulated with gloved hands, the radiation dose to an individual's finger tips can be much greater than that recorded by a film badge worn on the wrist. This work casts some doubt on the validity of using results obtained from wrist films to deduce the radiation doses received by the hand.

The Radiochemical Centre, Amersham, is an establishment where small scale chemical processing of a large variety of radioactive nuclides is carried out. Many of the operations are performed in glove boxes, or similar enclosures, using fixed gloves, often of the lead-loaded type. It has been found that the continuous wearing of finger doseimeters under these conditions is inconvenient. A doseimeter worn on the wrist, whether it is a film badge or a thermoluminescent type, is more practicable.

This paper describes an extensive programme of measurements, using both film badges and thermoluminescent doseimeters, which is being carried out to determine the dose distribution over the operators' hands in order to compare doses measured at the finger tips with those recorded at the wrist. From such measurements it is possible to find the optimum positions for doseimeters used to measure hand doses, which give reliable results and are also convenient to the wearer.

31 Read in title. An analysis of the magnitude and location of personal contamination detected by the doorpost monitors installed in the PLUTO reactor area. D. W. FLEETWOOD, Health Physics and Medical Division, AERE, Harwell (UK).

Earlier experiments at AERE, Harwell, showed that the efficiency of personal monitoring using the standard beta probe, is less than usually supposed. A brief description is given of the doorpost monitoring equipment which has been designed and installed to improve monitoring efficiency.

An analysis is made of skin, clothing and shoe contamination detected by the doorpost monitors during their first years of operation in the PLUTO reactor building. The improved efficiency of detection relative to that achieved with hand-held probes is demonstrated.

32 Read in title. A practical estimation of the dose to skin from radioactive particulate contamination of clothing. D. C. STEVENS and J. STEPHENSON, Health Physics and Medical Division, AERE, Harwell (UK).

A practical attempt is made to assess the dose to the skin from discrete radioactive particles embedded

in clothing. This work was initiated when protective clothing, worn during the decontamination of shielded cells, became contaminated with discrete particles of 90-strontium titanate. Later, however, the experiments were extended to particles containing ^{137}Cs and ^{60}Co and mixed fission products.

It was found that each particle fixed on clothing covering the trunk of the body irradiates about 1-2 cm² of skin. The particle activity which would result in a dose rate of 1 rad/hr averaged over 1 cm² was found to be about 1.3 μCi for $^{90}\text{Sr}/^{90}\text{Y}$; 1.6 μCi for ^{137}Cs and 2.7 μCi for ^{60}Co . The results are also expressed in terms of the counting rates observed on probes used for routine survey purposes.

A statistical analysis of the particulate contamination found on coveralls used during the decontamination work is presented and the results are related to the efficiency of removal of the particles by normal laundering processes. It is shown that 95% of the personnel would have received less than 15 rads to 1 cm² of skin from the most active particle on their coveralls during the cell decontamination work.

33 Oral presentation. Vergleich von Dekontaminationsmitteln. R. BERNER, EIR, Würenlingen (Switzerland).

Zahlreiche Firmen bieten Reinigungsmittel zur Entfernung radioaktiver Verunreinigungen an. In den Ausschreibungen und auch in wissenschaftlichen Arbeiten werden oft übertriebene Reinigungseffekte angegeben. Um einen objektiven Vergleich verschiedener Produkte zu ermöglichen, werden in der vorliegenden Arbeit Vorschläge für standardisierte Prüfbedingungen gemacht. Jedem Reinigungsschritt wird ein Reinigungsfaktor f_i zugeschrieben, der sich als Quotient der Ausgangsaktivität des betreffenden Schrittes durch die Endaktivität berechnen lässt:

$$f_i = \frac{A_i}{A_{i+1}}$$

Das Produkt der Reinigungsfaktoren ergibt den Dekontaminationsfaktor F der kombinierten Behandlung:

$$F = f_1 \cdot f_2 \cdot f_3 \cdot \dots \cdot f_n = \frac{A_1}{A_n}$$

Die für verschiedene Reinigungsmittel ermittelten Reinigungsfaktoren ergaben Werte von 1,3 bis über 100. Da ähnliche Effekte oft schon durch reines Wasser erreichbar sind, ist ein solcher Reinigungsschritt als erster vorzunehmen und für die Berechnung des Dekontaminationsfaktors zu vernachlässigen.

Aufgrund langjähriger Erfahrung wurden in

unseren Labors verschiedene Dekontaminationsmittel selbst hergestellt und geprüft. Eines davon zeigte sehr gute Reinigungswirkung für verschiedene Materialien:

Dekontaminationsmittel E-4: 25 g Oxalsäure
 10 g Kaliumpersulfat
 1 g Natriumfluorid
 1 g Netzmittel
 Wasser bis 1 Liter

Dieses Mittel, gemischt mit je 10% Glycerin und Natriumcarboxymethylcellulose ergibt eine Paste, mit der Kapellen, Wände, grosse Maschinenteile etc. durch Bestreichen und anschliessendes Abspülen mit Wasser dekontaminiert werden können.

Comparison of decontaminating agents.

Numerous firms offer cleansing agents to remove radioactive contamination. In the advertisements and in scientific articles their cleansing effects are often exaggerated. In order to facilitate an objective comparison of various products, suggestions for standardised testing conditions are put forward in this article. Each stage in cleansing will be ascribed a cleansing factor f_i which may be calculated as the quotient of the initial activity of the corresponding stage and the final activity:

$$f_i = \frac{A_i}{A_{i+1}}$$

The product of the cleansing factors gives the decontamination factor F of the combined treatment:

$$F = f_1 \cdot f_2 \cdot f_3 \cdot \dots \cdot f_n = \frac{A_1}{A_n}$$

The cleansing factors obtained from various cleansing agents were values of 1.3 up to 100. Since similar effects can often be obtained with pure water, this cleansing agent should be administered first and disregarded in the calculation of the decontamination factor.

On the basis of many years' experience, we produced and tested various decontaminating agents in our laboratories. One of these was very effective as a cleansing agent for various materials:

Dekontaminating agent E-4:
 25 g oxalic acid
 10 g potassium persulphate
 1 g sodium fluoride
 1 g wetting agent up to
 1 litre water

This agent, when mixed with 10% glycerine and 10% sodium-carboxide-methyl-cellulose produces a paste which, on being spread on and subsequently rinsed off in water, can decontaminate capsules, walls and large parts of machinery, etc.

34 Read in title. Arbeitstechnik im Umgang mit flugfähiger Kontamination. F. SUTER, EIR, Würenligen (Switzerland).

Die Atomtechnik hat sich während der letzten Jahre in den verschiedenartigsten Industrien etabliert. Die Beherrschung der damit verbundenen Kontaminationsprobleme mit den bis heute praktizierten Methoden ist relativ kompliziert und aufwendig. Es besteht das Bedürfnis, einfachere Methoden zu finden, ohne dadurch die Betriebssicherheit zu beeinträchtigen.

Arbeiten an kontaminierten Einrichtungen sind meist mit Oberflächen- und Luftkontaminationen verbunden. Es ist erstrebenswert, diese beiden Probleme auf eines, nämlich auf die nicht flugfähige Oberflächenkontamination zu reduzieren.

Im EIR befasst man sich seit mehr als zwei Jahren intensiv mit diesem Problem und hat in der Verwendung von Paraffinöl eine geeignete Lösung gefunden. Diese Paraffinmethode hat sich inzwischen im EIR, beim Umgang mit flugfähiger Aktivität zur Hauptarbeitstechnik durchgesetzt. Paraffinöl ist als Kontaksubstanz für die meisten Konstruktionsmaterialien unschädlich, zeichnet sich durch ein grosses Benetzungsvermögen aus, trocknet nicht ein und kann mittels eines Fettlösungsmittels leicht entfernt werden. Bei der Behandlung von Handschuhboxen, die mit Plutoniumoxyd kontaminiert waren, hat sich Paraffinöl überraschenderweise als gutes Dekontaminationsmittel erwiesen.

Der Anwendungsbereich der Paraffinmethode bewegt sich aufgrund der im EIR gemachten praktischen Erfahrungen innerhalb weiter Grenzen. Als Beispiele seien erwähnt: Die Behandlung von Werkzeugen, Handschuhboxen und Hotzellen. Mit Plutoniumoxyd kontaminierte Handschuhboxen wurden nach vorgängig grober Dekontamination mit Paraffinöl ohne Schwierigkeiten in Plastikzelten zerkleinert und in Abfallfässer verpackt.

Die Anwendbarkeitsgrenzen der Paraffinmethode, sowie die Verwendung anderer neuartiger Kontaminationsschutz-Hilfsmittel werden diskutiert.

Technical work on airborne contamination.

In the last few years, atomic techniques have established themselves in a great variety of industries. The control of the contamination problem involved is relatively complicated and long-winded with the methods used up till now. It is necessary to find simpler methods without thereby encroaching upon the operational safety of the operation.

Work on contaminated equipment involves for the most part surface and air contamination. It is worthwhile to reduce both of these problems to a

single problem, namely, that of non-airborne surface contamination.

In EIR we have been dealing intensively with this problem and have found a suitable solution in the use of liquid paraffin. In EIR most of our efforts on the problem of airborne activity have been concentrated on the paraffin method. Liquid paraffin on contact with most construction materials is harmless, it is distinguished by its moistening capacity, does not evaporate and can easily be removed by any grease solvent. In the treatment of glove-boxes which were contaminated with plutonium oxide, liquid paraffin surprisingly revealed itself as an excellent decontaminating agent.

The range of application of the paraffin method is extensive, according to the practical tests done in EIR. The following examples may be mentioned: treatment of tools, glove-boxes and hot cells. Glove-boxes which had been contaminated with plutonium oxide were decontaminated with liquid paraffin and were afterwards broken up and put in plastic bags without any difficulty and packed in refuse containers.

The range of application of the paraffin method as well as the use of other new decontamination agents will be discussed.

35 Read in title. Studies on the radioactive skin contamination of pig skin. S. TASHIRO and Y. WADACHI, Japan Atomic Energy Research Institute, Tokai-Mura (Japan).

The effective way to decontaminate the radioactivity on human skin may be obtained by studying the mechanism of contamination. In view of this, studies on radioactive contamination were carried out by using pig skin as a substitute for human skin.

The specimens of pig skin to be contaminated were prepared by shaving, washing and cutting the skin in 2 cm x 2 cm. The soiling radioisotopes, ^{32}P , ^{35}S , ^{60}Co , ^{90}Sr - ^{90}Y , ^{125}Sb , ^{131}I , ^{137}Cs , ^{147}Pm , ^{204}Tl , ^{210}Po , U-nat. and ^{239}Pu , were dissolved in aqueous solution, of which acidities were adjusted by addition of hydrochloric acid or sodium hydroxide.

It was found that the pig skin contamination with the aqueous solution of the radioisotopes varies greatly in intensity with the kind of isotopes and the acidity of the contaminating solution used. The isotopes which do not form colloids but exist as ions, showed characteristic tendencies of contamination classified into two types, cationic and anionic; ^{90}Sr , ^{137}Cs , etc. into the cationic and ^{32}P , ^{35}S , etc. into anionic type. On the other hand, the isotopes which form radiocolloids like ^{125}Sb , ^{147}Pm and ^{239}Pu , showed a tendency of skin contamination to vary with the conditions of radiocolloidal formation.

36 Read in title. Surface materials of nuclear power and RI handling facilities. Y. WADACHI, Japan Atomic Energy Research Institute, Tokai-Mura and H. YASUNAKA, Oarai Research Establishment (Japan).

Radioactive contamination protective paints are particularly desired to have quality of low contaminability, high decontaminability and radiation resistance.

In order to investigate these factors, the experiments were carried out with many kinds of paints by $^{233}\text{UO}_2(\text{NO}_3)_2$ aq. contamination and γ radiation.

Results obtained show that some two liquid hardening type epoxy resin paints, vinyl chloride resin paints and chlorinated rubber paint give low contaminability and high decontaminability. And microscopic observations, about 100 magnifications, indicate these coating surfaces are compact and ordered surfaces.

With respect to γ radiation resistance all of two liquid hardening type epoxy resin paints are considered good. If paints are to function as surface materials for radioactive contamination protection, 10^9 R seems to be upper limit of γ radiation dose.

Accelerator Problems

Rapporteur Presentation

37 Operational radiation safety for an 8 MV medical linear accelerator. S. C. BUSHONG, Baylor College of Medicine, Houston, Texas (USA).

A preoperational radiation control survey of a newly installed 8 MV medical linear accelerator showed that excessive levels of radiation existed in several areas outside the treatment room. These excessive radiation levels were due to improper accelerator head shielding and inadequate treatment room shielding. Clinical operation of the therapy unit was delayed while necessary alterations and shielding modifications were made. The high energy of radiation made difficult the accurate measurement of accelerator head leakage which was shown to be 0.377% of the useful beam. These difficulties were satisfactorily solved with film dosimetry and several different types of ionization chambers. The HVL of the leakage radiation was shown to be nearly as high as the primary beam (13.3 mmlPb). Precisely machined and irregularly shaped lead blocks were necessary to reduce the average head leakage to 0.118% of the useful beam. The treatment room shielding required shielding reinforcement and a compromise with regulations governing radiation

fields in controlled and uncontrolled areas. Subsequent film badge area monitoring showed this compromise to be justified. A retractable beam-stop proved to be a superfluous feature because a high radiation area was created outside the treatment room when the beam-stop was retracted. Area radiation monitoring devices were installed to provide adequate radiation control, and a number of machine operational safety features were developed. Rigorous daily procedures insure proper patient dose for both electron and photon beams. Emergency procedures were established and are reviewed periodically.

38 Radiation studies at a medium energy accelerator.

L. D. STEPHENS and A. J. MILLER, Lawrence Radiation Laboratory, Berkeley, California (USA).

The 88-in. Cyclotron is one of the new generation of sector focussed cyclotrons which has been built since 1960. These third generation machines combine the advantages of the high beam intensities of the conventional first generation cyclotrons with the high energies of the second generation synchrocyclotrons. The ability to accelerate different particles to various energies has been incorporated into the 88-in. machine. The range of energies possible with this machine are from 2-60 MeV for protons, 0.5-130 MeV alpha particles, and 1-170 MeV ^3He . Other energies and ions are also possible.

Originally the cyclotron was designed for a beam current of 1 mA. The shielding was designed to provide protection to personnel outside the vault with the full 1 mA beam of deuterons on a Be target in the vault.

Monitoring of the radiation outside the shield as well as inside the vault areas was done concurrently with the beam development. Work was also begun on a determination of the neutron yield from thick targets at various angles. We believe this is a necessary step for the development of economical and safe shielding which would soon be necessitated by the continuing development of the cyclotron facility.

Effective attenuation lengths were measured through the shield walls at several angles from a target. Attenuation of neutrons was measured for walls composed entirely of concrete as well as composite walls of concrete and iron, or walls of concrete, iron, and sand. Variations in shielding efficiency were determined and are available for present and future use.

Neutron flux measurements have been made along an extended beam line in an effort to improve beam transport and reduce personnel irradiation.

We have also made extensive activation studies of

many accelerator parts. These studies prove their worth in maintenance planning where it is desirable to minimize personnel exposures.

39 The surface dose hazard from radioactivity induced in high energy particle accelerators.

H. SCHÖNBACHER, A. H. SULLIVAN and J. BAARLI, European Organization for Nuclear Research, Geneva (CERN).

The radioactivity induced in high energy particle accelerators seriously affects maintenance due to the associated radiation hazard. As well as the general ambient gamma radiation levels an additional hazard occurs from local high concentrations of radioactivity where the dose-rate at the surface can be high. Dose-rates of the order of 1000 rads/min have been measured on accelerator target assemblies. The radiation composition and its variation with time for various irradiated materials has been investigated and methods and instrumentation are described for making surface dose measurements over a large dynamic range. The radiation hazard problems associated with surface dose-rate in accelerators are discussed and recommendations given for the safe handling of radioactive parts.

40 Scanning the radiation field of a 25 MeV medical betatron. Z. M. ALVI, Kaiser Medical Center, Los Angeles, California (USA).

Radiation fields of high energy accelerators can be readily scanned for beam flatness by means of a new mechanism. It is very useful in compensating filter alignment and patient dose uniformity checks.

The scanner consists of a mechanical probe carrier having 44 cm travel at 1 cm/sec velocity. The carrier can either be placed on a flat-top cart in front of the beam or attached to the collimator head using mounting brackets. The overall dimensions are $3\frac{1}{2}$ in. \times 5 in. \times 24 $\frac{1}{4}$ in. The scanner traverses the radiation field with a radiation sensor accurately positioned irrespective of radiation angle. A remote control console connected with a 50ft. multiconductor cable, operates and accurately displays the relative position of the scanner. The sensor consists of a semiconductor p-n junction detector. The detector proper is made of 1 mm dia. silicon discs doped with phosphorus and boron with 0.1 mm "depletion layer" between the discs. The detector current is measured through an external circuit with very low impedance—the so-called "short-circuit operation". The short-circuit current is equal to the radiation-induced current at zero bias i.e. proportional to exposure rate.

The dosimeter has an output of 33.6 pA/rad/min. The probe output is linear over a wide dynamic range and can be used without changing calibration for both continuous and pulsed radiation sources. Dosimeter amplifiers in the control console provide an output voltage which is linear with field strength up to a maximum of 10 V for 500 rads/min. The meter readout is either in mm position - 20 mv/mm at output terminals, 8.8 V max. or in field strength in rads/min. 0-10 V for 0-200 or 0-500 rads/min. The output of the control console goes into an x - y plotter with position signal in the x -axis and dose signal in the y -axis. An x - y plotter was used rather than a strip-chart recorder because it is not possible to retrace and compare different runs on the strip chart.

The tracings for the 10-25 MeV X-rays were taken using 4 cm thick lucite buildup cap, and 1.5 cm cap was used for 10-24 MeV electrons.

The radiation field scanner described is much faster and more accurate than the alternate methods available namely film dosimetry and water-phantom isodose plotter technique.

In addition to measuring field geometry, the scanner is useful in the studies of wedge filter symmetry block field dimensions, source position accuracy and effective source geometry.

The X-ray beam emerging tangentially from the equilibrium orbit in the betatron doughnut, encounters the following objects in its path: a. Porcelain wall of the doughnut; b. Laminated aluminum cone (compensator); c. Transmission ionization chamber; d. Inclined mirror of the localizing light; e. Motor-driven two lead collimators; f. 2 mm thick lucite face plate; g. Metal-screen table-top only when field shaping shielding blocks are used.

The emerging beam requires that routine flatness checks be made and the above scanning system fulfils a definite need.

41 The shielding of 14 MeV neutron generators.

T. O. MARSHALL and A. KNIGHT, Radiological Protection Service, Belmont, Surrey (UK).

Although 14 MeV neutron generators have for a number of years been a relatively common source of fast neutrons, there is nevertheless a shortage in the literature of data about the attenuation of neutrons of this energy. Moreover, the agreement between different sets of published data is poor, leading to a confusing situation.

This paper summarizes the theoretical, empirical and experimental data available for the common neutron shield materials. Also given is a summary of attenuation measurements made by the RPS. for a range of materials, namely, water, concrete,

steel, polyethylene, paraffin wax and combination shields of steel and polyethylene.

The choice of shield material is discussed in cases where the shield mass or the space it takes, and its cost, is important.

Measurements of the scattered neutrons, from a 14 MeV source, along a concrete maze are reported and the design of primary and secondary barriers is discussed.

42 Shielding of 14 MeV neutron generators. P. F.

SAUERMAN and W. SCHAFER, Health Physics Division, Julich Nuclear Centre (Germany).

In a careful planning of the shielding of nuclear installations the economical point of view should be taken into consideration. Low cost of shielding of accelerators producing fast neutrons with an energy of 14 MeV should be the aim of people engaged in this work.

To provide them with information on how to achieve this, we carried out experiments with the aim of demonstrating whether the dose-rate attenuation coefficients serving to calculate the required thickness of concrete shielding can be determined by measurements carried out on heaped individual ingredients of the different concretes concerned.

The attenuation coefficients of ordinary concrete, limonite concrete and iron-shot concrete of different compositions were calculated from the mass dose rate attenuation coefficients.

Furthermore, the dose rate equivalents behind shields consisting of slabs of different materials (iron-water, iron-ordinary concrete, and iron limonite concrete) were calculated with the aim of making recommendations for the most efficient design of the shields.

43 Radiation "skyshine" problems associated with GeV electron beams extracted into open-topped experimental areas.

F. J. COLEMAN and D. C. THOMAS, Daresbury Nuclear Physics Laboratory, Warrington (UK).

The 5 GeV Electron synchrotron accelerator at Daresbury Nuclear Physics Laboratory has provided two extracted electron beams of up to 0.4 μ A intensity. These beams are extracted into open-topped experimental areas equipped with very large spectrometry apparatus. "Skyshine" from such beams can produce relatively high radiation levels in the immediate environment of the experimental hall. Such levels can severely restrict other work in nearby areas or, alternatively, limit beam intensities thus interfering

with the experimental programme itself. The radiation is composed of a mixture of neutrons and photons in varying Dose Equivalent ratios, the main component being neutrons in nearly all cases.

Radiation surveys, using conventional portable monitors are discussed. Location of the sources of the "Skyshine" has been attempted using an overhead scanning technique. The electron beam paths have been scanned using a simple collimated radiation monitor. Conclusions drawn from the overhead scans have been substantiated by induced activity measurements made on the various beam-line components and by subsequent beam profile measurements using TLD(LiF) and ion chambers.

A significant penumbra was found accompanying the beam. The quality of this penumbra was assessed using moderated indium foils, TLD, ^{11}C and other activation detectors.

From all of these measurements it was found that the "Skyshine" problem could be reduced with improved beam transport, more careful positioning of experimental equipment and shielding within the area and by sensibly designed local shielding around ancillary beam-line equipment, such as beam intensity monitors, collimators, etc. With such improvements implemented, the experimenters' requirements for higher beam intensities and lower backgrounds can be satisfactorily achieved and the operational health physics problems obviously reduced.

SYMPOSIUM ON BIOLOGICAL RECOVERY FROM RADIATION DAMAGE

44 *Invited paper. Genetic recovery.** W. I. RUSSELL,
Biology Division, Oak Ridge National Laboratory,
Oak Ridge, Tennessee (USA).

What may loosely be called "genetic recovery" ranges from repair of mutational or pre-mutational damage at the molecular level to selective elimination of individuals from descendant generations of a population exposed to a mutagenic agent. The elimination of mutant cells during gametogenesis and the death of early embryos from newly occurring dominant mutations are examples of genetic "recovery" that fall between the above extremes. Another type of recovery from radiation damage that has genetic consequences is the repopulation of the spermatogonia in the testis. The mutational outcome is apparently dependent on the relative frequencies

of the different cell stages that survive at different doses. The nature and extent of these various recovery mechanisms in mice are discussed with regard to their importance in the estimation of genetic hazards of radiation.

45 *Invited paper. Repair mechanisms in DNA.*
G. DEAN, Chester Beatty Research Institute,
Sutton (UK).

Current concepts suggest that most proliferating cells possess enzymes capable of rectifying defects in their DNA and that these are normal cell components necessary for DNA replication, genetic recombination and perhaps transcription in addition to their error-correcting function. Much of our information on DNA repair processes has come from biochemical and genetic studies with bacterial cells exposed to ultraviolet light where the biologically important lesions are base alterations. These studies indicate that resistant cells possess enzymes capable of recognising defective regions in the DNA which are then excised and replaced by the proper bases using the complementary DNA strand as template. The "excision-repair" system is believed to be a general error-correcting mechanism and has been implicated in the repair of other informational and structural defects in the DNA of both eucaryotic and procaryotic cells.

In cells exposed to ionising radiation the predominant physico-chemical alteration is the introduction of breaks in the single polynucleotide strands of the DNA twin helix and both mammalian and bacterial cells have been found to repair efficiently many or all of these lesions. Double breaks, i.e. simultaneous scission of both strands, occur at a much lower frequency and are widely held to be lethal lesions. Recent evidence, however, suggests that even this damage may be subject to repair.

While there can be no doubt that structural changes in the bases and sugar moiety occur, when DNA is irradiated within a cell, no details of their chemical nature or frequency are known although it is likely that such defects could be restituted by a mechanism similar to that of "excision-repair". Indeed, the dearth of information on the precise chemical constitution of the lesions introduced precludes a critical evaluation of the repair of DNA damage in cells exposed to ionising radiation.

Evidence is accumulating that chromosomal DNA in bacterial and mammalian cells is attached to the cytoplasmic or nuclear membrane and that this association may fulfil a control function over the biological activities of the DNA. The radiobiological significance of a DNA-membrane complex is clear since any disorganisation could profoundly affect

* Research sponsored by the US Atomic Energy Commission under contract with the Union Carbide Corporation.

not only the capacity of a cell to reconstitute fully the DNA lesions but also prevent its subsequent replication.

46 Invited paper. Recovery from radiation damage in mammalian cells. G. SILINI, Laboratorio di Radiobiologia Animale, CISN, Casaccia del CNEN, Rome (Italy).

The paper will concisely review some radiobiological data dealing with cellular recovery, which are considered to be of major significance for radiation protection.

After a brief general discussion on the use of the term "recovery", a description will follow of the time- and dose-relationships for repair of sublethal damage in cultured mammalian cells and in other cellular systems *in vivo*. An attempt will be made to correlate the repair of single cells with the recovery phenomena of organized tissues; evidence will be provided to show that oscillations of sensitivity in animals irradiated whole-body with split doses of radiation may correlate with the recovery of bone-marrow stem cells. The relationships of sublethal damage recovery with some important radiobiological parameters like the dose-rate, the LET and the oxygen effect will also be examined.

Finally, experimental data on the recovery of tissues through cell division will be reviewed and the relationship of this mode of recovery with the kinetic parameters of the irradiated cell population.

47 Invited paper. Les phénomènes de restauration à l'échelle de l'organisme dans le syndrome d'irradiation aiguë. M. AVARGUES, Département de la Protection Sanitaire, Commissariat à l'Energie Atomique, Fontenay-aux-Roses (France).

L'irradiation constitue une agression vis-à-vis de laquelle l'organisme réagit, le plus souvent pour en corriger les effets biologiques et restaurer ses fonctions dans leur intégrité. En cas d'irradiation aiguë, à dose absorbée égale, la restauration est favorisée par la limitation topographique de l'exposition, ou encore par l'étalement de l'irradiation dans le temps. On peut analyser la radio-restauration en référence aux trois appareils significatifs, au plan de la Radio-pathologie: le tissu hématopoïétique, le tractus gastro-intestinal, et le système nerveux.

La restauration des troubles hématologiques dont le siège réel est situé au niveau des organes hématopoïétiques, repose principalement sur les processus de division cellulaire, et sur la dynamique des transferts entre les divers compartiments des lignées blanches et rouge. Cependant, des mécanismes

humoraux et neuro-endocriniens semblent également impliqués, mais la part qu'ils y prennent n'est pas encore clairement élucidée.

Le syndrome gastro-intestinal est dominé par des troubles dus à des modifications de structure de la paroi intestinale, dénudée de son épithélium par arrêt des mitoses des cellules-souches. La restauration est liée à la régénération de ces cellules et à leur migration depuis les cryptes vers la surface des villosités.

Le syndrome nerveux, pour des doses très élevées, peut revêtir des formes rapidement mortelles. Pour des doses plus faibles, les signes neurologiques sont habituellement totalement réversibles. La restauration implique ici celle de phénomènes métaboliques et biochimiques encore mal connus, sans exclure l'intervention de facteurs extrinsèques comme la circulation locale.

Le pouvoir de restauration mis en évidence au niveau des organes radiosensibles s'exprime également au niveau de l'organisme entier. Son analyse expérimentale a conduit parfois à l'expression mathématique des phénomènes. Plusieurs observations cliniques l'ont nettement confirmé chez l'homme.

L'existence du pouvoir de restauration des lésions radioinduites suggère que les traitements mis en oeuvre lors d'un accident d'irradiation puissent favoriser cette restauration et, en toute hypothèse, ne lui nuire en rien.

Dans l'établissement des normes de Radioprotection qui correspondent à des conditions d'irradiation favorables à la restauration par leur faible débit, les phénomènes de restauration devraient également être pris en considération.

Recovery processes of the organism in the acute radiation syndrome.

Irradiation results in an injury to which the organism reacts, more often to correct its biological effects and restore the integrity of its functions. In the case of acute exposure, with the same absorbed dose, recovery is better when the exposure is limited topographically or protracted over time. In the pathology of radiation disease, the recovery of three significant systems can be studied: the hematopoietic tissue, the gastrointestinal tract and the nervous system.

The repair of hematological changes, which are really determined at the level of hematopoietic organs, is mainly dependent on cellular division processes and dynamical transfers between the several compartments of the white and red series. However, humoral and neuroendocrine mechanisms too seem to come into play, but their part has not yet been clearly defined.

In the gastrointestinal syndrome there prevail injuries due to morphological changes in the intestinal wall, whose epithelium is destroyed by inhibition of the stem cell mitoses. Recovery is linked to the cell regeneration and migration from the crypts to the surface of the villi.

At very high doses, the nervous syndrome can quickly lead to death. At lower doses, neurological changes are usually wholly reversible. Here, recovery implies the restoration of metabolic and biochemical processes not well known so far, as well as the action of extrinsic factors such as local circulation.

The repair ability shown at the level of radio-sensitive organs is also seen at the level of the whole body; its experimental analysis has led sometimes to mathematical expressions of the processes and has been confirmed in man by several clinical observations.

The ability to repair from radiation injuries suggests that treatments operated in the case of radiation accident can enhance recovery but certainly do not impair it.

When setting up radiation protection standards applying to exposure conditions favourable to repair because of low dose rates, recovery processes should be considered too.

ACCIDENTS, EMERGENCY PROCEDURES AND LESSONS I

48 Oral presentation. Agricultural consequences of releases of radioactivity from nuclear installations into the atmosphere. R. S. BRUCE and R. SCOTT RUSSELL, ARC Letcombe Laboratory, Wantage (UK).

Quantitative relationships between the deposition of the nuclides ^{131}I , ^{137}Cs , ^{90}Sr and ^{89}Sr , and the contamination of agricultural produce are reviewed; from the agricultural aspect, other nuclides are, by comparison, of minor importance. In most Western countries the critical diet pathway to man for all the nuclides is by way of milk from cattle grazing pastures. If radioactivity is released in areas where milk is not produced, or at a time of year when cattle are fed predominantly on stored foods, the effects would be much less.

The relatively high abundance and volatility of ^{131}I , together with its ready transfer to milk and concentration in the small mass of the infant thyroid, make it the nuclide which is liable to cause the highest radiation doses to man. Quantitative relationships relevant to conditions in the United Kingdom will be discussed.

It is now evident that the isotopes of strontium are less important as dietary contaminants than at one time appeared possible. This is partly because bone and not bone marrow was then considered to be the critical tissue, and partly because uptake of ^{90}Sr by plants from the soil was overestimated. It now seems highly unlikely that deposition of ^{90}Sr would ever occur on a scale such that uptake from the soil would cause diet to be contaminated to an unacceptable level. Strontium-89 is likely to be more significant than ^{90}Sr in the initial period after a major discharge but the resultant tissue dose should be very small relative to that from ^{131}I . Caesium-137 may be intermediate between ^{131}I and ^{89}Sr in importance.

It may be concluded that, from the agricultural aspect, ^{131}I alone deserves consideration when planning safeguards for releases to atmosphere from a nuclear installation. Other nuclides would be significant as dietary contaminants only if radiation doses from ^{131}I were very large. In planning control measures which could be taken after a major release of ^{131}I , it is to be borne in mind that their purpose is to reduce the total dose to the thyroid due to intake of the nuclide from all sources, and that for limited groups near the reactor, inhalation is likely to be the dominant cause of exposure. Any adequate plan must therefore take account of both aspects.

49 Oral presentation. The radiological implications of fission products released to the environment from a major reactor accident. J. R. BEATTIE and PAMELA M. BRYANT, UKAEA Health and Safety Branch (UK).

The consequences of hypothetical accidents commonly postulated for present-day reactors are assessed in terms of radiation doses to members of the public. The assessment is based on a review of currently available information on the relative proportions of fission products which may be released, on their dispersion and deposition in the environment, and on metabolic and dosimetric data relevant to estimating the exposure of persons to external and internal radiation from the cloud and deposited activity. The importance of inhaled iodine as a primary source of hazard is re-affirmed. Whole-body doses from the cloud are not a serious hazard unless the release is very large and then only within a kilometre or so of the reactor. The hazards due to ground deposition and ingestion of iodine extend to greater distances, but protective action is more readily taken. The consequence of releases of strontium, caesium, ruthenium and the noble gases are also evaluated; if in certain reactor types the release of

iodine can be prevented, any public health hazard will probably be due to one or more of these nuclides.

(Withdrawn) See 241

50 Oral presentation. The buoyancy of radioactive clouds as a factor in emergency planning. L. CAVE, P. HALLIDAY and L. D. HUTCHINGS, Atomic Power Constructors Ltd., Sutton (UK).

Recent work has shown that as the sites for large nuclear power stations are brought closer to centres of population there may be a disproportionate increase in the potential hazard to the community. The extent of this increase depends largely upon the time available for temporary evacuation of the population within a few miles of the reactor. Thus in planning emergency measures for such circumstances it is particularly important to know how much time would be available for evacuation. For some types of reactors adequate evacuation time is provided by their thermal inertia or other features which lead to substantial delays in any large release for the majority of conceivable accidents. However, there remains a remote possibility of a large, rapid release of fission products.

Recent work on the rise of radioactive clouds has shown that in some circumstances the additional buoyancy due to self-heating by the radiated energy would cause the cloud to rise sufficiently to reduce substantially the concentration of activity at ground level. This effect is particularly marked for large, rapid releases.

In this paper the effect of meteorological conditions and of the nature of the activity released from the reactor (including coolant density) are examined in some detail, in order to establish the extent to which buoyancy can be relied on to mitigate the ill-effects of such large, rapid releases from reactor sites close to centres of population. It is concluded that there should be a useful mitigating effect due to buoyancy in these cases, so that less account needs to be taken of rapid releases in any emergency planning. The effect is particularly marked for helium cooled reactors.

51 Oral presentation. Stationary monitor for detecting the accidental release of fission products into the atmosphere. J. PENSKO, J. JAGIELAK and B. GWIAZDOWSKI, Central Laboratory for Radiological Protection, Warsaw (Poland).

Most radionuclides which enter into the natural environments as a result of accidental release from nuclear installations, during serious transportation accidents or following the nuclear weapon tests,

are gamma-emitting fission products. These radionuclides can be easily detected using gamma-ray measurements technique. This paper discusses some methods which were checked in this laboratory as suitable for identification and continuous control of environmental contamination caused by gamma-ray emitting radionuclides. A high pressure ionization chamber makes it possible to estimate the total exposure rate very quickly and accurately whereas the gamma-ray spectrometry of soil samples is more time-consuming. However the most rapid and full information about the atmospheric contamination and ground deposition of fission products can be supplied by the stationary spectrometric monitor specially designed in this laboratory. The construction of this monitor and method of identification and continuous measurements of gamma-radioactive contamination of soil and atmosphere is described in this paper.

52 (Withdrawn) See 245

MONITORING OF WORKERS II

53 Oral presentation. Anwendung eines differentiellen Abtastverfahrens für Phosphatgläser in der Personendosimetrie? H. KIEFFER and E. PIESCH, Kernforschungszentrum Karlsruhe (Germany).

An Personendosimeter zur Überwachung strahlenexponierter Personen werden von den Benutzern aufgrund verschiedener Auffassung über den Zweck der Personendosimetrie zwei unterschiedliche Anforderungen gestellt: Entweder zuverlässige und genaue Messung ausschließlich der Personendosis an

der Körperoberfläche mit energieunabhängig anzeigenden Dosimetern. Oder Möglichkeit der Energie- und Dosisbestimmung zur Interpretation des Bestrahlungsfalles mit energieabhängigen Dosimetern, wobei größere Meßfehler in Kauf genommen werden.

Die erste Forderung wird vor allem in der Kerntechnik gestellt, während man bei Personenüberwachungen im medizinischen Bereich mit Hilfe zusätzlicher Aussagen die Bestrahlungsursache ermitteln will.

Glasdosimeter, heute als energie- und richtungsunabhängige Dosimeter von hoher Genauigkeit in der Routinedosimetrie eingesetzt, können auch zur Ermittlung der Strahlenqualität und der Strahlungseinfallsrichtung herangezogen werden. So wird ein Dosimeter *beiden* oben gestellten Anforderungen gerecht. Hierfür bewährt hat sich ein differentielles Abtastverfahren, mit dessen Hilfe die differentielle Dosisverteilung im Glas in Abhängigkeit von der Glasstärke ermittelt wird.

Unter Verwendung eines Alderson-Menschphantoms wurden mit Glasdosimetern Meßreihen mit verschiedenen Strahlungsenergien im Bereich 10 keV-1,2 MeV und mit verschiedenen Strahlungseinfallsrichtungen zwischen 0° und 180° durchgeführt. Die Dosimeter wurden hierbei auf der Phantomvorderseite in Brusthöhe exponiert. Aufgrund der Meßergebnisse wird gezeigt, daß man mit Phosphatglas-Personendosimetern unter Zuhilfenahme des differentiellen Abtastverfahrens zusätzliche Aussagen über Strahlenqualität und Strahlungseinfallsrichtung erhalten kann. Es werden Möglichkeiten zur Korrektur des Körpereinflusses bei Rückwärtseinstrahlung sowie Möglichkeiten einer Anwendung dieser Auswertemethode in der Personendosimetrie am Beispiel verschiedener Dosimeterarten diskutiert.

The application of a differential read-out method for phosphate glass in personal dosimetry.

The different requirements are established by the users of personal dosimeters for the monitoring of persons exposed to radiation. These are on the basis of different concepts of the purpose of personal dosimetry. Either they require reliable and exact measurements to elucidate the personal dose at the body surface with a dosimeter having a response independent of energy, or they require the possibility of both energy and dose determination for the assessment of the conditions of the irradiation, and thus need energy dependence dosimeters. These in addition can deal with errors of measurement.

The first requirement is principally met in nuclear technology, while in the monitoring of people in medical work it is desirable to ascertain the cause of exposure with the help of additional evidence.

Glass dosimeters currently established as being

both energy and direction independent and of being of high precision in routine dosimetry, can also be used for a determination of radiation quality and the direction of incidence. In this way, one dosimeter can satisfy both requirements. For this purpose a differential read-out method has proved satisfactory, and with its help the differential dose distribution in glass as a function of depth can be determined.

Measurements were made in the energy range from 10 keV to 1.2 MeV and with angle of incidence between 0 and 180°, with glass dosimeters on an Alderson man-like phantom. The dosimeters were exposed at the surface of the phantom at chest height. The results showed that it is possible to obtain additional information about the radiation quality and the direction of incidence, with phosphate glass personal dosimeters using the differential read-out method. The discussion reviews the possibility of correcting the body dose for backscatter and the possibility of using this method of personal dosimetry with different examples of dosimeter.

54 Oral presentation. Simultaneous estimation of exposure dose and time lapse since exposure using a multipeak thermoluminescent dosimeter. Z. SPORNY, Nuclear Research Institute, Prague (Czechoslovakia).

The knowledge of the time of exposure may be useful in personal monitoring, for example, in time-reconstruction of over-exposures or nuclear accidents, or in choice of therapy procedures, etc.

This paper describes the application of the multi-peak thermoluminescent phosphor (natural CaF_2) for simultaneous estimation of exposure and time elapsed since this exposure. Natural CaF_2 used for this purpose has three sorts of traps (the glow curve has three maxima: 100-180-260°C), which can easily supply both pieces of information. From the area of the last peak (260°C) the exposure within the range of mR-kR can be estimated with a precision better than 5%. Spontaneous decay of electrons from shallow traps at normal temperature (fading) with post-exposure time leads to the degradation of peak-areas; the 100°C peak decreases at first and then, after about one month, the second one also decreases. When measuring the ratios of the peak-areas (or of the peak-heights) the time elapsed from the exposure may be assessed in the range 1-10⁴ days with a precision of about 10%. These ratios are independent of the exposure, LET and applied dose-rate.

The preparation of a dosimeter, its parameters and a technique for simultaneous measurement of both values are described and an application of this principle in personal monitoring is discussed.

55 Read in title. Le déclin de la luminescence des dosimètres radiophotoluminescents: Application à la conception d'un nouveau type de lecteur de doses. J. BARTHE, D. BLANC et L. COMMANAY, Centre de Physique Atomique, Université de Toulouse, J.-L. TEYSSIER, Laboratoire des Radiations Ionisantes, Limoges, et H. FRANCOIS, Service Technique d'Etudes de Protection du CEA, CEN, Fontenay-aux-Roses (France).

Malgré leurs qualités, les verres radiophotoluminescents présentent une pré-dose élevée (dose apparente sans irradiation) qui limite leur emploi. Les lecteurs actuels ne permettent pas de mesurer avec une précision acceptable des doses inférieures à 100 mR. Toutefois à partir de la forme du déclin de la radiophotoluminescence il semble possible de concevoir un lecteur mesurant des doses beaucoup plus faibles.

Les verres français (CEC) et japonais (TOSHIBA) présentent, après 0.5 μ sec, trois composantes exponentielles définies par les couples (amplitude, constante de temps) A_1T_1 , A_2T_2 et A_3T_3 . Dans le cas des verres CEC, par exemple, les constantes de temps T_1 , T_2 et T_3 sont respectivement 0.7, 3 et 32 μ sec pour les verres non irradiés tandis qu'elles sont 0.7, 2 et 5 μ sec pour les verres irradiés à 200 R. Les amplitudes (à l'origine des temps) A_1 , A_2 et A_3 ne croissent pas linéairement avec la dose.

En basant l'étude sur le fait qu'il n'existe pas de constante de temps de 5 μ sec pour les verres non irradiés, la mesure du couple de valeur ($A_3T_3 = 5 \mu$ sec) doit nous permettre de séparer presque totalement les contributions de la dose et de la pré-dose à fluorescence du verre.

The decay of luminescence in radiophotoluminescent dosimeters: the application of this concept to a new type of reader.

In spite of their advantages, radiophotoluminescent glasses show a high pre-dose (apparent dose in the absence of irradiation) which limits their usefulness. Doses below 100 mR cannot be measured with current readers with an adequate accuracy. Nevertheless, it seems possible to visualise a much more sensitive reader based on the pattern of decay of the radiophotoluminescence.

Glasses made in France (CEC) and in Japan (TOSHIBA) show three exponential decays after the initial 0.5 μ sec. These can be defined by pairs of numbers (amplitude and time constant) A_1T_1 , A_2T_2 , and A_3T_3 . For example in the case of the CEC glasses, the time constants T_1 , T_2 and T_3 are, respectively, 0.7, 3 and 32 μ sec for unirradiated glass, while the values for glass irradiated to 200 R are

0.7, 2 and 5 μ sec. The amplitudes (at zero time) A_1 , A_2 and A_3 do not increase linearly with dose.

Starting from the fact that there is no time constant of 5 μ sec in the unirradiated glass, it should be possible to separate almost completely the fluorescence due to dose and to pre-dose by measuring the value of A_3 associated with the value of 5 μ sec for T_3 .

Review and Use of TLD and TSEE

Rapporteur Presentation

56 Thermoluminescence personnel dosimetry at Hanford.* R. L. KATHREN, L. F. KOCHER and G. W. R. ENDRES, Battelle-Northwest, Richland, Washington (USA).

Initial investigations into the applications of the thermoluminescence phenomena for personnel dosimetry at Hanford were directed towards securing a suitable, successful, and convenient physical form. In mid-1967, a flexible rubber finger ring utilizing a lozenge shaped wafer of ^7LiF in a teflon matrix was introduced for routine hand dosimetry. The TL dosimeter provided a significant improvement over previously used film dosimeters, having a useful range of $0.03-10^5$ rads with a standard deviation of $\pm 10\%$, minimal energy dependence, and resistance to the environment. Subsequently, a basic dosimeter with a range of $0.03-10^5$ was introduced for personnel who do not routinely work with ionizing radiation. This dosimeter utilizes a single ^7LiF block— $3.2 \times 3.2 \times 0.9$ mm—for routine readout and an 8 mm dia. ^7LiF -teflon disc as backup, sealed in an individually identified card, allowing the badges to be read out annually in a fully automated system without handling the dosimeter material. A more complete dosimeter for personnel who may be routinely exposed to radiation is in the final stages of development. This dosimeter utilizes five small LiF-blocks—2 with natural isotopic content and 3 enriched in ^7Li . By appropriate filters, two of the ^7LiF blocks provide a direct indication of penetrating and non-penetrating exposure other than neutrons over the range of $0.03-10^5$ rads. The other LiF's are used in conjunction with body backscatter and activation foils to provide an indication of neutron dose over an energy range of thermal to 14 MeV. A fully automated readout

* Work performed under contract to the US Atomic Energy Commission.

system now under development will permit interpretation with a minimum of time and manual input.

57 Radiothermoluminescent dosimetry in radiological protection in the United Kingdom. W. N. SAXBY, AWRÉ, Aldermastou and D. F. WHITE, UKAEA Health and Safety Branch, Harwell (UK).

The ways in which radiothermoluminescent dosimetry (TLD) is currently being utilised in the United Kingdom for radiological protection purposes are reviewed briefly, together with supporting investigational and development programmes. The circumstances which give rise to an operational need to use TLD now are discussed. The paper also discusses the circumstances in which TLD may be a viable alternative to other methods of personal dosimetry. Finally the authors discuss the possible need for some rationalisation and uniformity in the processing of TLD devices.

58 Progress towards a thermoluminescent dosimetry system for large-scale routine personnel monitoring.

K. E. G. PERRY and H. E. PRESTON, AEE, Winfrith (UK).

Experience of using thermoluminescent lithium fluoride in personal dosimeters on a relatively small scale for measuring whole body exposures has shown that this form of dosimetry has many attractions. However the simple "badge" and associated reading equipment, at present employed, are not suitable for use on a large scale and more sophisticated forms of these items have now been developed.

The new "badge" incorporates two LiF/PTFE discs retained in a plastic insert, which is provided with a coded identification system. In use the insert is worn in a holder in such a way that one disc is shielded by aluminium, and the other virtually unshielded, thus allowing an assessment of dose from both penetrating and soft radiation.

After removal from the holder the complete insert is fed manually (or automatically) into the reader which sequentially reads out the identification number and the light output from heating the two discs. The information obtained can either be printed out or fed to a computer. Particular attention has been given to the method of heating the discs to ensure near complete read out, thus reducing the requirement for subsequent annealing.

Preliminary results obtained with using such a system are given.

59 Experience in the use of thermoluminescent dosimeters for dose control purposes. H. E. PRESTON, J. J. CLIFTON and C. D. HALLETT, AEE, Winfrith (UK).

Situations frequently arise when personnel may be exposed to dose rates, which are grossly non-uniform in time. For example men entering hot cells for maintenance purposes, or reactor containments during shut-down, may accumulate a substantial fraction of the quarterly permissible dose in a matter of hours or days. Some form of short-term control dosimeter is required if adequate supervision is to be exercised.

Although direct reading quartz fibre electrometers can, and are being used for this purpose, their accuracy and reliability leaves much to be desired.

During the last few years thermoluminescent lithium fluoride dosimeters have found increasing use for this purpose.

Initially finger sachets containing lithium fluoride powder were incorporated into a holder, with appropriate filters to give whole body and skin doses separately. This form of dosimeter is quite satisfactory for small numbers but the inconvenience of using powder produces difficulties of handling in large quantities. This has led to the use of LiF/teflon discs in a holder designed to take two discs.

Extensive experience with the two types of lithium fluoride dosimeter both in laboratory tests and operational use is described, and the dosimetric information compared with that obtained from the conventional film badge.

60 New solid CaSO_4 , CaF_2 and $\text{Li}_2\text{B}_4\text{O}_7\text{:Mn}$ TLDs. F. M. COX, R. A. ARNOLD, H. PACKER, R. H. MOSS and C. S. SWINEHART, Harshaw Chemical Company, Solon, Ohio (USA).

The Harshaw Chemical Company is developing some new, solid thermoluminescent dosimeters, including calcium sulphate (manganese), calcium sulphate (dysprosium), calcium fluoride (manganese) and lithium borate (manganese) types. Until now some of these TLD materials have been available only as powders and not in solid forms. Some others have been available mixed with binders or in hot-pressed forms. A new technique consisting of mixing the thermoluminescent phosphor with a pure, non-thermoluminescent binder of low effective atomic number—lithium fluoride—is described. By selectively varying the ratio of phosphors and binder one can control such parameters as response vs. energy, TL response per unit mass of material per unit exposure, and other physical properties such as density. These composite TLDs can be made in a

variety of useful geometries and are described in some detail.

61 A study on the dosimetric properties of beryllium oxide. G. SCARPA, Laboratorio Dosimetria e Standardizzazione, Casaccia (Italy).

A preliminary study on the dosimetric characteristics of three different grades of commercial beryllium oxide was carried out. The samples were made available by a British firm in the form of sintered discs.

Among useful features of this promising thermoluminescent material, a very low sensitivity to thermal neutrons (0,2 gamma rads per 10^{10} neutrons/cm²) a fairly high sensitivity to gamma rays and a good energy response are emphasized.

These parameters put beryllium oxide in a position of privilege among detectors that can be used in mixed fields of thermal neutrons and gamma rays, such as in nuclear reactor facilities.

Sensitivity to fast neutrons was found to be between 6 and 9% of that to ⁶⁰Co gamma rays.

Other parameters tested were glow-curve, fading, linearity with dose and light decay.

62 The development and use of lithium borate as a thermoluminescent phosphor for radiation. R. T. BRUNSKILL, Health and Safety Department, UKAEA Windscale Works, Sellafield (UK).

Thermoluminescent lithium borate has been prepared from a stoichiometric mixture of lithium carbonate and boric acid by doping with 0.15% w/w manganese, melting under argon and subsequent cooling to 680°C in argon and to room temperature in air. The properties of the powdered lithium borate have been compared with samples of commercially available thermoluminescent lithium fluoride. The relative sensitivity to gamma radiation of the lithium borate when compared with lithium fluoride depends on the photomultiplier tube used in the read out assembly, a variation in relative sensitivity (borate/fluoride) between 1.8 and 0.8 having been measured for a variety of photocathodes. The material has been compared with powdered lithium fluoride and monitoring films as a personal dosimeter in a number of radiation fields at Windscale Works. The results show that there is generally good agreement between doses measured by thermoluminescent dosimeters and a less well defined agreement between doses measured by thermoluminescent dosimeters and the film, particularly in those areas where soft X-radiation makes a significant contribution to total dose. Examination of the thermoluminescent data

indicates that there is no significant difference in the minimum detectable dose for the freshly cured powders but the background associated with lithium borate shows greater stability after extended issue than the fluoride and the material appears to be more reliable and accurate for dosimetric use.

63 Studies of the thermoluminescent LiF powder doped with several activators, and its properties. K. NABA, 1st Institute, Japan Defence Agency; Y. MURAYAMA and M. TAKAHASHI, Neimoto Spec Chemical Co.; T. OSHIMA and K. MAEKAWA, Japan Radiation and Medical Electric Co.; Y. NISHIWAKI and Y. FUKANO, Tokyo Institute of Technology (Japan).

In a recent paper, several kinds of TLD powder and some practical application have been reported. Considering practical application, it is necessary to choose suitable TLD powder for the following uses: (1) environmental radiation survey, (2) personal dosimetry, and (3) medical application. We think that the necessary properties for such uses are: (1) tissue equivalent, (2) little fading below 40°C, (3) energy independence for low energy photon, and (4) linearity response for the wide dose range from mR to 10⁴R.

The sensitivity of the special grade of LiF was compared with that of the super special grade for ⁶⁰Co gamma radiation. The result is that the special grade has higher sensitivity than the super special grade. Both grades were analysed by flame photometry and neutron activation analysis. As the result, it became clear that the sensitivity difference between the two grades is caused by the impurity contents such as magnesium, manganese, potassium and others.

Under the above assumption, several activators were doped in the special grade of LiF:

- (1) single activators: Mg, K, Na, Eu, Yb
- (2) double activators: Mg-K, Eu-K, Yb-K
- (3) triple activators: Mg-Eu-K, Mg-Yb-K

The sensitivity and fading of these samples were compared. The best TLD powder was found to be LiF: Mg.

Considering practical application, several tests and studies were carried out on the following problems.

- (1) spurious luminescence,
- (2) suitable thickness,
- (3) emission spectra,
- (4) linear response to dose,
- (5) fading,
- (6) effect of temperature,
- (7) energy dependence,
- (8) oxygen effect.

The results are as follows:

- (1) spurious luminescence can be easily erased,
- (2) suitable thickness is 25-50 mg/cm²,
- (3) emission spectra are mainly from 300-500 mμ,
- (4) no fading at 40°C,
- (5) energy dependence is maximum 1.5 (effective X-ray energy) in practice,
- (6) superlinearity from 10 mR to 10 R.

Considering the lower cost, we think that the LiF of special grade doped with impurity is more advantageous than the highly purified LiF single crystal materials.

64 Repetitive use of LiF loaded teflon discs with and without annealing procedures. D. M. WALLACE, AWRF, Aldermaston (UK).

In view of many apparent advantages, for operational health physics works, of LiF loaded teflon discs over loose LiF powder in radiothermoluminescent dosimetry, investigations were undertaken to determine the reproducibility of disc measurements and the disc life when the discs are subjected to the standard annealing procedures and similarly when the annealing procedures were omitted.

Experiments based on the standard annealing procedure gave a variable performance and a declining efficiency, twenty operational cycles being the practical limit of use for discs. In addition the discs appeared to give unsatisfactory measures of background radiation levels.

Experiments using discs without either high or low temperature annealing but using only the readout cycle for treatment indicated a long useful life at a constant efficiency and a reasonably stable and controllable background. Repeated cycling showed no deterioration in sensitivity or appearance for about 100 cycles for doses in the region of up to one rad per cycle. The second method appears to have many advantages especially if discs are given simple treatment before readout to remove the low temperature peaks.

65 An improved TLD reader. R. C. MCCALL, G. L. BABCOCK and G. K. SVENSSON, Stanford Linear Accelerator Center, Stanford, California (USA).

A TLD reader is described which incorporates several improvements. The reader is built around the Conrad readout chamber for versatility, but is applicable to any readout geometry. The major improvement is a heating system which utilizes a lead sulfide cell as a temperature sensor. The sample heater is heated to a preselected temperature in 1 sec. and that temperature is maintained until readout is

complete. Other improvements include a solid state electrometer and digital readout. The reader exhibits the following characteristics:

1. Since for LiF, the sample heater temperature is held to 240°C, black body radiation is virtually eliminated.
2. For the same reason, teflon dosimeters are never damaged by overheating.
3. For reasons not yet understood, reproducibility is improved by this heating cycle, e.g., with loose LiF powder, 0.8% S.D. at 500 mrad is obtainable.
4. High readout speed, e.g., 10 sec for loose LiF powder or 16 sec for thick teflon dosimeters, is normal.
5. Zero drift is virtually non-existent.
6. It is possible to change from one type of dosimeter to another with only seconds delay.

An analysis is made of the causes of the observed 0.8% S.D. of measurement; e.g., integrator accuracy, powder dispensing accuracy, background variation, etc. Based on this analysis, the potential accuracy of thermoluminescent dosimetry is discussed.

66 The response of thermoluminescent LiF to beta radiation and its use in beta dosimetry. J. R. HARVEY and S. TOWNSEND, CEEGB, Berkeley Nuclear Laboratories (UK).

Thermoluminescent lithium fluoride is used extensively in the nuclear industry for the measurement of dose to skin, particularly on the hands. Skin dose is usually the dominant hazard when the body is irradiated with beta or Compton electron radiation. A proper understanding of the response of LiF to beta and electron radiation is therefore very important. In this paper the theoretical response of an homogeneous layer of LiF is first examined. This is followed by a description of a series of experiments in which layers of LiF crystals were exposed to beta sources of various end point energies. The dose rates measured in this way were then compared with measurements made with an extrapolation chamber. It is concluded that: thermoluminescent light output is proportional to energy absorbed regardless of the beta energy; the light output depends critically upon the degree of crystal dispersion and the density of the medium surrounding the crystals.

67 A thermoluminescent dosimeter for low-energy beta and gamma radiation. M. MARSHALL and J. DOCHERTY, Health Physics and Medical Division, AERE, Harwell (UK).

A thermoluminescent dosimeter designed to measure the dose to the body and extremities from low

energy beta radiation is described. Very thin, teflon discs, 9 mg cm^{-2} thick and 12.7 mm dia., loaded with lithium fluoride provide a convenient measure of beta-ray dose. When covered by a polythene window of 3.5 mg cm^{-2} their response is equivalent to the dose under 7 mg cm^{-2} of tissue and varies by less than 10% for maximum β -ray energies of 0.15 MeV to 2.25 MeV. Gamma radiation ($> 10 \text{ keV}$) produces a similar response to beta radiation and thus the dosimeter can be used in mixed radiation fields.

68 Lithiumfluorid als radiophotolumineszenzdosimeter. D. REGULLA, Gesellschaft für Strahlenforschung, 8042 Neuherberg (Germany).

Lithiumfluorid wird bisher ausschließlich auf Grund der durch ionisierende Strahlung induzierten und thermisch stimulierbaren Lumineszenzfähigkeit zur Dosimetrie verwendet. Bei der Auswertung der Lithiumfluorid-Dosimeter wird allerdings die Dosisinformation gelöscht; Meßwertkontrollen oder Zwischenauswertungen bei Dosisakkumulationen werden dadurch unmöglich.

Ziel unserer Untersuchungen war die Auswertung von Lithiumfluorid-Dosimetern ohne Zerstörung der Dosisinformation. Beachtenswerte Ergebnisse lieferten dabei Messungen der optisch stimulierten Fluoreszenzspektren strahlenexponierter Lithiumfluorid-Kristalle: Diese emittieren bei Anregung mit 450 nm grünes Fluoreszenzlicht, dessen Intensität sich im Bereich von augenblicklich noch etwa 10 R bis 1 MR dosisproportional verhält. Lithiumfluorid-Dosimeter zeigen also neben Radiothermolumineszenz- auch Radiophotolumineszenzeigenschaften, die eine wiederholbare Auswertung ermöglichen. Neben den RPL-Spektren wird über die dosimetrische Anwendbarkeit der RPL von Lithiumfluorid berichtet (Dosis- und Energieabhängigkeit, Fading, Regenerierbarkeit). Die Ergebnisse werden mit denen aus Thermolumineszenzmessungen verglichen, die physikalischen Aspekte kurz diskutiert.

Lithium fluoride as a radiophotoluminescent dosimeter.

Lithium fluoride has so far been used as a dosimeter on the basis of its radiation-induced luminescent capacity, thermally stimulated for read-out. On reading the lithium fluoride dosimeter, the information about the dose is of course destroyed; as a result, related measurements or intermediate evaluation of accumulating dose becomes impossible.

The aim of our research was the reading of lithium fluoride dosimeters without disturbing the dose

information. Significant results were obtained showing the occurrence of optically-stimulated fluorescent spectra from lithium fluoride crystals exposed to radiation. These crystals, on stimulation with 450 nm light, emit green fluorescent light, whose intensity is proportional to dose over the range 10 R-1 MR. Therefore lithium fluoride dosimeters display, in addition to radiothermoluminescence, radiophotoluminescent properties which make a repeated evaluation possible. Besides the RPL spectra, the RPI from lithium fluoride is discussed from the point of view of the dosimetric applicability (dose and energy dependence, fading, reconditioning). The results are compared with those from the thermoluminescent measurements; the physical aspects are briefly discussed.

69 (Withdrawn)

70 Read in title. The design of a TSEE dosimeter reader and a comparison of exoelectron emission sensitivity with thermoluminescent sensitivity for various phosphors. L. D. BROWN, Edwards Radiation Laboratory, West Ham College of Technology, London (UK).

A small multichannel analyser has been modified to provide quick and comprehensive read out facilities for both TLD and TSEE dosimeter heads. The special features of this arrangement are discussed and some of the problems arising in the design of a TSEE reader are surveyed. Initial results reported include a comparison of relative TLD and TSEE sensitivities for a number of phosphors of possible interest in dosimetry.

71 Read in title. An investigation of relatively low temperature radiothermoluminescence (TL) in various materials, including those used for reference light sources. D. M. WALLACE, AWRE, Aldermaston (UK).

In the course of a routine TL dosimetry programme it was suspected that the output of the reference light source was varying in an unusual manner with the temperature of the flushing nitrogen. This led to the development of a convenient system for investigating low temperature thermoluminescent peaks. The apparatus incorporates a Peltier effect module, for rapid adjustment or control of the sample temperature.

The commercial radioluminescent light source for our reader was found to exhibit low temperature thermoluminescent peaks which could account for the observed variations in its output. The apparatus

has also been used to study some common phosphors employed in scintillation counting and attention is drawn to the possible implications of thermoluminescence in these materials.

72 Read in title. The application of thermoluminescent dosimetry to various aspects of health physics. E. W. MASON, N. T. HARRISON and G. S. LINSLEY, Radiological Protection Service, Scottish Regional Centre, Glasgow (UK).

The problems and attributes associated with the use of thermoluminescent dosimetry in individual dosimetry, neutron activation analysis and radiotherapy will be discussed. Recent work has shown that the use of CON-RAD type-7 lithium fluoride as a gamma-ray detector in mixed thermal neutron and gamma-ray fields is not always justified. The mixed field conditions under which valid results may be expected are discussed and recommendations are made concerning suitable shielding arrangements which enable the use of type-7 LiF as a gamma-ray detector in mixed fields.

The problem of re-estimation of the original dose received by a thermoluminescent dosimeter and recent investigations of a suitable solution to this problem will be discussed.

73 Read in title. A personal dosimeter which is sensitive to thermal and intermediate energy neutrons and to gamma and beta radiation. J. R. HARVEY, W. H. R. HUDD and S. TOWNSEND, CECB, Berkeley Nuclear Laboratories, Gloucestershire (UK).

The dosimeter is sensitive and accurate over a uniquely wide range of types and energies of radiation, but was developed primarily for measuring neutron dose (equivalent). It utilizes the thermalizing properties of the wearer's body so that incident neutrons which have been reduced to thermal energy are detected by thermoluminescent lithium six fluoride in the dosimeter. It represents an improvement over existing dosimeters of this type in which thermal and intermediate components of neutron dose are monitored by separate neutron detectors. In this design a thermal neutron shield of boron loaded bakelite is used to modify the thermalizing properties of the body in the vicinity of the dosimeter so that one detector monitors dose over the entire energy range: thermal--30 keV. In many areas around reactors we have found that neutron dose rate in this energy range is a roughly constant fraction of total neutron dose rate so that the dosimeter can be used to monitor total neutron dose. The dosimeter also carries a lithium seven fluoride

thermoluminescent detector which is roughly gonad equivalent and monitors gamma dose and can be simply extended to carry a teflon disc loaded with lithium seven fluoride behind a thin melinex window to monitor skin dose.

OPERATIONAL HEALTH PHYSICS II

74 Invited paper. Radiological protection problems in the developing countries. P. N. KRISHNA-MOORTHY, Directorate of Radiation Protection, Bhabha Atomic Research Centre, Bombay (India).

The extremely rapid development of worldwide applications of atomic energy has resulted in the concomitant need for the formulation, development and implementation of radiological protection measures. While the development of such measures in advanced countries has been able to keep pace with the development of the atomic energy programme itself, the problems faced by developing countries are of an entirely different dimension altogether. In developing countries; the predominant application of radiation has been in the field of medicine, although agricultural, industrial and research applications are slowly increasing. In addition, in some developing countries, there are the problems arising from the installation and operation of nuclear reactors both for research and isotope production and for power generation. The conventional use of X-ray machines and radium in medicine still constitutes the major area of radiological hazards in most developing countries.

Any national programme for radiological protection in a developing country, irrespective of the scope and extent of its atomic energy programme, has certain common elements. First and foremost amongst these is the need for appropriately trained personnel, both scientists and technicians. There is also the problem of availability of adequate nuclear electronics instrumentation and protective equipment and devices. Another major problem area is the repair and maintenance of such equipment and devices. In addition, there is the need for (a) the enactment and enforcement of appropriate legislative measures which are aimed at ensuring that radiation protection norms are adhered to; (b) the proper planning of radiation installations in order to provide maximum built-in radiation safety; (c) the adoption of safe work practices and good house-keeping measures which would minimise radiation hazards. This paper discusses some of the problems associated with the implementation of radiation safety programmes in developing countries and also deals with some lessons learnt in the implementation of such programmes.

75 Oral presentation. Sur les caractéristiques des aérosols radioactifs présents dans les mines françaises d'uranium. A. CHAPUIS, A. LOPEZ, D. BLANC et J. FONTAN, Centre de Physique Atomique et Nucléaire de l'Université de Toulouse, et F. BILLARD, G. MADELAINE et J. PRADEL, Service Technique d'Etudes de Protection du CEA, Fontenay-aux-Roses (France).

Ces recherches ont pour objet la radioprotection des mineurs contre les irradiations externe et interne. Le calcul des doses absorbées nécessite la connaissance du degré d'équilibre entre le radon et ses descendants. On décrit deux méthodes qui donnent les quantités respectives de RaA, RaB et RaC: le comptage α total, la spectrométrie, et l'on présente leurs principales caractéristiques.

Par ailleurs, la granulométrie, l'état de charge et la nature des aérosols sont des paramètres dont la connaissance est indispensable. On mesure les dimensions des particules chargées par des précipitateurs électrostatiques et celles des particules neutres par des batteries de diffusion. La spectrométrie α permet de différencier le RaA et le RaC'.

Enfin, la mesure des noyaux de condensation permet d'évaluer la concentration des poussières et de chiffrer l'indice de coagulation.

On the characteristics of radioactive aerosols occurring in French uranium mines.

These studies are concerned with the protection of miners against external and internal exposure. The calculation of absorbed doses requires a knowledge of the degree of equilibrium between radium and its daughters. Two methods are described, giving the quantities of RaA, RaB and RaC. These are total α counting and spectrometry and the principal characteristics of each are presented.

In addition, the particle size distributions, the electron charge and the nature of the aerosols must be known. The size of charged particles is measured by electrostatic precipitation and that of neutral particles by diffusion batteries. Alpha spectrometry differentiates between RaA and RaC'.

Finally, the measurement of condensation nuclei allows the dust concentration to be assessed and a coagulation index to be evaluated.

76 Oral presentation. Particle size distribution of plutonium aerosols in laboratory air. A. R. SUNDARARAJAN, S. KRISHNAMONY, V. B. MENON and B. RAGHUNATH, Health Physics Division, Bhabha Atomic Research Centre, Bombay (India).

A number of samples of airborne dust obtained in laboratories handling plutonium have been auto-

radiographed using personnel neutron monitoring film (Kodak Type A). The size and activity distribution of the plutonium aerosols were found from these autoradiographs. From the plots of mass frequency of the size intervals on a log-probability paper, mass median diameters (MMD) and geometric standard deviations have been determined.

Dust samples taken for size analysis were obtained during different operations. Samples have been collected, in particular during such operations as glove change, active material transfer etc., which may give rise to release of Pu aerosols and are likely to involve personnel exposure. Particle-size characteristics obtained for samples from personal air samplers are compared with those obtained for samples from fixed air monitors.

The significance of the results of this particle size study has been discussed in the light of the general lung model used for respiratory deposition, retention and clearance.

77 Read in title. The removal of radon and thoron daughter products from air sample filters. J. STEPHENSON and D. C. STEVENS, Health Physics and Medical Division, AERE, Harwell (UK).

Naturally occurring radon and thoron daughter products in the atmosphere are collected with atmospheric dust, on air sample filters and prevent immediate estimation of any long lived highly toxic nuclide that may also be present. A period of up to 48 hr may be necessary to allow the natural activity to decay.

This report describes a method of removing most of the natural activity from the filter within a few minutes, thus allowing a more rapid estimation of the hazard from long lived toxic nuclides. The removal of the radon and thoron daughter products is effected by passing air carrying chlorine gas (produced by bubbling the air through thionyl chloride) through a glass fibre air sample filter which is heated to about 400°C in a small furnace. The chlorides of Bismuth and lead which comprise the bulk of the natural activity are produced, and being volatile, are carried away in the gas stream. Between 85 and 95% of the natural alpha and beta activity is removed giving a corresponding reduction in the uncertainty in estimation of long lived nuclides.

78 Read in title. Application of impregnated charcoals to air monitoring of chemical plant. S. FUKUDA, Oarai Research Establishment and M. NARITOMI, Tokai Research Establishment (Japan).

In order to improve the performance of activated charcoals for collecting airborne radioiodine under

conditions of high relative humidity and long sampling period, the charcoals were impregnated with TEDA, SnI_2 , $\text{KI} + \text{I}_2$ or KSCN .

These impregnated charcoals being cartridges and filter paper were applied to the air monitoring of the ^{131}I production plant and the fuel reprocessing plant, JAERI, to perform the efficient sampling of airborne radioiodine discharged through the stack during the processing and examined for dependence of collection efficiency on properties of airborne radioiodine, sampling period and face velocity by taking the unimpregnated charcoals as a reference.

The performance of the charcoals impregnated with TEDA or SnI_2 was improved greatly as compared with that of the unimpregnated charcoals; in the impregnated charcoal cartridge (5 cm dia., 2 cm thick, 30-mesh granules) were maintained to be more than 98% at the production plant and 85% at the reprocessing plant, respectively, over long period of 14 hr—sampling at relative humidity ranging from 60 to 85%. The charcoals impregnated with SnI_2 were found to be most suitable for the monitoring of the stack effluent of the reprocessing plant in which chemically reactive gaseous materials such as NO , NO_2 and organic vapours of DBP, TBP are present. On the other hand, the charcoals impregnated with $\text{KI} + \text{I}_2$ or SnI_2 were little improved in their collection efficiencies.

The paper presented will describe the results obtained in airborne radioiodine sampling of the chemical plants by using the impregnated charcoal filter paper as well as charcoal cartridge and discuss the effectiveness of the impregnants for collecting airborne radioiodine.

79 Read in title. The planning of radiation protection monitoring for air contamination at the alpha-gamma cave facility in Japan. J. KATOH, Power Reactor and Nuclear Fuel Development Corporation, Tokyo (Japan).

The alpha-gamma cave facility at the Power Reactor and Nuclear Fuel Development Corporation, Japan, is a laboratory handling very high radioactivities such as irradiated UO_2 , PuO_2 mixed oxide fuel. The facility is now under construction, and is intended to begin the operation in August 1970. Because of the large quantity of plutonium to be handled, isolation boxes are used in the cell cave and many efforts are made to prevent spreading radioactive contamination.

This report describes the planning of radiation protection monitoring, especially for airborne contamination in the facility.

The air contamination monitoring consists of spot

air monitoring by the fixed type air sampler and movable continuous air monitor for plutonium particulates $\beta - \gamma$ particulates and iodine. The sampler heads of the former are sited at 30 various locations and each sampling flow rate is about 50 l/min. These continuous air monitors have the fixed type filter paper and the radiation detector of ZnS scintillation counter, GM counter and NaI scintillation counter respectively. The air pumps of the air sampler and continuous air monitor are located in a remote place to avoid its noisy sound. Other continuous air monitors will be prepared for the stack air exhausted from the facility.

The report will show the layout of these monitoring instruments together with the alpha-gamma facility, specification of the instruments and the monitoring method.

80 Read in title. Reassessment of the present situation in monitoring the artificial α aerosol activity. A. MARTINEC, F. HUMBEL and E. KOWALSKI, Landis & Gyr AG, Zug (Switzerland).

For the suppression of the natural α aerosol activity background in filter-type aerosol monitors at least four different techniques are known, namely, delayed measurement, measurement of the β/α -ratio, the so-called pseudocoincidence method and the energy analysis of the filter deposit. The main advantages and disadvantages of the particular methods will be compared.

Due to the inherent delay in the result indication, the delayed measurement cannot be used for monitoring of possible incidental radioactivity outlets in research laboratories, fuel reprocessing plants, etc. Both the β/α -ratio measurement and the $\alpha-\beta$ pseudocoincidence method are based on the assumption of non-disturbed equilibrium of the natural Rn and Tn decay families. Any disturbance of the equilibrium between Rn and its daughter products caused e.g. by variations in the ventilation air cycle, changed climatic conditions etc. leads to false indications. With the energy analysis the results may be adversely affected by absorption in the filter deposit—hence the use of aerosol monitors based on this background suppression technique is restricted to sites with low dust-content of the air, like hot-laboratories or in general all air-conditioned research facilities.

Finally a novel aerosol monitor of the continuously moving-filter type will be described, in which the background suppression is accomplished by means of a semiconductor detector energy spectrometer. The results of measurements will be discussed and a critical analysis of the monitor characteristics will be given.

(Withdrawn)
81 Read in title. Simulation of the regional aerosol deposition in the respiratory tract: preliminary results. C. MELANDRI and V. PRODI, CIVEN, Centro di Calcolo, Bologna (Italy).

A device has been studied that simulates the behaviour of the airways as far as deposition is concerned.

The main section consists of a sieve plate liquid column into which the aerosol is injected and rises in uniform bubbles.

The deposition of aerosol particles in these bubbles closely follows, in the 0.02 to 5 μm range, the total deposition curves of the respiratory tract given by the ICRP Task Group on Lung Dynamics.

Regional deposition has been simulated adding before the column a properly designed stage with a capture efficiency close to the deposition efficiency in the nasopharyngeal plus tracheo-bronchial regions.

As can be seen from the curves of deposition efficiency as a function of size for various kinds of particles, when water is used as bubbling liquid the whole system looks very promising for health physics applications, as it allows the assessment of the aerosol fraction deposited in the pulmonary region without size distribution measurements.

82 Read in title. A study of the size of airborne plutonium contaminants in a plutonium production plant. R. T. BRUNSKILL and B. TAGG, Health and Safety Department, UKAEA Windscale Works, Sellafield (UK).

Static size selective air samplers have been used to investigate the particle size spectra in a number of operational areas at the Windscale Works where plutonium is processed. Results have been compared with particle spectra obtained by autoradiography of personal air samples. Under normal conditions there is fairly good agreement between the two sets of data but where personal air samplers indicate unusually high exposures the particle size spectrum is invariably considerably coarser than that obtained under normal conditions. Static size selective devices suffer from the same disadvantage as the static air samplers in that their results can be completely non-representative of conditions in the breathing zone. The need for a size selective personal air sampler will be apparent.

RADIATION EFFECTS IN MAN I

83 Invited paper. Radiation effects in man: current views and prospects. R. H. MOIR, Director, MRC Radiobiological Unit, Harwell (UK).

Current views include the beliefs that limitation of bone marrow exposure is the key to protection of the

whole body, that the predominant effect of ^{90}Sr in the human body is to cause bone tumours, that the younger the individual the more sensitive he is to a given exposure to ionizing radiation, that there is a generally deleterious somatic effect of such exposures apart from cancer induction, that the lens of the human eye is unusually sensitive to high LET radiation, that a linear dose-response relationship is applicable to all forms of radiation damage. Increasing knowledge and understanding show that none of these working hypotheses is true in more than a rather limited sense. Some of the increase in knowledge comes from continuing follow-up of well-established groups of irradiated persons but unusually valuable and wholly new information has recently been made available about the effects of ^{224}Ra in children and adults. There is no more evidence than there ever has been of measurable effects from radiation exposures of the order of background.

Invaluable information from surveys of irradiated human populations will still be coming in for two more decades at least and during that time generalisations from biological experimental work may begin to play a useful part in radiation protection.

84 Oral presentation. The maximum permissible body burden of radium in light of the Argonne radium studies.* A. J. FINKEL and C. E. MILLER, Argonne National Laboratory, Argonne, Ill., and R. J. HASTERLIK, Argonne Cancer Research Hospital, Chicago (USA).

The value of 0.1 μCi of radium as the established maximum permissible body burden was examined against our 20 yr experience with approximately 300 persons who acquired varying body burdens of radium 35-50 yr ago. Serious deleterious effects attributable to radium in these patients have ranged from disabling orthopedic conditions to blood dyscrasias and malignant tumors of skeletal tissue and of epithelial linings of mastoid air cells and paranasal sinuses. For those patients for whom data are adequate, we reconstructed individual patterns of radium retention, and we computed various relevant indices such as the estimated maximum burden (i.e., peak initial burden), the estimated total radium absorbed into the blood stream, and the cumulative rads to the standard skeleton at various intervals during and subsequent to the period of exposure (despite the questionable validity of cumulating rads for these and other purposes). These computed values for patients

* Work supported by the US Atomic Energy Commission.

with malignant diseases attributable to radium have been compared with those for hypothetical cases with either (a) a constant body burden of $0.1 \mu\text{Ci } ^{226}\text{Ra}$ or (b) orally acquired radium with a retention of $0.1 \mu\text{Ci}$ at 14,000 days (38.33 yr) after cessation of ingestion. These comparisons point to a substantial margin of safety in the present $0.1 \mu\text{Ci}$ radium standard.

85 Oral presentation. Late effects of ^{224}Ra injections in man. H. SPIESS, Kinderpoliklinik der Universität München (Germany).

On a recommendation of a German country doctor during the years 1944–1951 about 2000 patients were given repeated injections of ^{224}Ra as so-called "Pectosthor". These patients had mainly lung and bone tuberculosis or ankylosing spondylitis. The duration of the ^{224}Ra injections varied from a few weeks to a few years. The injection of ^{224}Ra into children was stopped in 1951, continued in adults with ankylosis spondylitis in some German hospitals up to now. The first follow-up was made in 1955, the last started in August 1969 and was finished at the beginning of 1970.

^{224}Ra concentrates in growing bone. Repeated injections depending on ^{224}Ra dose and age led to serious damage of the epiphyseal cartilage.

Up to August 1969 a total of 1814 persons were known with repeated ^{224}Ra injections. But from only 891 exact information (including ^{224}Ra dosage) is available, 221 between 1–20 yr of age at the beginning of ^{224}Ra injections and 670 with 21 yr and over. The most important late effect is the appearance of 43 osteosarcomas and 6 chondrosarcomas. 37 of the osteosarcoma have died, 6 are living. 28 osteosarcomas and 6 chondrosarcomas were in the younger ages. 27 soft tissue tumours, mostly cancers of the lung and digestive tract were observed in the higher ages and seem not positively related to radiation. Only 3 leukemias are recorded. Benign bone tumours were observed in 18 cases of osteochondroma, in 6 of them multiple, 1 osteofibroma and 1 osteochondroblastoma. Besides this, growth retardation in ^{224}Ra injected children, the observation of breaking of teeth and 13 cataracts may be mentioned.

86 Oral presentation. Correlation of radiation doses and blood counts. E. E. SMITH, Radiological Protection Service, Belmont, Surrey (UK).

In view of the interest in discovering a biological index of whole-body irradiation and the continuing practice of carrying out blood counts on occupationally exposed persons, some unpublished data on a

small group of workers who were exposed to radiation about 20 yr ago when the "tolerance dose" was 1 roentgen per week will be presented. The group includes two persons whose cumulative whole-body doses (mainly from radium gamma rays) exceed 300 rads, and who averaged about 1 rad/week over a period of four consecutive years. Blood counts were taken during the period of heaviest exposure and during the subsequent period. However, even at a dose rate which is ten times the current maximum permissible dose rate and with a cumulative dose in 4 or 5 yr equal to the current lifetime dose, the existence of a correlation between dose and blood count is by no means certain.

87 Read in title. Etude comparative de l'excrétion urinaire de la sérine, de la thréonine et de l'éthanolamine après irradiation gamma et neutronique. G. MARBLE, C. VALLEE, C. LAUNAY et E. PETROCHILO, Département de la Protection Sanitaire, Commissariat à l'Energie Atomique, Fontenay-aux-Roses (France).

A la suite d'une irradiation accidentelle humaine (accident de criticité) une diminution de l'excrétion urinaire des acides α aminés à fonction alcool:sérine et thréonine, avait été notée. La variation de l'excrétion de l'éthanolamine était également de même sens.

Une étude expérimentale, chez le lapin, a permis de comparer les excrétions urinaires de ces trois composés aminés après irradiation gamma et après irradiation mixte: gamma + neutrons. Alors que l'on note une augmentation de l'excrétion des deux acides aminés après irradiation gamma, une diminution nette apparaît après irradiation mixte. En ce qui concerne l'éthanolamine, une diminution est observée après irradiation mixte alors qu'après irradiation gamma il n'y a pas de variation par rapport au taux normal d'excrétion.

Ces résultats sont analogues à ceux obtenus chez l'homme irradié accidentellement et mettent en évidence les réponses différentes de l'organisme aux deux types d'irradiation.

Comparative study of the urinary excretion of serine, threonine and ethanolamine after gamma and neutron irradiation.

Following the accidental irradiation of a man (criticality accident) it has been reported that there is a reduction in the urinary excretion of α amino-acids as a function of the ratio of alcohol:serine and alcohol:threonine. The variation of the excretion of ethanolamine was also in the same direction.

An experimental study with rabbits has allowed a comparison of the urinary excretion of these three amino compounds after γ irradiation and irradiation with both γ and neutrons. Although there is an increase in the excretion of the two aminoacids after γ irradiation, a net decrease was observed after the combined irradiation. For ethanolamine a reduction occurs after the mixed irradiation, while there is no variation in respect of the normal rate of excretion after γ irradiation.

These results are comparable with those obtained on the accidentally irradiated man and indicate different responses of the organism to the two types of irradiation.

88 Read in title. Results and experiences from systematic examinations of the eyesight in persons exposed to ionising radiation. S. SAVIĆ, M. KILIBARDA and M. JEREMIĆ, Institute of Occupational and Radiological Health, Belgrade (Yugoslavia).

During work with sources of ionising radiation, impairment of the eyesight may occur, particularly cataract. Therefore, since 1962, persons working with ionising radiation are submitted to obligatory ophthalmological control in the Institute of Occupational and Radiological Health in Belgrade.

During this 7-yr period, systematic examinations of the eyes have been performed on 171 persons exposed to gamma radiation, 183 chronically exposed to the effects of X-radiation, 391 workers in uranium mines, as well as three persons who were accidentally irradiated by a larger dose of neutron radiation. The data on this exposure to ionising radiation sources are given.

At the examinations, particular attention was paid to the possible incidence of cataract. Among other findings, few cataracts were recorded, though one showed a completely characteristic picture of the cataract caused by ionising radiation. It is considered that ionising radiation in the other cases was a contributory factor in its faster development. Consequently, the question arises as to whether these cataracts are of occupational aetiology or not.

RELEASE OF ACTIVITY INTO THE ENVIRONMENT II

89 Oral presentation. Atmospheric diffusion in an urban area. F. A. GIFFORD Jr., Air Resources Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee (USA).

Urban air pollution can be considered to result from isolated, elevated point sources such as power

plant stacks plus a distributed, low-level area source representing the remainder of the city. The possibility that either or both may have a radioactive component makes it necessary to consider urban atmospheric diffusion models. Elevated point-source radioactivity could conceivably arise from the radioactivity content of coal or from nuclear reactor waste off-gas. The feasibility of nuclear stimulation of natural gas reservoirs is now being investigated. Combustion of natural gas from this source could provide both point and area sources of radioactivity. An urban diffusion model is developed, based on a simple point source model. This is applied to diffusion in the Los Angeles basin, and the variability of long-term average concentration patterns is examined.

90 Oral presentation. Untersuchungen über Luftströmungen im Hinblick auf die Ueberwachung der Umgebung von Atomanlagen. P. COURVOISIER und E. NAGEL, EIR, Würenlingen (Switzerland).

Allgemeine klimatologische Statistiken über Richtung und Geschwindigkeit von Luftströmungen liefern nur einen Teil der für eine korrekte Beurteilung der Verhältnisse notwendigen Angaben. Meist fehlen Angaben über diejenigen Strömungen, die weniger als ca. 1 m/sec Geschwindigkeit aufweisen. Da es bei der Ueberwachung von Reaktoren wesentlich auf die schwachen Winde ankommt (in den klassischen Diffusionsformeln geht bekanntlich die Windgeschwindigkeit im Nenner ein), ist man allgemein bestrebt eben diesen Teil der Statistik zu ergänzen.

Während 16 Monaten wurden im ganzen unteren Aaretal, wo sich die Reaktoren des Eidg. Instituts für Reaktorforschung befinden, Messungen mit hochempfindlichen Windmessern durchgeführt, die im Eidg. Institut für Reaktorforschung entwickelt worden sind. Sie wurden an 12 markanten Standorten aufgestellt. Auf Grund dieses Materials wurden insbesondere Strömungskarten für jede zweite Stunde gezeichnet (fast 6000 Karteu).

Die Resultate zeigen, dass während dieser ganzen Zeit an keiner Station echte Windstillen beobachtet werden konnten; bei schwachen Winden herrschen nicht selten sehr uneinheitliche, ja chaotische Strömungsrichtungsverhältnisse, so dass keine eindeutigen Abflussrichtungen für Abluft aus den Reaktoren zu erkennen sind. Die weit überwiegende Zahl von Strömungskarten zeigt jedoch eindeutige Strömungsverhältnisse an, über deren Andauer Aussagen gemacht werden können.

Ferner vermittelt das enge Messnetz Einzelheiten über den Einfluss, den das hügelige Gelände (Höhenunterschiede bis zu 280 m) auf die allgemeine Strömungsrichtung hat. Hier schälen sich zwei

deutliche Typen heraus: Strömungen, bei denen, unabhängig von der Windgeschwindigkeit, markante Unterschiede in Windrichtung und -stärke zwischen dem für die Verbreitung von Pollutanten wichtigen Talgrund und den Talkanten zu beobachten waren, und Strömungen, auf die das Relief im betrachteten Gebiet keinen Einfluß hat.

Diese Tatsachen konnten zum Teil auch mit Hilfe von Schwebeballonsflügen und bei der Messung des mit der Abluft des Schwerwasserreaktors des Eidg. Instituts für Reaktorforschung in der Umgebung sich ausbreitenden Argon-41 bestätigt werden.

Examination of air currents with regard to the control of the environment of atomic plants.

General climatological statistics about the direction and speed of air currents provide only a small amount of the information necessary for a correct assessment of conditions. For the most part, information is lacking about those currents which show a speed of less than about 1 m/sec. Since, in the monitoring of reactors, conditions of low wind speed are of particular importance (it is well known that in the classical diffusion formula speed comes into the denomination), we are striving to enlarge this part of the statistical information.

For 16 months, throughout the lower Aar Valley, where the reactors of the Eidg. Institute for Reactor Research are sited, measurements were carried out with the highly sensitive anemometers which were developed in the Eidg. Institute for Reactor Research. These were placed at twelve representative points. On the basis of this information, air current charts were drawn every 2 hr (almost 6000 charts).

The results show that during this whole period there was no real calm observed at any of these stations; in the case of weak winds, very often irregular, almost chaotic wind directions prevailed, so that no significant directions of outlet for the air leaving the reactors could be recognised. However, the majority of the charts show significant current conditions and statements can be made about their duration.

Moreover, the measurement system provides details about the influence which the hilly countryside (differences in altitude of up to 280 m) had on the general wind direction. Two clear types may be distinguished here: (1) currents which, independent of wind speed, showed significant differences in wind direction and wind force at the bottom of the valley as compared with the sides of the valley, and hence are important for the distribution of pollutant; (2) currents on which the relief of the area under observation had no influence whatsoever.

These facts can be partly confirmed with the aid of

balloons and by measuring the distribution of ^{41}Ar from the outlet of the heavy water reactor of the Eidg. Institute for Reactor Research.

91 Oral presentation. De la gestion des déchets et effluents radioactifs. H. JOFFRE, PH. KISSEL, Y. MARQUE et J. PRADEL, Service Technique d'Etudes de Protection du CEA, Fontenay-aux-Roses (France).

Dans cette communication les auteurs présentent les résultats d'une longue expérience du CEA, dans le domaine de la gestion des déchets solides et des effluents liquides radioactifs.

A partir de bases à la fois techniques et économiques, on propose des dispositions pratiques pour le classement, le conditionnement et l'identification de ces produits.

Ces dispositions sont adaptées à la réglementation française qui est très proche, —notamment en ce qui concerne le transport des matières radioactives—des recommandations de l'Agence Internationale de l'Énergie Atomique.

Certaines lacunes dans les textes réglementaires apparaissent; et l'on fait quelques suggestions pouvant présenter un intérêt en ce domaine.

On the management of radioactive wastes and effluents.

The authors present in this paper the results of long experience in the CEA in the management of solid radioactive wastes and of radioactive liquid effluents.

Based on both technical and economic considerations, practical proposals are made for the classification, treatment and identification of these materials.

These procedures are in line with the French regulations which follow closely the recommendations of the International Atomic Energy Agency, particularly with respect to the transport of radioactive materials.

Certain gaps are apparent in the regulations and suggestions are made which may be of interest in this field.

92 Oral presentation. Conséquences sanitaires des rejets atmosphériques d'eau tritiée. J. PLANET, G. UZZAN et J. LE GRAND, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

Deux mécanismes de contamination de la population sont liés aux rejets dans l'atmosphère de vapeur d'eau tritiée:

—d'une part l'inhalation et l'absorption transcutanée de la vapeur d'eau tritiée contenue dans l'air.

—d'autre part l'ingestion de produits alimentaires contaminés.

Une méthode générale a été mise au point permettant l'évaluation de l'irradiation des groupes de population concernés en fonction des nombreux phénomènes qui interviennent:

—*phénomènes de dispersion physique dans le milieu:*

Dispersion dans l'air en fonction des conditions météorologiques, contamination des pluies par lessivage de l'atmosphère, contamination de la nappe phréatique.

—*phénomènes de transfert dans la chaîne alimentaire:*

—contamination des produits végétaux en tenant compte des échanges d'eau en phase vapeur entre l'atmosphère et les parties aériennes des plantes, de l'absorption par voie foliaire de l'eau tritiée apportée par les précipitations et la rosée sur l'appareil végétatif et de l'absorption par voie racinaire de l'eau tritiée se trouvant dans le sol.

—contamination des aliments d'origine animale (lait et viande) en fonction de la contamination des pâturages et du mode d'élevage du bétail.

L'application de cette méthode à un cas particulier permet de se faire une idée de l'ordre de grandeur des risques qu'entraînent les rejets d'eau tritiée dans l'atmosphère.

Health implications of atmospheric discharges of tritiated water.

There are two mechanisms of contamination of the population associated with the discharge to atmosphere of tritiated water vapour:

- on one hand is the inhalation and skin absorption of the tritiated water vapour content in the air;
- on the other is the ingestion of contaminated food products.

A general method is applied to evaluate the dose to groups of population as a function of the numerous processes that are involved:

—*physical dispersion in the environment:*

dispersion in the air as a function of meteorological conditions, contamination of rain by washout from the atmosphere, contamination of the water table;

—*transfer mechanisms in the food chain:*

contamination of vegetable products taking account of the exchange of water in the vapour phase between the atmosphere and the exposed parts of plants, of the foliar absorption of tritiated water carried by rain and dew, and of the uptakes through the roots of tritiated water in the soil,

contamination of food of animal origin (milk and meat) as a function of the contamination of pasture and the method of rearing of livestock.

The application of this method in a particular case gives an indication of the order of magnitude of the risks following the discharge of tritiated water to the atmosphere.

93 Oral presentation. Evaluation des doses d'irradiation interne délivrée aux individus du public par suite de la pollution des aliments par le ^{90}Sr et le ^{137}Cs , en vue de la détermination des niveaux de rejet des radionuclides dans le milieu ambiant.
ARLETTE GARNIER, Département de la Protection Sanitaire, GEA, Fontenay-aux-Roses (France).

L'étude est orientée vers la recherche de modèles permettant de déterminer les niveaux de rejet des substances radioactives dans le milieu ambiant.

Dans ce but, on se propose d'évaluer les doses moyennes d'irradiation interne résultant de la contamination de la chaîne alimentaire par le ^{90}Sr et le ^{137}Cs en tenant compte:

- des conditions et mécanismes de transfert à partir du milieu ambiant,
- des différents vecteurs alimentaires,
- des caractéristiques des groupes de population concernés (âge, diète, paramètres anatomiques et physiologiques).

Les paramètres introduits dans les modèles ont été choisis soit d'après des études bibliographiques de synthèse, soit d'après des résultats d'études expérimentales ou d'enquêtes (telles que les enquêtes alimentaires familiales par pesées). L'influence de leur variabilité n'est pas étudiée ici, où apparaissent seulement l'influence du régime alimentaire et, surtout, l'influence du rythme d'apport et d'élimination du radionucléide dans le milieu ambiant associée à celle de l'âge à partir duquel les individus sont soumis à la contamination interne.

La détermination du group critique en cas de contamination continue exige une très complète définition des hypothèses de travail.

Evaluation of the internal radiation doses to individuals of the public following the contamination of foodstuffs by ^{90}Sr and ^{137}Cs , with the aim of setting levels of discharge for radionuclides in the environment.

This study is aimed at the investigation of models allowing levels of discharge of radioactive substances into the environment to be determined. For this purpose, it is proposed to estimate the average internal

radiation dose resulting from contamination of the food-chain by ^{90}Sr and ^{137}Cs , taking account of:

- the conditions and transfer mechanisms of the environment,
- the various links in the food-chain,
- the characteristics of the population groups concerned (age, diet, and anatomical and physiological parameters).

The parameters used in the models have been chosen either by biographical reference or after the results of experimental studies or enquiries (such as those into the weights of the components of family diets). The effect of the variations of these factors has not been studied here, where we have dealt only with the influence of the diet and, particularly, with the influence of the pattern of addition and removal of radionuclides in the environment associated also with the influence of the age at which the individuals became subject to internal contamination.

The determination of a critical group in the case of continued contamination requires a very complete definition of the working hypotheses.

POPULATION EXPOSURE I

(withdrawing) See 200

94 *Oral presentation.* ~~Population exposure considerations for commercial applications of contained nuclear explosions.~~ R. L. GORMAN, Reynolds Electrical and Engineering Co. Inc., Las Vegas (USA).

~~Some of the anticipated health physics problems associated with chronic, long-term radiation exposure of sizable segments of the public following commercial uses of contained nuclear explosions for stimulation of natural gas and oil reservoirs, formation of large underground storage reservoirs and recovery of low-grade mineral deposits are discussed. Computations of expected ranges of radioactive contamination in some commercial products removed from sites of contained explosions, and proposed release rates of ^{85}Kr and HTO to the environment from such sites, are also presented.~~

95 *Oral presentation.* **Consideration of the radiological impact from the hypothetical use of contaminated natural gas from nuclearly stimulated reservoirs.** D. G. JACOBS, C. R. BOWMAN and E. G. STRUXNESS, Health Physics Division, Oak Ridge National Laboratory, Tennessee (USA).

Commercial utilization of nuclear engineering in underground applications, such as stimulation of a gas

reservoir, may result in detectable quantities of residual radionuclides becoming a part of the distributed product. The concentration of radionuclides will be small, but their existence implies that sizable population groups could be exposed. It is prudent to consider the impact of such radiation exposures before they occur and, unless they are clearly insignificant, balance them against the benefit the population would derive from this application of Plowshare technology.

Tritium and ^{85}Kr were the only radioactive products of the Gasbuggy detonation found in detectable concentrations in gas removed from the well during production testing which began in July 1968. The original concentrations of these nuclides were about 700 and 125 pCi/cm^3 , respectively, and the concentration has decreased exponentially with the quantity of gas removed from the well. None of the gas removed from the well has actually entered the production system, but an assessment has been made of the potential impact to consumers and workers assuming the hypothetical introduction of Gasbuggy gas into the actual gas collection and processing system.

The concentration of combustion products in homes has been estimated for houses of various types of construction, assuming release of all combustion products inside the house. At the first hypothetical point of use of Gasbuggy gas, a farm tap in the San Juan basin, the potential dose to the whole body for the first year of use for 6000° days of heating would be about 15 mrem and would decline exponentially with time. The potential dose is directly related to the degree days of heating required, since the amount of gas used for other appliances is considerably less than that used for home heating.

At the processing plant, approximately 2.5% of the radionuclide content of the incoming gas stream would be released during combustion to provide power for operation of the plant. Workers at the plant could potentially receive a dose equivalent of 0.3 mrem to the whole body from these releases during the first year and could receive as much as 1.7 mrem from home heating using the gas processed through the plant.

As the gas proceeds to more distant consumers, it is further diluted with gas from other basins. The potential dose to users would be further decreased due to this dilution but would be modified by the number of degree days of heating required. The potential contribution of tritium and ^{85}Kr to the general background has also been considered in areas of high rates of gas use, but is small in relation to the potential dose obtained from occupation of a home heated without venting the combustion products.

96 Oral presentation. Radiation protection and industrial applications of nuclear explosions. W. S. JOHNSON, Sr., Eberline Instrument Corporation, Santa Fe, New Mexico (USA).

The so-called Nuclear Non-Proliferation Treaty provides for a broad exchange of information and technical assistance among nations to exploit the use of nuclear explosions for non-weapons purposes. In the United States this program (Plowshare) envisions several experimental or demonstration projects of which two have been detonated (Projects GAS-BUGGY and RULISON).

Simply stated, these projects take advantage of one or more of the three basic phenomena which occur in the vicinity of the detonation, namely, the cavity formation, the fracturing and the rubble pile. Examples of these phenomena and their industrial applications are explained.

Radiological protection procedures for project personnel have evolved into a fairly routine operation largely based on the substantial experiences of the weapons testing program. These are described and illustrated, using actual field installations and data.

The present status of Plowshare indicates that more extensive applications are not restricted by technical or radiological problems but rather by the ill-defined limitations of public acceptance, geopolitics, product liability, and especially, economics.

97 Oral presentation. X-rays from colour television receivers in Britain. M. G. O'RiORDAN and P. N. CASBOLT, Radiological Protection Service, Belmont, Surrey (UK).

An extensive survey of colour television receivers manufactured in Britain will be described. Aspects discussed will include:

- (i) dose patterns around receivers,
- (ii) effect of variations in the high voltage supply,
- (iii) estimation of population dose,
- (iv) protection of service personnel.

NEUTRON DOSIMETRY AND RADIATION PHYSICS I

Discussion Group

98 Method of fast-neutron spectrometry by means of a semiconductor detector and a small scattering chamber. L. S. CHUANG, T. H. LU and K. H. CHEUNG, Chung Chi College, The Chinese University of Hong Kong, and the National Tsing Hua University, Hsin Chu, Taiwan.

A tiny solid state detector of surface barrier type is combined with a thin polyethylene film at a dis-

tance, separated by a proton beam collimation and defining system, for an absolute determination of the neutron flux, to provide a small fast-neutron spectrometer. The polyethylene target is fixed at a position in a bellows which also carries the detector. The detector can be rotated on a goniometer in an angular range 0-90°. Monoenergetic fast-neutrons from ${}^1_0\text{H}^2$ -d source were detected with and without polyethylene target in place. Subtraction of the two recoil proton spectra measured at three different scattering angles for the same incident neutrons, showed recoil proton peaks at energies identical with that of calculated values from kinematics consideration. Absolute determination of the number of incident neutrons at the target point can be made for the incident neutron energy as high as that can be accepted by the detector combined with the goniometer. Neutron flux measured agrees well, within the experimental error, with that calculated.

99 The evaluation of integral neutron field parameters by the multisphere technique F. GRÜNAUER, H. SCHRAUBE and G. BURGER, Gesellschaft für Strahlenforschung mbH, Institut für Strahlenschutz und Physikalisch Technische Abteilung, Neuherberg bei München (Germany).

The multisphere technique is used widely for evaluating the integral values in stray and leakage-neutron fields. Based on the multisphere response functions, it is possible to represent every desired response, e.g. the ICRP-equivalent dose recommendation by a linear combination. In the past, various authors have proposed different sets of spheres and certain fixed expansion coefficients.

It will be shown that the error of the calculated values depends on the expansion coefficients. Thus, an adequate series expansion has to furnish expansion coefficients which do not only supply a good response approximation but also minimize the error of the result.

This is the idea of the mathematical method presented; it allows to take into account all important errors in the expansion procedure such as

- (a) statistical and systematic errors of the counting rates
- (b) the deviation of the desired and the approximated response
- (c) calibration errors
- (d) the uncertainty of the response matrix.

Considering certain neutron spectra, suitable sets of spheres can be selected for optimal determination of integral values. Optimal measuring periods for the different spheres can be calculated depending on the accepted total error. For every given data

vector the desired integral values are calculated on the basis of specific expansion coefficients resulting from separate optimization procedures.

At different reactor positions, the equivalent dose, the fluence and herewith the conversion factors were determined by the described analysis. The conversion factors are shown to represent a good one-parameter-criterion for the readings of routine neutron detecting instruments.

100 Personal dosimeter for neutrons. M. NICOLAE, Institute for Atomic Physics, Bucharest (Romania).

In this paper is presented a personal dosimeter for neutrons in γ radiation field. It contains three dosimetric systems comprised in a single dosimetric badge, as follows: the first dosimetric system intended for thermal neutrons in the range of current and accidental exposure doses, the second one for intermediary neutrons in the range of 10^8 – 10^{11} n/cm², the third one for fast neutrons in the range of current and accidental exposure doses. This dosimeter uses photographic and track solid detectors with different characteristics, according to the type of the dosimetric system and the exposure range. Therefore, this dosimeter contains five different detectors, namely: a conventional dosimetric film in the range of current exposures to thermal neutrons, a mica sheet, coated with an uranium salt for accidental exposures to thermal neutrons, a nuclear emulsion tick sheet for fast neutrons in the range of current exposure, two films of cellulose nitrate, respectively for intermediary neutrons and fast neutrons at high exposure doses. Each detector is intended to record a secondary product of a given neutron interaction. The correspondent absorbants used in this dosimeter are also pointed out.

The method for dose establishment for each dosimetric system is briefly presented, some considerations concerning the accuracy of the method including. Also, the inferior and superior limit dose in each case are indicated.

101 On the detection of fast neutrons by the etch-pit method of nuclear track registration in plastics. Y. NISHIWAKI and T. TSURUTA, Tokyo Institute of Technology, Meguro-ku, Tokyo (Japan).

We have irradiated plastics, such as polycarbonate, cellulose nitrate and cellulose acetate with fast neutrons (2.5 MeV, 14 MeV) and observed the rate of increase in the number of etch-pits on the surfaces of the irradiated plastics after etching with suitable chemical reagent. After a series of experiments, it was found that the number of etch-pits increases with the etching time, and that a close correlation

seems to exist between ΔP , the increment in the number of etch-pits per unit area, and Δl , the increment of the dissolved thickness of the plastic surface, for the same etching time interval Δt , during the relatively early period of etching. In other words, an approximate relation $\Delta P/\Delta l = k$ was observed to hold for the initial etching period, where k is a constant and may be considered to correspond to the number of etchable initial damages produced by fast neutron irradiation per unit volume. The value of k was found to correspond to the estimated number of recoil carbons and oxygens in case of polycarbonate which consists of C, O, and H. Therefore, it may be inferred that the etch-pits observed in polycarbonate might have developed at the site of radiation damage caused by the recoil carbons and oxygens due to fast neutron irradiation.

102 A feasibility study of the use of track registration from fission fragments for neutron personnel dosimetry at the 20 GeV Stanford Linear Electron Accelerator (SLAC). G. K. SVENSSON, Stanford Linear Accelerator Center, Stanford, California (USA).

The fissile materials to be discussed are thick foils of Thorium and Uranium with different degrees of depletion.

The energy distribution of the radiation field as well as particle type distribution varies strongly around the accelerator, depending on the shielding configuration. Giant resonance neutrons (e.g., 10–20 MeV) will dominate where shields are thin, while very high energy neutrons are important in the forward direction and in thick shield configurations.

One important advantage of using ²³²Th when in a broad energy range like this, is that the fission cross section for nucleons seems to stay at a constant level (about 0.6 barn) up to at least 350 MeV.

A major problem for any neutron dosimetry system applied at SLAC is the photon component, which has a wide energy distribution. To evaluate the importance of such a photon field when using Thorium and Uranium foils together with Lexan and Mica, an exposure was made in a 13 GeV bremsstrahlung beam at SLAC. The significance of the evaluated cross section per equivalent quanta, when applied in a mixed neutron-photon field will be discussed.

103 The determination of neutron doses with activation detectors. I. MIRIĆ, P. MIRIĆ and D. VELIĆKOVIĆ, Boris Kidrić Institute of Nuclear Sciences, Vinča (Yugoslavia).

The determination of neutron doses in a mixed radiation field is performed using the following

activation detectors: In, Au, Cu, S, Ni, Mg and Al.

The method of spectra indexes was used for the evaluation of the neutron spectra. It was supposed that the neutron flux intensity in the intermediate energy region is inversely proportional to the energy (E), and that, in definite energy intervals, in the high energy region, it is given by

$$\phi(E) = kE^{1/2} e^{-\alpha E}$$

The paper presents an analysis of the results obtained using the heavy water reactor at Vinča. The experimental results obtained with different activation detectors are compared and related to the theoretical values.

104 Space dose distribution of monoenergetic neutrons in the human body for different neutron incidence angles. V. G. ZOLOTUKHIN, G. M. OBATUROV and Z. A. PROKOPIEVA, Institute of Physics and Power Engineering, Obninsk, and I. B. KEYRID-MARKUS, O. A. KOCHETKOV and V. I. TSVETKOV, Institute of Biological Physics, Moscow (USSR).

At present the neutron dose loading in a human body is calculated from Snyder and Neufeld's well-known data.

But the knowledge of one-sided neutron dose distribution in a human body is not sufficient for solution of many practical problems of dosimetry, normalization, radiobiology, etc.

Therefore the authors carried out the calculation of the absorbed dose and dose equivalent distribution of monoenergetic neutrons in a human body for eight different directions of neutron incidence.

The body was approximated by a homogeneous elliptic phantom with the sizes being nearly equal to those of a trunk.

The calculation results are represented by isodoses for both separate dose equivalent components and their sum. The authors considered the data obtained and showed that the isodose distribution was essentially dependent on a neutron incidence angle upon phantom.

105 Some aspects of neutron radiation normalization.

I. B. KEYRID-MARKUS, O. A. KOCHETKOV and V. I. TSVETKOV, Institute of Biological Physics, Moscow; and V. G. ZOLOTUKHIN and G. M. OBATUROV, Institute of Physics and Power Engineering, Obninsk (USSR).

At present the neutron radiation normalization is based on Snyder and Neufeld's data on monoenergetic neutron dose equivalent distribution in a half-infinite tissue-equivalent plate for normal and one-sided incidence upon it.

But such a way of normalization does not take into consideration the factors of essential self-screening of neutron radiation by a human body, the dependence of dose value and distribution on a neutron spectral-angular distribution, geometrical sizes of body, etc.

The paper shows that if these factors are taken into consideration the surface dose equivalent for multi-sided neutron exposure is smaller than that for normal and one-sided exposure.

Therefore a neutron dosimeter detecting the value of the "air" dose equivalent registers higher dose equivalent values than real ones in a man. In order to take into account the screening effect for normalization of neutron flux we propose to introduce the coefficient of isotopy of a man exposition.

106 Distribution de la dose de première collision des neutrons en fonction du TEL. M. DOUSSET, J. HAMARD et A. RICOURT, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

En vue d'interpréter les résultats obtenus en irradiant des échantillons biologiques minces, on a été amené à établir un programme général permettant de calculer, pour une énergie quelconque de neutrons monoénergétiques (entre 0,025 eV et 10 MeV), la distribution de la dose de première collision en fonction du TEL.

Les conditions d'équilibre des particules secondaires chargées ainsi que les conditions d'épaisseur de l'échantillon qu'exige l'égalité numérique du kerma des neutrons incidents (exprimé en hectoergs par gramme) et de la dose (en rads) sont supposées réalisées.

Un second programme permet de tenir compte de l'anisotropie pour les noyaux lourds de recul.

Pour les valeurs du kerma et la contribution des principales réactions ainsi que pour les valeurs des fractions d'énergie cédées par les particules chargées dans les différents intervalles de TEL, un choix a dû être fait parmi les données trouvées dans différentes publications récentes.

A partir des résultats de ces calculs il est facile d'obtenir, pour un spectre énergétique quelconque de neutrons, la distribution de la dose de première collision en fonction du TEL.

Distribution of the first collision dose of neutrons as a function of LET.

With the aim of interpreting the results obtained by irradiating thin biological samples, a general programme has been set up to calculate the distribution of the first collision dose as a function of LET for

any energy of monoenergetic neutrons between 0.025 eV and 10 MeV.

The conditions of equilibrium of the secondary charged particles, as well as the condition of thickness of the sample, were assumed to be such that the kerma of the incident neutrons (expressed in hectoergs/g) was numerically equal to the dose (in rads).

A second programme allowed account to be taken of the anisotropic distribution of the heavy recoil nuclei.

A choice had to be made from information found in different recent publications for the values of kerma and for the contribution of the principal reactions, as well as for the fractions of energy deposited by charged particles in different intervals of LET.

From the results of these calculations, it is easy to obtain the distribution of the first collision dose as a function of LET for any energy spectrum of neutrons.

107 Neutron average energies: calculations and theory of measurements. S. MAKRA, Central Research Institute for Physics, Budapest (Hungary).

Basic features of neutron average energy (\bar{E}) measuring techniques are dealt with, and calculated \bar{E} values are presented.

An average energy measuring device determines the following quantity:

$$\bar{E}_{\text{eff}} = \frac{\int_{E_1}^{E_2} Ek(E)\Phi(E) dE}{\int_{E_1}^{E_2} k(E)\Phi(E) dE}$$

where $\Phi(E)$ is the neutron spectrum, and $k(E)$ is a weight factor. Generally $k(E) \neq 1$, resulting in a difference between \bar{E} (when $k(E) = 1$) and \bar{E}_{eff} .

In this paper the Block and Shon technique (based on the energy dependence of the spatial distribution of thermalized neutrons in a moderator), as well as the double sphere one (based on the energy dependence of the counting ratio of two Bonner spheres of different diameters) are investigated. The energy dependence of sensitivity, the $k(E)$ factors, the accuracy, and the optimum sphere diameters, too, are calculated.

Both \bar{E} and \bar{E}_{eff} for some reactor sources, after penetration through different shields (water, polyethylene, iron, concrete, and some of their mixtures) are determined, using the spectra calculated by discrete ordinates method, and in some cases are compared with values, measured at different reactors.

\bar{E} values for reactor spectra penetrated through different shields varies by a factor of 25, while $\bar{E}_{\text{eff}}/\bar{E}$ is to be found 1.0 ± 0.3 for both techniques, if $\bar{E} > 0.5$ MeV, and may reach 2-3 if \bar{E} is low.

NEUTRON DOSIMETRY AND RADIATION PHYSICS II

Discussion Group

108 An alternative approach to the formulation of quality factor.* J. NEUFELD, Health Physics Division, Oak Ridge National Laboratory, Tennessee (USA).

There are certain requirements in radiation protection work which have not been clearly recognized by the current definition of the quality factor (QF) and by its various interpretations, such as the ones expressed by a "localized" quality factor which varies from one point to another, an "effective" quality factor which is often related to the peak value of the dose equivalent, and an "average" quality factor. A suggestion is made that the current recommendations be reformulated and a different basis be established for determining whether permissible radiation levels have been attained or exceeded. The main requirements on which the suggested recommendations are based are as follows: (1) The measurement of radiation field should be expressed in terms of a "reference dose" (D_r) which should be defined as the absorbed dose in a macroscopically small element of a standard substance, such as soft tissue. This would satisfy the need for standardization and would assure uniformity in reporting. (2) Radiation protection measures should be anticipatory; one should be able to prevent the occurrence of injury and to limit the risk of radiation effects to an acceptable level. Therefore, any measurement of the reference dose should be performed in a radiation field when there is no exposure, and should be indicative of the possible risk hazards if there is exposure. It is proposed that a quantity representing "quality index" be introduced and defined as $Q = (DE)_{\text{max}}/D_r$. In this relationship D_r is the reference dose measured in an *unperturbed* field and $(DE)_{\text{max}}$ is the peak value of the dose equivalent for a phantom placed in a region in which the measurement of D_r has been previously made; $(DE)_{\text{max}}$ is therefore obtained from a radiation field perturbed by the phantom. The proposed quality index, based on

* Work sponsored by the US Atomic Energy Commission under contract with the Union Carbide Corporation.

anticipatory measurements, is intended to supplement rather than to replace the currently used concepts which are applicable to simultaneous measurements such as those obtained with instruments carried by workers in a radiation area.

109 What quality factor? H. WADE PATTERSON, J. T. ROUNTI and R. H. THOMAS, Lawrence Radiation Laboratory and Stanford University, Berkeley, California (USA).

This paper discusses the evaluation of Dose Equivalent rates in mixed radiation environments such as are found, for example, around a high energy particle accelerator. It is shown that it is not possible to evaluate absorbed dose and Dose Equivalent rates by any single measurement, with sufficient accuracy for purposes of radiation protection, in such complicated environments.

This paper studies in detail the problems of evaluating Dose Equivalent from measurements of Absorbed Dose using a tissue equivalent ionization chamber. Recently the USAEC has published tables of Quality Factors for monoenergetic neutrons as a function of neutron energy, but no values were given for the spectra spanning the large energy range typically found around high energy accelerators and reactors. Using the values of Quality Factor recommended for monoenergetic neutrons the QF for a variety of typical neutron spectra is calculated. The neutron spectra studied include the Watt fission spectrum, the PuBe spectrum, the cosmic-ray neutron spectrum and three typical accelerator spectra measured at CERN and the Lawrence Radiation Laboratory. In addition, calculations were made for a variety of spectra expressed in simple exponential form. These calculations indicate the Quality Factor to be an extremely sensitive function of neutron spectrum and maximum energy cut off in the range of practical interest—the average Quality Factor varying by more than a factor of

~~counters. Some theoretical principles of the method, mathematical technique of data processing and parameters of the used counters are summarised. Results of the measurements of LET-spectra for X-, γ - and neutron radiations on the surface of human phantom and in air are presented. Results are compared with available data of calculations and experiments.~~

111 Use of stilbene scintillators to measure equivalent dose in a mixed γ -n field. R. BARDINA, Laboratori Gas Ionizzati, Frascati, and M. LADU, M. PELLICIONI and M. ROCCELLA, Laboratori Nazionali di Frascati del CNEN, Rome (Italy).

The possibility of using a trans-stilbene crystal to measure the equivalent dose in a mixed γ -n field has been studied.

We have found that each of the γ -ray and neutron signals, separated by pulse-shape discrimination, gave a good equivalent dose response to the radiation component to which it was sensitive. For neutron signals we have obtained good agreement with the theoretical curve of proton recoil equivalent dose in the range 0.1–10 MeV, where the protons are the most important contributors to the neutron dose. For the γ component we directly measured the absorbed dose in the scintillator because of its tissue equivalence up to several MeV.

In the range of γ -ray exposure up to 0.1–0.2 R/hr, the sum of the two signals was constant within few percent when the relative intensity of γ -rays and neutrons was varied, for a fixed total equivalent dose rate.

Some possibilities of extending the energy and exposure dose rate ranges are discussed in view of possible applications of our dosimeter. Indeed it seems very promising to use this instrument to measure the QF of γ -n mixed fields when used together with a tissue equivalent chamber. We think this could be of usefulness near high energy electron accelerators, where noticeable variations

110

DOSE DISTRIBUTION OF β -RADIATION OF FISSION PRODUCTS IN THE TISSUE-EQUIVALENT MATERIAL

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Abstract—In this paper a one-dimensional depth distribution of absorbed doses is found in the semi-infinite tissue-equivalent medium, on the surface of which there is an infinitely thin uniform layer of a mixture of Pu²³⁹ prompt fission products. These calculations are made using the method of a "single dose function" based on experimental studies of dose distributions from wide monodirectional beams of monoenergetic electrons. The approximate formula $C(E_0 - E)^2(E + 0.51)^2$ is used for describing the shape of partial β -spectra. It is shown that at the depth of 0.007 g/cm², corresponding to the basal layer in the human skin, dose rate is rather slightly dependent (approximately by a factor of 2) on the fission products "age" (varying from 1 day to 1 yr) and consequently on the strongly varying spectral composition of the β -radiation.

radiation dose to the spinal cord resulting from the radioactivity injected into the arachnoid space be known accurately. Since the radiation dose to the spinal cord in cisternography depends on the elimination rate and the dose rate to the spinal cord from the surface of the radioactive liquid surrounding the spinal cord, the authors have focussed their attention on the measurement of beta dose rates at the surfaces of liquids.

The measurement of dose rate at the surface of a liquid has been shown to be feasible since the development of the extrapolation chamber. Several modified extrapolation chamber designs have appeared in the literature in the ensuing years. In 1963, Dr. E. M. Smith, while on duty at the National Institutes of Health, worked on the design and construction of an improved extrapolation chamber. The authors have further modified the instrument to adapt it for the measurement of beta dose from the surfaces of radioactive liquids.

The system used for these measurements consisted of an extrapolation chamber coupled to a vibrating reed electrometer. Aluminized mylar served as an upper electrode and also as a supporting surface for the radioactive liquid. By adding sheets of mylar below the supporting surface, the effect of "mylar thickness" was determined. By varying the spacing between upper and lower electrodes of the ion chamber, the effect of volume was determined. The measured dose rates at the surface of liquids of infinite thickness for several isotopes in solution are compared with calculated doses. For average beta or beta-type energies between 0.014 MeV (^{99m}Tc) and 0.188 MeV (^{131}I) the agreement between the calculated and measured surface dose is reasonably close. The calculated values tend to overestimate the surface dose in all instances. This is particularly noticeable for the higher energies where a significant portion of the beta particle energy escapes the collecting volume.

113 Sur la dose déposée par des électrons et le spectre électronique au voisinage d'une interface: application aux chambres d'ionisation remplies de diélectriques liquides. J.-P. PATAU, D. BLANC et J. MATHIEU, Centre de Physique Atomique et Nucléaire de l'Université de Toulouse (France).

Par simulation du cheminement des électrons dans la matière, on calcule la dose déposée au voisinage de l'interface séparant deux milieux homogènes différents. On en déduit le spectre d'énergie et de TLE des électrons qui traversent l'interface ou tout plan parallèle à cet interface. De l'analyse des résultats obtenus, on tire des

résultats généraux sur les phénomènes qui se produisent à l'interface, en fonction de la nature des milieux qu'il sépare.

Ces calculs sont appliqués au cas d'une chambre d'ionisation à électrodes de béryllium planes et parallèles, remplie de triméthyl 2-2-4 pentane, irradiée par des électrons de 1 MeV et de 2 MeV. Ces calculs et leur vérification expérimentale permettent d'atteindre certaines conclusions concernant l'emploi de tels débitmètres équivalents aux tissus biologiques.

On the dose deposited by electrons and on the energy spectrum of electrons in the neighbourhood of an interface: application of a liquid ionisation chamber.

The dose deposited in the neighbourhood of an interface separating two different homogeneous media is calculated by the simulation of the track of the electrons in matter. From this is deduced the energy spectrum and the LET of the electrons traversing the interface and planes parallel to the interface. From this analysis, general results are derived on the phenomena occurring at the interface as a function of the properties of the two media.

The calculations are applied to the case of a parallel plane ionisation chamber with beryllium electrodes, filled with trimethyl 2-2-4 pentane and irradiated by electrons of 1 MeV and 2 MeV. From these calculations and their experimental verification, certain conclusions can be drawn about the use of tissue equivalent dose-rate meters of this kind.

114 Dosimétrie biologique à gel bactérien. P. BONETS MAURY et T. KAHN, Institut du Radium, Paris (France).

Le bacille paradysentérique Y6R, anaérobie facultatif et non-virulent, ensemencé en gel nutritif translucide, donne naissance à des colonies, apparaissant comme de petits points blancs, répartis de façon remarquablement uniforme dans la masse du gel transparent.

La concentration N (nombre de colonies/ml) de ces colonies dans le gel se détermine, soit par comptage direct ($N < 300$) ou par mesure de la densité optique ($N > 300$). Le nombre de colonies observé est proportionnel au nombre de bactéries ensemencées (inoculum); une colonie correspond en moyenne à environ 2 bactéries.

Si on irradie, avec les rayons γ du ^{60}Co , un gel ensemencé pour donner N_0 colonies, on observe un nombre N/N_0 et décroissant avec la dose absorbée D suivant une loi logarithmique régulière.

La mesure de N , par comptage ou photométrie, permet ainsi de déterminer la dose D reçue par un gel bactérien irradié.

La détermination de la dose en un point quelconque d'un gel bactérien s'obtient, soit en le découpant en petits éléments de mesure commode, soit en le disposant dans des cuves plates en lucite, de dimensions convenables, pour permettre la photométrie ou la numération directe.

Ce dosimètre a été utilisé avec des résultats satisfaisants pour déterminer le parcours et l'EBR d'un faisceau de protons de 150 MeV, ainsi que les courbes d'isodoses d'une source de ^{60}Co .

Biological dosimetry by bacterial jelly.

If the paradysentery bacterium Y6R, which is anaerobic and non-virulent, is implanted in a translucent, nutrient jelly, it gives rise to colonies which appear as small white spots. These are distributed in a remarkably uniform way throughout the body of the transparent jelly.

The concentration, N , of these colonies in the jelly (number of colonies/ml) is measured either by direct counting ($N < 300$) or by measurement of the optical density ($N > 300$). The number of colonies observed is proportional to the number of bacteria implanted; one colony corresponding on average to about two bacteria.

If a jelly inoculated to give N_0 colonies is irradiated with gamma rays from ^{60}Co , the observed number of colonies becomes N and the ratio N/N_0 decreases with the absorbed dose D following a regular logarithmic law. The measurement of N , either by counting or photometry, thus allows the determination of the dose D received by an irradiated bacterial jelly.

The determination of dose at a specific point in an irradiated jelly can be made either by cutting it into small conveniently-sized elements, or by placing it in flat lucite dishes of suitable size to allow photometry or direct counting.

This method of dosimetry has been used with satisfactory results for determining the track and the RBE of a beam of 150 MeV protons and also for determining the isodose curves of a ^{60}Co source.

RADIATION PROTECTION STANDARDS I

115 Invited paper. Radiation protection trends in the United States. L. S. TAYLOR, National Council on Radiation Protection and Measurements, Washington D.C. (USA).

Following the last major change in radiation protection standards introduced by the National

Council on Radiation Protection and Measurements (NCRP) in 1957, the basic protection criteria have been under continuous review. It is noteworthy that during the ensuing period no breakthrough has occurred in our fundamental knowledge that justifies any significant changes in our protection standards. If anything, new data tend to show that standards adopted two decades ago were overly conservative although not sufficiently to warrant upward revisions. The 1970 report on Basic Radiation Protection Criteria will show no startling changes, and much of its content is directed toward rationalizing the explanation for current recommendations. Some minor adjustments, mainly in the direction of numerical simplification, will be proposed. In spite of the fairly well stabilized position of radiation protection philosophy, especially in relation to other environmental pollutants, radiation hazard as a "headline catcher" continues to flourish in the U.S. This causes undue alarm and concern among patients reading death calculating stories about radiation; it provides various anti-groups with a means of promoting their causes; it fosters an undesirable and even dangerous public fear of radiation. Improvement in the efficiency of radiation usage is nevertheless progressing in an orderly manner, but vast numbers of professional man-hours are being wasted fighting radiation hazard windmills instead of performing useful work. An important trend in the US is toward governmental control of all uses of radiation. Applied rationally, this promises to be useful, but radiation control is already better than for most pollutants and there is dubious need for continued frenetic attacks on the problem.

116 Oral presentation. The basis of ICRP's dose limits. F. D. SOWAY, Scientific Secretary, ICRP, Sutton, Surrey (ICRP).

The development of nuclear energy has been rather unique in that, from its beginning, a conscious decision was taken to incorporate a high degree of safety. This has meant that authorities responsible for planning nuclear establishments and other sources of radiation have needed quantitative information on which to base their calculations of factors such as shielding thicknesses and discharge levels. The provision of agreed quantitative recommendations at the international level has made it possible to develop fairly uniform world-wide standards, which in practice have resulted in a high degree of protection. In formulating its recommendations the ICRP's principal objectives are to provide

advice so that acute radiation effects can be prevented, and the risks of late effects kept to an acceptable level. Much is currently said about the need to balance the risk of an exposure against the benefit of the practice giving rise to the exposure. However, our present inadequate knowledge of the risks, together with the problems inherent in quantitating benefits, emphasise a continuing need for basic guidance on dose limits, as provided by ICRP. The fundamental principles underlying the selection of dose limits by the Commission are discussed in the paper.

117 Oral presentation. Radiation standards: a critical review of developing needs in the United States. M. EISENBUD, Laboratory for Environmental Studies, New York University Medical Center (USA).

The radiation standards promulgated by the United States Atomic Energy Commission which are derived basically from the recommendations of ICRP have served well in the civilian atomic energy program up to the present time, but a number of fundamental changes in approach will be necessary to accommodate the proliferation of reactors in the decades ahead.

Although ICRP provides sound basic guidance, difficulties arise when a regulatory program relies excessively on Tables of MPC_a and MPC_w to control emissions to the environment. A system of control based on the permissible daily intake from all sources is preferable to the use of MPC_a and MPC_w , because it takes into consideration such complicating factors as multiple sources of exposure and biological concentration.

This paper describes further the kinds of standards that must be evolved and the form in which they should be promulgated, both by ICRP and a governmental regulatory authority.

118 Read in title. Measurements of the depth of the basal layer of the skin and the health physics implications. J. T. WHITTON and J. R. HARVEY, CEGB, Berkeley Nuclear Laboratories, Gloucestershire (UK).

For accurate skin dosimetry of "soft" radiation the depth of the sensitive (basal) layer at various body sites must be known. Widely used values for this depth are strongly influenced by measurements made a century ago on a few unsuitable subjects with methods which are now suspect. The paper describes techniques which we have used to measure the depth of the basal layer at various body sites on a number of

subjects. The results indicate that skin on the fingertips is thicker than the accepted value whereas that on the face, for example, is very much thinner. With this information it is possible to define the characteristics of the ideal skin dosimeter. One important practical consequence of this work is that alpha radiation can no longer be disregarded as a source of external radiation.

119 Read in title. Concentration maximale admissible, dans l'air, de l'uranium naturel irradié. M. DELPLA et R. SCHAEFFER, Electricité de France, Paris (France).

Dans les conditions de travail habituelles, on ignore l'origine, donc la nature exacte des radionucléides qui contaminent l'atmosphère. Il est commode de connaître une valeur limite de la contamination maximale admissible (CMA).

Après avoir établi la variation de l'activité massique de l'uranium naturel en fonction du taux d'irradiation et du temps écoulé depuis la fin de l'irradiation, les auteurs calculent les valeurs correspondantes de la CMA du mélange des produits d'activation de l'uranium 238 et des produits de fission qu'il renferme.

Celle-ci varie dans le même sens que la puissance massique du réacteur. Pour une puissance moyenne de 3,5 MW/t, elle ne devient inférieure à 10^{-9} Ci/m³ (pour une exposition de 168 hr/semaine) que si le temps écoulé depuis la fin de l'irradiation dépasse un an. L'américium 241 constitue alors le radionucléide le plus influent, en raison de sa formation par décroissance radioactive du plutonium 241.

L'adjonction de produits d'activation des matériaux de structure du réacteur ne peut que relever la CMA au-dessus de 10^{-9} Ci/m³.

Maximum permissible concentration in air of irradiated natural uranium.

In normal conditions of work, the origin and thus the exact nature of radionuclides which contaminate the atmosphere are not known. It is convenient to know a limiting value of maximum permissible concentration.

Having established the variation of the gross activity of natural uranium as a function of the irradiation level and of the cooling time after the end of irradiation, the authors calculate the corresponding values of the MPC of a mixture of activation products of ²³⁸U and of the fission products.

The MPC varies in the same way as the gross rating of the reactor. For an average rating of 3.5 MW/t, it can only be less than 10^{-9} Ci/m³ (for

an exposure of 168 hr/week) if the cooling time after the end of irradiation exceeds 1 yr. Americium-241 then constitutes the most important radionuclide because of its formation by the radioactivity decay of ^{241}Pu .

The addition of activation products of the structural materials of the reactor can only raise the MPC above 10^{-9} Ci/m³.

120 Read in title. Health physics aspects of radioactive selfluminous paints for aircraft dials and safety devices. K. HATA and M. TAKAGI, Sinlohi Company; K. NABA, 1st Institute, Japan Defense Agency and Y. NISHIWAKI, Tokyo Institute of Technology (Japan).

In 1967, a recommendation of IAEA concerning Radiation Protection Standards for Radioluminous Timepieces was issued, but any recommendation about the aircraft dials and safety devices in commercial aircraft has not yet been achieved by direct measurement methods which are not necessary for decomposition. These methods are as follows:

I. The measurement method for ^{147}Pm radioactive selfluminous paints:

1. To convert all β emission to bremsstrahlung, samples were covered by resin or glass with the thickness of over 50 mg/cm²;

2. Considering the geometric effects, the GM tube (wide end window, 3 mg/cm², 50 mm) was set at 10 cm from the source, and measurable area was restricted to the diameter of 60 mm or less;

3. The radioactivity of samples was compared with that of standard ^{147}Pm paints which was measured by the same method.

II. The measurement method for ^{226}Ra radioactive selfluminous paints:

1. Measurement for mR/hr was carried out by Na(Tl) scintillation counter.

2. The radioactivity of ^{226}Ra in the sample was estimated by comparison with the standard ^{226}Ra Rm value.

The condition of an aircraft fire accident was simulated by the combustion equipment using quartz glass tube, at a temperature 800–850°C, for 10 min. The results of this combustion experiment are as follows.

The contamination of ^{147}Pm is localized near the sample. For ^3H paints during the combustion, ^3H vaporises and diffuses into the atmosphere, but the significant contamination of ^3H does not appear near the sample.

Considering the above results and health physics evaluation, the suggested maximum permissible radioactive levels for aircraft dials and safety devices have been estimated as follows:

- (1) 1 Ci for ^3H ,
- (2) 500 μCi for ^{147}Pm ,
- (3) ^{226}Ra paints should not be permitted,
- (4) the cover of the radioactive selfluminous paints should be over 50 mg/cm².

121 Read in title. Radiation safety aspects of smoke detectors for fire prevention. N. ROSENAL and Y. FEIGE, Soreq Nuclear Research Centre, Yavne (Israel).

The increasing use of smoke detectors containing radioactive materials for early detection of fires may involve, despite the obvious usefulness of these devices, some radiation hazards.

These radiation hazards may be classified into two categories:

(a) Occupational hazards to workers manufacturing them and/or performing maintenance tasks;

(b) Hazards to the general public due to external radiation, spread of contamination, and hazards arising after a destructive fire.

Regulations to be met in assembling the maintenance workshops for smoke detectors will be discussed. Standards of acceptable radiation and contamination levels, as well as degrees of fire resistance for these devices, will be suggested in order to assure their safety for general use, and possible exemption from licensing.

MONITORING OF WORKERS III

122 Oral presentation. Evaluation of dose equivalent by fission track detector. H. TAISUTA and K. BINGO, Japan Atomic Energy Research Institute, Tokai-mura (Japan).

The fraction of incident fluence reflected as thermal neutrons from a human body (phantom) is constant approximately, if energies of incident neutrons are low (thermal to 10 keV). On the other hand, a dose equivalent (DE) per unit neutron fluence has a roughly fixed value in this energy range. So, if a detector, having a response to thermal neutrons reflected from a body only, is used, DE in above-mentioned energy range may be estimated without the consideration of the energy spectrum of incident neutrons. Now, two kinds of fission track detectors, i.e. a dosimeter glass with a UO_2 foil (natural) and

one with a UO_2 foil (slightly enriched, ^{235}U below 2%), are used. Thermal neutrons reflected from the body are evaluated, taking account of the difference of ^{235}U contents between two kinds of detectors, and fast neutrons are evaluated, taking the nearly equal contents of ^{238}U in two detectors into consideration.

The minimum detectable DE evaluated by this dosimeter system is about 3.4 rems, in case that the neutron fluence spectrum is equal to an uncollided fission spectrum and that the microscopic scanning area of the detector is 64 mm^2 .

123 Oral presentation. A proportional counter as a personal neutron dosimeter. H. J. DELAFIELD, W. G. SPARKE and J. A. DENNIS, Health Physics and Medical Division, AERE, Harwell (UK).

A description is given of an instrument consisting of a small proportional counter and associated electronics for the measurement of the neutron dose-equivalent to personnel. The energy range of the instrument is from thermal to 20 MeV and it is small enough to be carried conveniently as a personal dosimeter.

Practical experience with the prototype instruments is described.

124 Oral presentation. A field study of personal air sampling and bioassay techniques for monitoring radon progeny inhalation exposures of uranium miners. K. J. SCHAIGER, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins (USA).

Forty uranium miners, working routinely in atmospheres containing radon progeny concentrations of 0.5–1.5 Working Levels (WL), were individually monitored for a 1 yr period using personal air sampling and bioassay techniques. Earlier studies, involving more closely supervised monitoring of a smaller group of miners routinely exposed to concentrations of 2–10 WL, had demonstrated the feasibility of direct exposure monitoring using battery-powered, personal air samplers combined with thermoluminescent dosimetry. The previous work had also indicated a positive correlation between estimated exposures to the short-lived radon daughters and concentrations of long-lived decay products in blood and hair. Whiskers were found to be the bioassay medium of choice for convenience of collection and analysis.

The present study was designed to evaluate the relationship between radon progeny exposure estimates based upon spot samples of mine atmospheres

and exposure data obtained by continuous, personal monitoring of air in the breathing zones of individual miners. Evaluation of the sensitivity and reliability of bioassay techniques for monitoring chronic exposures to uranium mine atmospheres was also included in the study. In addition to the forty miners, ten control subjects (long-term residents of the area who had never worked in uranium mines) contributed blood and whisker samples during the study.

The results of the study are reported, and the practical problems involved in utilizing personal monitoring techniques for uranium miners are discussed and evaluated with regard to the potential application of these techniques to large groups of miners.

125 Oral presentation. Interprétation, en termes de doses d'irradiation, de cas de contamination par molécules tritiées. G. F. KOCH et J. L. DULGINO, Centre d'Etudes Nucléaires, Mol-Donk et P. A. DELWAIDE, Service de Chimie Médicale, Université de Liège (Belgium).

Pour apprécier la dose d'irradiation reçue en cas de contamination interne par molécules marquées au tritium, il est indispensable de connaître le métabolisme de la molécule particulière en cause. La voie d'approche habituelle est l'analyse d'urines, moins souvent d'autres échantillons biologiques, aux fins de mesure quantitative des métabolites tritiés. De l'analyse de ceux-ci on peut induire les voies métaboliques, grâce auxquelles on peut définir la charge corporelle, la période biologique d'élimination et les organes critiques.

Tant dans les mesures de contrôle physique et de surveillance du personnel qui manipule ces molécules marquées, que dans le cas de patients qui les reçoivent, des interprétations en termes de doses d'irradiation sont proposées à partir des niveaux de contamination urinaire, en particulier pour des stéroïdes, des phénols, des médicaments marqués et des acides aminés. Les procédures radio-chimiques utilisées sont décrites.

Dans les cas examinés, le foie, centre principal du métabolisme de ces substances, apparaît comme l'organe critique, suivi par le rein, et non le corps entier comme dans le cas de l'eau tritiée.

Les demi-vies biologiques des molécules marquées envisagées sont plus courtes que celles de l'eau tritiée. Il en résulte fréquemment, lors de contaminations uniques, qu'à des taux égaux d'excrétion urinaire, correspondent des charges corporelles, et par conséquent des doses d'irradiation plus faibles, même au niveau de l'organe critique.

The interpretation, in terms of radiation dose, of cases of contamination by tritiated molecules.

To assess the radiation dose received following internal contamination by molecules labelled with tritium, it is necessary to know the metabolism of the particular molecule. The usual method is to analyse urine, less often to analyse other biological samples, and finally to measure quantitatively the tritiated metabolites. From the analysis of this last one can deduce metabolic pathways and thence establish the body burden, the biological excretion period and the critical organs.

It is suggested that interpretation in terms of radiation dose should be used just as much in the physical control and surveillance of personnel working with labelled molecules as in studies of patients who have received these molecules. Interpretation is based on levels of urinary contamination, specifically for steroids, phenols, labelled pharmaceuticals and aminoacids. The radiochemical procedures used are described.

In the case studied the liver, the principal metabolic centre of these substances, shows as the critical organ, followed by the kidney, and not the whole body as is the case for tritiated water.

The biological half-lives of the labelled molecules are shorter than those of tritiated water. In the case of single intakes it thus happens frequently that the uniform rates of urinary excretion correspond to body burdens and, as a result, to lower radiation doses, even at the level of the critical organs.

126 Oral presentation. Investigation of ZrT aerosols. J. BIRÓ and I. FEHÉR, Central Research Institute for Physics, Budapest (Hungary).

The tritium incorporation hazard in the environment of (*d, T*) neutron generators is due to the intake of ZrT particles detached from the targets.^(1,2)

In order to investigate the mechanism of the ZrT intake, the activity vs diameter distribution of the particles detached from the targets was analysed by a quantitative autoradiographic method and the exposure of the personnel was assessed. The activity median diameter of the usually lamellar particles was found to lie in the range of 5–20 μm with a geometric standard deviation of ~ 2 .

The activity aerodynamic diameter distribution of the particles was evaluated by sedimentation method. The activity median aerodynamic diameter (AMAD) was evaluated from the measured data as $> 10 \mu\text{m}$. The dependence of the AMAD on the nature and handling of the targets is discussed.

The persons working with ZrT targets have been provided with personal aerosol samplers. The

data obtained by the measurements with samplers are compared with those measured in the AMAD test experiments and conclusions are drawn on the possible intake mechanism.

References

1. J. BIRÓ, I. FEHÉR and T. SZARVAS, *2nd. Symp. Health Physics*, Pécs, Hungary p. 87 (1966).
2. J. BIRÓ and I. FEHÉR, *Proc. Assessment of Airborne Radioactivity*, Vienna p. 501 (1967).

RADIOECOLOGY I

127 Oral presentation. A comparison of the ^{90}Sr content in bone of population groups with high and low calcium diets. D. VAN AS and H. O. FOURIE, Atomic Energy Board, Pretoria (South Africa).

The two main population groups in South Africa viz. the white and the Bantu have vastly different dietary habits. The white population has an annual per capita calcium intake of 292 g/yr of which 70% is contributed by milk.

The Bantu live on a cereal diet consisting primarily of maize and has an annual per capita calcium of 102 g of which only 40% is contributed by milk.

The results of ^{90}Sr analysis on bone samples from both population groups as well as milk and maize samples from a country wide survey are presented and the differences correlated with dietary habits.

128 Oral presentation. Considerations on concentration factors in freshwater radioecology. M. DE BORTOLI and P. GAGLIONE, Euratom Joint Nuclear Research Centre, Ispra and G. POLVANI, CNEN Division of Radiation Protection, Rome (Italy).

The wide use which is made of concentration factors (CF) in radioecology suggests the discussion of some aspects of this parameter less frequently considered, with the aim of contributing to its correct use in radiation protection and thus preventing erroneous conclusions.

The authors had the opportunity of following for almost ten years the accumulation of world-wide fallout radionuclides (mainly ^{90}Sr and ^{137}Cs) by some fish species, living in lakes with different ecological characteristics.

The following subjects are discussed:

- (a) The multiplicative property of the factors affecting accumulation (zoological species, environment, etc.), which is well evidenced by the statistical analysis of the "observed" CF;
- (b) The geometric mean, which, as a consequence of this property, approaches the "true" CF

better than other estimates, when the contamination of water varies with time and therefore fishes cannot attain equilibrium conditions; this is clearly shown also by simple mathematical models. In this connection, the skewness of the "observed" values distribution is also discussed;

- (c) The specific activity approach for the description of accumulation phenomena, which was studied through the behaviour of the natural elements corresponding to the radionuclides considered. The validity of this approach seems questionable in the case of cesium, also from the evidence of other data, concerning the relative accumulation of cesium and potassium;
- (d) The CF differences among species, which can be better understood making use of Comar's "observed ratio" and Pendleton's "increase ratio".

(Withdrawn) See 130

129 Oral presentation. Effect of the natural factors on ^{137}Cs accumulation in the body of residents in some geographical regions. A. N. MAREI, R. N. BARKHODAROV, N. J. NOVIKOVA, E. V. PETUKHOVA, V. K. CHOMAK, L. D. DUBOVA and V. M. BRIGANINA, Institute of Biological Physics, Moscow (USSR).

The report contains results obtained at the first stage of the investigation intended to identify regions with raised ^{137}Cs content in the body of inhabitants due to stratospheric fallout; to establish distribution curve of accumulation levels incidence of this isotope in various age population groups; to determine sources and characteristics of ^{137}Cs migration in the human body.

As a result of three year observations we determined the territory with the area of more than 75,000 km² where ^{137}Cs content in the human body ranges between 10^{-9} and 10^{-7} Ci/body. We observed no essential differences in ^{137}Cs concentration between children and adults. The main supplier of ^{137}Cs to the diet is milk where concentrations of this isotope reach 2000 pCi/l. and in a less degree it is meat, vegetables and fish. Contamination of these food-stuffs is due to intensive ^{137}Cs migration from soil though its concentrations there do not usually exceed those observed in the flat country of middle latitudes in the Northern hemisphere. Increased ^{137}Cs migration from soil probably results from its structure, mechanical, mineral and chemical composition and acidity. The constants of ^{137}Cs transfer in the link grass/soil increase from 1.6 to 23.2 as a function of the type and characteristics of the soil.

The object of further investigations will be mechanism and causality of the increased ^{137}Cs migration from soil.

Annal (See 129)

130 Read in title. On the origin of ^{134}Cs in rainwater: data from 1961 to 1969. A. A. CIGNA, G. F. GLEMENTE and F. G. GIORCELLI, Laboratorio Radioattività Ambientale, CSN, Casaccia (Italy).

Caesium-134 has been measured in samples of rainwater collected monthly at the Casaccia Nuclear Center (Rome). Measurements were performed by a gamma-gamma sum-coincidence technique taking into account the weak interference due to ^{106}Rh . The results of these measurements are reported and compared with similar results obtained by other authors. On the basis of these data, the possible origin of the ^{134}Cs contamination is discussed. The analysis of the data available led to the hypothesis that a major amount of this nuclide could have been injected into the stratosphere by nuclear tests before 1961. The contribution of the 1961 and 1962 explosions was less than the expected, taking into account the increase of ^{137}Cs . The Chinese tests after 1965 seem to have given a detectable contribution to ^{134}Cs concentration in rainwater. In fact such a concentration has been found to be fairly constant (monthly average deposition: about 5 $\mu\text{Ci}/\text{km}^2$) during the period 1966-1969.

131 Read in title. Uptake of ^{137}Cs due to nuclear weapon fallout, in subjects from West Cumberland. R. HESP and R. M. LEDGERWOOD, UKAEA Windscale Works (UK).

Results of *in vivo* radioactivity measurements of fallout ^{137}Cs are presented. The data were derived from "Whole Body Counter" measurements made on adult male subjects from West Cumberland during the period 1961-1968.

The maximum mean values (39.1 nCi, 272 pCi per g potassium, 539 pCi per kg) occurred during the third quarter of 1964.

From 1965 until the fourth quarter of 1968 the body content of ^{137}Cs decreased with a half-time of 1.21 ± 0.06 yr.

132 Read in title. Données sur le métabolisme du césium chez les ruminants. R. HANOUT et F. DANURON, Laboratoire-Etable de Radiobiologie Appliquée, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

Le ^{137}Cs est un des produits de fission majeurs, en raison tant de son rendement de fission que de sa longue période. C'est un des rares radioéléments qui se concentrent dans toutes les cellules. Aussi, était-il intéressant d'étudier quelques facteurs de son utilisation par les ruminants. En effet, ceux-ci

fournissent l'essentiel de la viande et la totalité des produits laitiers consommés par l'homme.

Nous avons réalisé deux groupes d'expériences. Deux brebis en lactation ont reçu du ^{132}Cs avec 500 mg de l'isotope stable et deux brebis sèches ont reçu du ^{131}Cs sans entraîneur. Ces quatre animaux ont subi une administration unique du radioélément; ils recevaient une ration de granulés concentrés.

Dans un autre type d'expériences, les deux brebis qui avaient reçu du ^{132}Cs ont été nourries pendant quatre mois avec du foin de montagne contenant, par kilogramme, environ 6 nCi de ^{137}Cs de retombées. Une brebis, sur ration de luzerne, a reçu pendant 40 jours environ, 1 nCi par jour de ^{137}Cs recueilli sur les filtres du réseau de surveillance atmosphérique.

Les données obtenues, homogènes entre elles dans les deux groupes d'expériences ont été traitées par ordinateur.

Les résultats obtenus montrent que la cinétique de l'élément n'est modifié ni par la présence de l'isotope stable ni par la lactation, chez la brebis. Ils montrent aussi que l'expérience de laboratoire ne reproduit pas correctement les faits tels qu'ils ont lieu dans la nature. Ils indiquent qu'en ce qui concerne l'alimentation humaine, la viande serait une source de Cs plus importante que le lait, dans le cas d'une contamination prolongée des animaux par le nuclide.

Data on the metabolism of ^{137}Cs in ruminants.

Caesium-137 is one of the major fission products because of its fission yield and long half-life. It is one of the few radioelements which is deposited in all cells. It is also interesting to study some factors influencing its utilisation by ruminants. In fact, ruminants provide most of the meat and all the milk products consumed by man.

We have carried out two groups of experiments. Two lactating sheep received ^{132}Cs with 500 mg of the stable isotope and two non-lactating sheep received ^{131}Cs without carrier. The four animals were given a single dose of radioelement and were fed on concentrates.

In other experiments, the two sheep which had received ^{132}Cs were fed over 4 months on mountain hay containing about 6 nCi/kg of ^{137}Cs from fallout. One sheep fed on lucerne (alfalfa) received about 1 nCi/day of ^{137}Cs for 40 days, obtained from the filters of the atmospheric monitoring network.

The data, consistent between themselves from the two groups of experiments, have been analysed by computer.

The results show that the kinetics of the element are modified neither by the presence of stable isotope nor by lactation in sheep. They also show that the

laboratory experiment did not correctly represent the situation as it is in nature. They show, in relation to human foodstuffs, that meat would be a more important source of caesium than milk in the case of prolonged contamination of animals.

Natural Radioactivity and Fallout

Rapporteur Presentation

133 The dose rate to man from cosmic ray neutrons.

D. S. WOODHEAD, MAFF Fisheries Radiobiological Laboratory, Lowestoft and G. R. HILL, Institute of Cancer Research, Sutton (UK).

The interaction of the primary cosmic radiation with the atmosphere generates a secondary radiation flux which penetrates to sea level, and which includes some components, principally fast neutrons, of high LET. It appears that such high LET radiation may deliver an appreciable fraction of the total biologically effective background dose rate to man, particularly in view of recent reports on the influence of low dose rate on RBE. In this paper the present knowledge of the nature, origin, and magnitude of this secondary radiation flux is briefly surveyed and a new experimental determination of the absorbed dose rate from the fast neutron component is reported.

The measurements were made using a very large "tissue equivalent" proportional counter of the type developed by Hurst, and included an investigation of the effect of shielding by building structures. The following results were obtained:

Location	Absorbed dose rate (mrad yr ⁻¹)
In the open air at ground level	1.62 ± 0.19
Basement laboratory under approximately 50 g cm ⁻² of shielding	0.80 ± 0.14
Low background laboratory under approximately 380 g cm ⁻² of shielding	0.33 ± 0.10

134 Measurement of absorption dose rate from terrestrial background radiation in Hong Kong.

L. S. CHUANG, C. Y. WONG and S. Y. LAU, Chung Chi College, The Chinese University of Hong Kong.

Measurements of the absorption dose rate from soil samples and from the ground at the site from

which the soil samples were taken had been carried out in Hong Kong by means of spectrometric method using a plastic scintillator. Under the present experimental set up, a correlation factor of 14.9 between the absorption dose rate at 1 m above the ground in site measurement and that of the corresponding soil sample was obtained. The overall average values of 70.3 mR/yr and 15.8 mR/yr respectively were obtained for the absorption dose rate due to natural radioactivity and fall-out radioactivity. The absorption dose rates due to the fall-out differ by a factor of approximately three, between the two geographically separated areas; Stanley—Sau Ki Wan and Kowloon—N. T.

135 Radium-226 in environmental materials and in foods. M. DE BORTOLI and P. GAGLIONE, Protection Service, Euratom Joint Nuclear Research Centre, Ispra (EURATOM).

In the frame of the environmental radiation protection monitoring performed at the Euratom Research Establishment at Ispra, Italy, the natural levels of ^{226}Ra in the environment and in the population diet have been studied.

Determinations of the radionuclide have been carried out, by the emanation technique, on several materials from soil through foods in the attempt of estimating the ^{226}Ra intake by the population living in the area. Another purpose of this study is that of gaining information about the transfer of radium through the different environmental chains, also in comparison with calcium.

The mean ^{226}Ra content of the soil is 0.72 pCi/g, which allows to regard the area considered as average from the standpoint of the ^{226}Ra activity.

136 Correlation between exposure doses of natural gamma radiation and concentration of U, ^{226}Ra and ^{210}Pb in food and animal bones. R. RADOVANOVIĆ, L. MIJATOVIĆ, M. VUKOTIĆ and D. HAJDUKOVIĆ, Institute of Occupational and Radiological Health, Belgrade (Yugoslavia).

We measured the exposure doses of natural gamma radiation on 760 representative spots covering an area of 150,000 km². The measurements are performed 1 m above the surface, giving results from 3-35 $\mu\text{R/hr}$; average value of 12 $\mu\text{R/hr}$ U, ^{226}Ra and ^{210}Pb were determined.

Concentration of ^{226}Ra in food is 1-24 pCi/kg,

U 1-22 gamma/kg and ^{210}Pb 1-113 pCi/kg showing a good correlation with natural exposure doses. Animal bones showed the following content: ^{226}Ra 1-75 pCi/kg, ^{210}Pb 16-240 pCi/kg. It was established that ^{210}Pb is especially increased in food and bone samples around lead mines.

Taking into consideration the concentration of these radionuclides in waters, we found a correlation with their content in animal bones and exposure doses of natural gamma radiation.

137 Measurements of radon-concentration in caves of Budapest. E. VIRÁGH and A. URBÁN, University Reactor, Technical University of Budapest (Hungary).

The most significant components of natural airborne radioactivity are radon and its decay products. Generally the radon concentration of air is in the order of 10^{-13} Ci/l. but in closed spaces this value may increase, depending on the radon content of the environment.

According to the ICRP recommendation, the maximum permissible concentration of radon is $1 \cdot 10^{-11}$ Ci/l. But we must take into account the fact that the usual value for the population is only the 1/30 part of the above mentioned value. It is useful to make estimations for the scale of the radiation damage in every case when the specific radon concentration is higher than the average concentration.

The Health Physics Group of the University Reactor at the Technical University of Budapest and the Health Physics Department of KÖJÁL (Institute of Hygiene and Epidemiology of Budapest) made measurements in some Budapest caves which will be used for medical purposes. Further we give an account of observed results.

First we deal with the experimental method: the estimation of radon concentration based on fractional aerosol sampling and alpha-activity measurement of radon decay products. During the measurements we have tested two different type aerosol samplers (Fleming + AUFS filter, FH-422) and we find that FH-422 type aerosol sampler operating with principle of electrostatic precipitation has an efficiency of only 16%, because of the high moisture content in the cave, so its use for sampling purposes is not successful.

In the second part of the paper we summarize Rn, RaA, RaB and RaC concentrations measured in the caves. It can be seen from the table that the concentrations in caves are in the order of 10^{-12} Ci/l. generally.

Finally, we estimated radiation exposure of persons existing for a long time in the cave.

138 A complete survey of the radioactive environment in a radon spa and the resultant radiation load to the inhabitants. E. POHL, Physiological Institute, University of Innsbruck and J. POHTRÖLING, Research Institute Gastein of the Austrian Academy of Science (Austria).

The investigation of a radiation load of a population living in an increased naturally radioactive environment is of interest for the study of biological effects owing to continuous low-level irradiation. In this paper we discuss all necessary investigations required for a thorough survey of all radioactive environmental components and their contribution to the inhabitants' doses, these investigations and the corresponding calculations were carried out for a special case. The components in question are the following:

(1) External gamma- and hard beta-irradiation from the radionuclides in the ground, in the building materials, and in the air, as well as cosmic rays. The corresponding measurements by accumulating dosimeters and the calculation of the doses are relatively easy to accomplish.

(2) Internal irradiation owing to the inhalation of ^{222}Rn , ^{220}Rn , their short-lived decay products and long-lived activities in the atmosphere. The measurements of all these radionuclides in open air and in rooms require not only expended equipments but also series of measurements extending over long periods to comprehend the great fluctuations according to weather and seasons. In the case of radionuclide inhalation the evaluation of the dose distribution requires a profound knowledge of their deposition mechanism in the respiratory tract and their transport to the other organs of the organism, as well as their metabolic pattern. Furthermore the size distribution of the aerosols is important.

(3) Internal irradiation caused by incorporation of natural radionuclides through water and nutrition in the case of radon baths also by uptake through the skin. In order to estimate the dose the metabolism of the various radionuclides in the organism is to be known.

All these measurements and calculations were carried out for the radon spa Badgastein in Austria whose special radioactive environment is given by the origin of 19 thermal springs in the centre of the town, supplying more than 5000 m³ water with a mean ^{222}Rn content of 40 nCi/l. Great part of the radon is delivered into the atmosphere. Our investigation showed that the radiation dose is elevated compared with normal conditions and is mainly caused by the inhalation of ^{222}Rn and its short-lived daughters. The radon content differs considerably for the various living, working, and sleeping rooms. The mean dose for an inhabitant is to be calculated according to his

customs of living and working. The highest doses are received by persons occupying baths and treatment rooms. Nevertheless their doses in all their organs remain below the maximum permissible ones.

139 The concentration of uranium in man and his diet.

E. HAMILTON, Radiological Protection Service, Belmont, Surrey (UK).

There is very little information concerning the concentrations of uranium in man and his diet. Such information is important in deciding the possible fate of uranium once it has entered the body. The concentration of uranium has been determined in a large number of samples of human tissues and representative items of diet for residents of the United Kingdom.

A mean concentration of 7×10^{-10} gU/ml (range $3-25 \times 10^{-10}$) blood has been obtained for samples from different environments; the possibility that the concentration of uranium in blood is related to environment is being investigated. The range of concentration of uranium is $1-9 \times 10^{-10}$ gU/g of wet soft tissue, and approximately 1×10^{-8} gU/g of wet bone. The concentration of uranium in the average national diet for the United Kingdom amounts to an intake of 0.9 μg U/day. Starch root vegetables constitute the most important source of uranium to the diet while salt has the highest concentration of uranium (0.05 ppm U).

140 Effects of radiation fallout on the pregnant woman and the foetus.

H. YAMASHITA, Keiō University, Y. KIMURA and Y. HONDA, Atomic Energy Research Institute, Kinki University, H. FUJIMORI, Osaka City University and Y. NISHIWAKI, Tokyo Institute of Technology (Japan).

Radionuclides in fallout are taken into the human body through the food-chains.

Among various radionuclides included in the fallout, ^{90}Sr and ^{137}Cs are considered to be the most important. Their long physical half-lives and their chemical similarities to natural body constituents (respectively, calcium for skeletal formation and potassium for cellular function) result in relatively high uptake in the human body.

Therefore, it is important from the radiation protection point of view to study the degree of accumulation of these radionuclides in human placenta, although the direct effects might be very small at the present level.

Measurements have been made on the ^{90}Sr and ^{137}Cs content in Japan during the period from March 1966 to December 1968.

The authors attempt to discuss some of the results of the determination of ^{90}Sr and ^{137}Cs in the human placenta and foetus and those in the food for pregnant women in the hospital.

141 Distribution of fission product ^{137}Cs in soils and agricultural produce. R. PERRY and J. W. LUCAS, University of Manchester Radiological Protection Service (UK).

Direct aerial deposition and rainfall have been the primary sources of the ^{137}Cs contamination of growing crops to date. It has not yet been possible to ascertain the full extent of the indirect and much smaller contribution from the soil under field conditions. The present programme is designed to assess the contribution from this source and especially its dependence on farm practice. The Haughley Experimental Farms in Suffolk have provided an excellent source for samples, as the farms are managed and fertilised rigorously in three independent sections, organic, mixed and stockless (chemical). Samples of barley, wheat, and tick-beans have been collected and analysed during the harvests of 1967-1969, and the soils were sampled and tested comprehensively in 1968. The sampling and analytical procedures are reviewed and the results of about 200 measurements are summarised with comparisons between the three farm sections. There was a marked rise in the produce levels from 1967 to 1968 arising from more recent nuclear weapons tests and an abnormally wet summer with the consequence that any soil effect has been effectively masked. The soil profiles from the three sections showed a very similar distribution in ^{137}Cs for permanent pastures and the availability of the Cs as measured chemically was always very low. Work is now proceeding to examine the behaviour of Cs in relation to the various fractions of the soil.

142 Evaluation de l'irradiation de la moelle osseuse résultant de la contamination du lait par du ^{90}Sr après dépôt continue ou accidentel sur des pâturages. M. ODIEVRE, J. PLANET et G. UZZAN, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

On a évalué l'irradiation de la moelle osseuse consécutive à la consommation de lait contaminé dans deux cas:

- celui d'une contamination permanente du lait consécutive à des rejets atmosphériques continus à niveau constant de ^{90}Sr ;
- celui d'une contamination de courte durée consécutive à un rejet atmosphérique accidentel de ^{90}Sr .

Dans le premier cas on a été conduit à étudier d'abord, l'évolution de la contamination du lait compte tenu des deux mécanismes de transfert, le dépôt direct sur les pâturages et les cultures fourragères, et la contamination par voie racinaire consécutive à l'accumulation dans le sol du ^{90}Sr . La contamination du lait croît avec le temps pour atteindre une valeur d'équilibre à un temps variable avec la nature du sol. On en déduit ensuite le débit de dose à la moelle osseuse en fonction de l'âge des consommateurs de lait et en fonction du décalage entre le début des rejets atmosphériques et le début de la consommation.

Dans le deuxième cas on a procédé à l'évaluation de la dose engagée à la moelle osseuse en fonction de l'âge du sujet au moment de la contamination accidentelle.

La méthode générale d'évaluation est décrite et des résultats numériques sont donnés, sous forme de courbes, pour des valeurs particulières des paramètres de transfert et de la consommation de lait en fonction de l'âge.

The evaluation of the dose to the bone marrow resulting from the contamination of milk by ^{90}Sr after continuous or accidental deposition on pasture.

The dose to the bone marrow following the consumption of contaminated milk is calculated in two cases:

- that of a continuing contamination of milk following the continuous discharge of ^{90}Sr to atmosphere at a constant rate;
- that of a short contamination following an accidental release of ^{90}Sr to atmosphere.

In the first case, the development of the contamination of the milk has been studied taking into account the two transfer mechanisms, the direct deposition on pasture and fodder and the contamination via the routes following the accumulation of ^{90}Sr in the soil. The contamination of milk increases with time, to reach an equilibrium value at a time dependent on the nature of the soil. The dose rate to the bone marrow has then been assessed as a function of the age of the milk consumer and of the time-lag between the start of the atmospheric discharges and the start of consumption.

In the second case, the dose commitment to the bone marrow has been evaluated as a function of the age of the subject at the time of the accidental contamination.

The general method of calculation is described and numerical results are given in the form of curves for particular values of the transfer parameters and the intake of milk as a function of age.

143 Predictions of ^{90}Sr levels in milk on the basis of deposition values. E. VAN DER STRICHT, Commission of the European Communities, Brussels and P. GAGLIONE and M. DE BORTOLI, Joint Nuclear Research Centre, Ispra, Italy (EURATOM).

The ^{90}Sr levels in milk, as a consequence of the long term contamination of pastures, can be described in terms of the activity deposited onto growing herbage, on one side, and of the activity accumulated during the previous years, on the other side.

The correlation equation adopted in this paper is of the simple type $z = ax + by$, but of considerable importance is the choice of the parameters and, particularly, of the cumulative deposit. This, in fact, has to be corrected each year by a decreasing factor (0.85), to allow for the reduction through different mechanisms of the radioactivity which can be absorbed by plants.

This model has been tested with different sets of data, covering several years of fallout contamination in Europe and the correlations obtained are remarkably better (correlation coefficients higher than 0.99) than those found using the raw data.

The deviations still existing between predicted and observed values may be explained, at least in part, by the variations occurring in the meteorological conditions of the growing season; a method to take this effect into account is proposed.

The meaning and the validity of the correlation coefficients a and b are discussed.

144 Strontium-90 in Finnish ecosystems. O. PAAKOLA and A. SALO, Institute of Radiation Physics, Helsinki (Finland).

Radioecological aspects of the contamination and movement of ^{90}Sr have been studied in Finland since 1959. This paper gives a general picture of the studies carried out in Finland.

Strontium-90 in precipitation and surface air, and in plants and soil, will be discussed and the results for a 10 yr period given.

Since about 10% of the total surface area of Finland is covered with lakes and rivers our interest was in the contamination of waters. The highest concentrations, about 5 pCi/l., were found in 1964 in the mid-eastern part of Finland. The fixation of ^{90}Sr in sediments and its transport into the Baltic Sea will be discussed.

According to FAO statistics milk consumption in Finland is the highest in the whole world, about 630 l./capita/yr. Thus one of our main studies is the occurrence of radiostrontium in milk. The highest annual mean value for the whole of Finland has been

22.8 pCi/g Ca and the highest single value 59.6 pCi/g Ca, both in 1963.

Terrestrial and aquatic food chains in Finland will be discussed as well as the arctic food chain, which is known to be very high in ^{137}Cs but also in ^{90}Sr .

The results of ^{90}Sr measurements in man will also be given.

145 The behaviour of ^{137}Cs in turfpodzolic sandy soils of Ukrainian Polesya and transfer of ^{137}Cs to vegetation and milk. E. I. BELOVA and H. E. SHARONOV, Institute of Biophysics, Moscow, A. A. MOISEEV, Central Institute of Post-graduate Studies, Moscow and I. E. MURKIN, Institute of the Common and Environmental Hygiene, Kiev (USSR).

The present study was carried out to determine the behaviour of ^{137}Cs in turfpodzolic sandy soils in the several villages of Chernigov region of the Ukrainian SSR where the increased ^{137}Cs content in vegetation and milk has been previously found. Detailed results on the study of physico-chemical characteristics of the soils obtained in the area of these villages are given. It was shown, that the increased concentrations of ^{137}Cs in pasture vegetation and milk is due only to the specific conditions of soils in the given area. The turfpodzolic sandy soils of Ukrainian Polesya due to low sorption ability leads to greater transfer of ^{137}Cs via food chain soil-vegetation-milk. It was established that the distribution of ^{137}Cs along the soil profile in the investigated areas is different from the vertical distribution of nuclide in other soils of the USSR. The upper 4 cm. of these soil types contained about 40% of the ^{137}Cs activity. The rest 60% of the ^{137}Cs activity is rather uniformly distributed along the layer of soil 4-25 cm thick. These results indicate that for the given areas ^{137}Cs migrates more intensively along the soil profile. The transfer coefficient vegetation/soil depending on the soil type varied from 1.0 to 22.5.

146 Read in title. Die Untersuchung der Radioaktivität des Fallout in Ungarn. E. POLGÁR and I. KURCZ-CSEKY, State Institute of Hygiene, Budapest (Hungary).

Die systematischen Falloutprüfungen haben in der Kontrolle der künstlichen Radioaktivität der Biosphäre eine wichtige Rolle, weil sie relative einfach und schnell für die Rutinkontrolle vertrauenswürdige Informationen bezüglich der aus der Atmosphäre ausgeschiedenen, am Boden und auf den Pflanzen abgesetzten radioaktiven Stoffe geben.

Wir messen die Gesamt- β -Aktivität und den ^{90}Sr Gehalt der in Budapest gesammelten atmosphärischen Niederachläge und Fallout seit 1963. In der vorliegenden Arbeit veröffentlichen wir die seit 1963 gefundenen Monatsdurchschnittswerte, welche in 1964 eine wesentliche Abnahme zeigten, usw. als Ergebnis des Atomstillstandes. Die Abnahme meldete sich wegem Abklingen der kurzlebigen Spaltprodukten hauptsächlich bei der Gesamt- β -Aktivität. Die niedrigsten Werte wurden in 1967 bemessen. Seit 1968 kann wieder ein Anwachsen der künstlichen Aktivität der Biosphäre beobachtet werden. Die Steigerungstendenz war auch in 1969 konstaterbar. Es würde auch die Gesamt- β -Aktivität und der ^{90}Sr Gehalt der aus verschiedenen Gegenden Ungarns stammenden Falloutproben geprüft. Die Ergebnisse bewegen sich in der Höhe der Budapester Falloutaktivität.

Zwecks Untersuchung der verunreinigenden Wirkung von Kohlenarten mit erhöhtem Urangelhalt, wurden Falloutproben in der Umgebung von zwei Kraftwerke eingesammelt und auf Gesamt- β -Aktivität und ^{226}Ra Gehalt geprüft. Die gemessene Gesamt- β -Aktivität entspricht deren, aus anderen Gegenden Ungarns stammenden Falloutproben. Bis aber im Budapester Fallout kein Radium nachweisbar war, zeigten die aus der Umgebung beider Kraftwerke stammenden Falloutproben einen gut messbaren ^{226}Ra Gehalt.

In der Umgebung der herkömmlichen Kraftwerke müssen wir bei der Schätzung der Strahlenbelastung der Bevölkerung neben den Spaltprodukten der Atomwaffenversuche auch mit den etwaigen natürlichen radioaktiven Stoffen der Flugasche rechnen.

The investigation of the radioactivity of the fallout in Hungary.

The systematic fallout tests have an important role in checking the artificial radioactivity of the biosphere as, relatively simply and quickly, they give reliable information relative to the radioactive material eliminated from the atmosphere and deposited on the ground and on plants for routine checking.

We are measuring the total β activity and the ^{90}Sr content of the atmospheric precipitation and fallout collected in Budapest since 1963. In the present work we are publishing the average monthly values found since 1963 which show a remarkable decrease, i.e. as a result of the Test Ban Treaty. The decrease is shown because of the dying away of the short-lived fission products chiefly with the total β activity. The lowest values were recorded in 1967. Since 1968, a growth of the artificial activity of the biosphere can again be observed. The tendency to

increase was also noticeable in 1969. The total β activity and the ^{90}Sr content of the fallout tests originating from different regions in Hungary were also tested. The results are in the region of the Budapest fallout activity.

For the purpose of examination of the contamination effect of types of coal with increased uranium content, fallout samples were collected in the surroundings of two power stations and tested for total β activity and ^{226}Ra content. When measured, the total β activity corresponds in those fallout samples originating from other regions in Hungary. However, while no radium was detectable in the Budapest fallout, the fallout tests originating from the surroundings of both power stations showed a readily measurable ^{226}Ra content.

In the surroundings of conventional power stations we must reckon with the eventual natural radioactive materials of the fly ash, as well as with the radiation exposure of the population from the fission products of the atomic weapons experiments.

147 Read in title. Contamination des os d'animaux par du ^{90}Sr dues aux retombées radioactives dans les environs de Belgrade. R. BRNOVIĆ, M. JEREMIĆ and D. PANOV, Institut pour la Médecine du travail et Protection Radiologique "Dr Dragomir Karajovic" (Yugoslavia).

Dans le but de suivre le passage du ^{90}Sr dans la biosphère, on a effectué une étude dans les environs de Belgrade concernant la teneur du ^{90}Sr dans les milieux suivants: dans les précipitations, dans les végétaux et dans les os des animaux.

Par les précipitations atmosphériques, pendant la période allant de 1962 à 1968, ont été déposés 34 mCi $^{90}\text{Sr}/\text{km}^2$, avec un maximum de 13.17 mCi $^{90}\text{Sr}/\text{km}^2$ en 1963.

Au cours des années 1967-1968 on a analysé la contamination des vaches par le ^{90}Sr introduit par l'intermédiaire de la nourriture. Cette analyse a été faite par jour et les valeurs obtenus vont de 1000 à 2500 pCi $^{90}\text{Sr}/\text{jour}$.

Les doses de ^{90}Sr déposés dans les os des animaux pendant la période de 1965 à 1968 ont une valeur allant de 89.5-26.5 mrad/an.

Contamination of animal bones by ^{90}Sr from radioactive fallout in the neighbourhood of Belgrade.

A study has been carried out in the neighbourhood of Belgrade on the amount of ^{90}Sr in the following materials: rainfall, vegetation and animal bone.

The aim of these studies is to follow the movement of ^{90}Sr in the biosphere.

34 mCi $^{90}\text{Sr}/\text{km}^2$ were deposited by rainfall during the period from 1962 to 1968, with a maximum of 13.17 mCi $^{90}\text{Sr}/\text{km}^2$ in 1963.

During 1967-1968, analyses have been made of the contamination of cows by ^{90}Sr taken in their food. The results have been expressed on a daily basis and the values obtained run from 1000 to 2500 pCi $^{90}\text{Sr}/\text{day}$.

The doses from ^{90}Sr deposited in the animal bones during the period 1965-1968 have values between 80.5 and 26.5 mrad/yr.

148 Read in title. Radioactive cesium in estuaries.

G. K. RIEL, U.S. Naval Ordnance Laboratory, Silver Spring, Maryland (USA).

The mixing zone between fresh and salt water tends to retain cesium, thus the ^{137}Cs concentration is higher in an estuary than in its source waters. Four estuaries* on the east coast of the United States had ^{137}Cs concentrations between 0.2 and 0.5 pCi/l. (picocuries per liter), while the concentration in the adjacent Atlantic Ocean and upstream in the rivers was less than 0.1 pCi/l. Two factors contribute to this increased concentration. Cesium that was transported down the river in clay sediments is released by exchange with sodium in the salt water. The slow exchange of estuarine with ocean water allows cesium to accumulate. Evaporation is also an important factor; the ratio of ^{137}Cs concentration to salinity in the surface waters of the Chesapeake Bay is twice that in its deep waters. Estuaries are important as the breeding ground for most fish and for commerce and recreation at our largest cities, so we must understand how radioisotopes behave in the estuarine waters.

RADIATION PROTECTION STANDARDS II

149 Oral presentation. PQR—A special way of thinking? A. HEDGRAN and B. LINDELL, National Institute of Radiation Protection, Stockholm (Sweden).

The authors have arbitrarily adopted the letters "PQR" to symbolize a quantitative measure of the impact of any given radiation exposure at low doses. The philosophy they have developed on this basis is

* Savannah, Neuse, and Patuxent Rivers and the Chesapeake Bay.

not unique, and since it was doubtful whether it would be of particular value to anybody else, they have not until now considered giving publicity to it. Experience has shown, however, that in spite of conspicuous imperfections, the concept of PQR has been of considerable use in a number of practical situations where it has prevented the mind from following lines of thought which might have been obvious but which were nevertheless misleading.

Radiation protection is partly aimed at preventing accidents at high doses and partly aimed at keeping low doses low at the imaginary level implied by paragraph 52 of *ICRP Publication 9*.

In the latter case, and assuming that we wish to hold on to the basic assumptions of linearity and non-threshold relationships, it is obviously the number of manrads that should be minimized in radiation protection. But how far should one go? The law of diminishing return would imply that there is a practical optimum. One should not spend efforts in reducing a certain radiation exposure, if the same efforts would result in a higher manrad reduction if spent somewhere else. We should try to be consistent, but in order to be consistent we need to know the effort that our society is usually willing to spend for the reduction of one manrad. It is this "standard cost" of a unity dose reduction that the authors denote "PQR", and the product of the PQR and the number of manrads in any given operation is the "PQR-cost" or the "PQR-value" of that operation.

The authors have tried to assess the PQR by various methods and arrive at a value of about \$100 per manrad. As examples, various radiation exposures are described by their PQR-values. A comparison could as easily be made directly of the number of manrads, but the interesting aspect of the PQR-value is that it is not entirely void of any relations to other value standards, such as the efforts which are usually spent in situations where human lives are at stake at the same degree of risk but from other causes than radiation. And last but not least: it is sometimes easier to convey an assessment of the situation to the layman by referring to dollars than by referring to manrads or risk statistics.

150 Oral presentation. The use of risk estimates in setting and using basic radiation protection standards. H. J. DUNSTER and A. S. MCLEAN, UKAEA Health and Safety Branch (UK).

The setting of maximum permissible doses and the interpretation of phrases such as "as low as practicable" both involve a process of judgement using some information which is quantitative, at least in principle, and some which is qualitative by nature. Preliminary

assessments of the relationship between risk and radiation dose are already available and it is important to establish the most appropriate ways of incorporating these estimates into the wider problem of making decisions about basic standards.

Two developments of present concepts are put forward. The first is that of a "supportable dose" selected so that any higher dose is "unsupportable", i.e. intolerable, in any normal situation. The choice is dictated only by a comparison of radiation and other, pre-existing risks. The second is that of a "justifiable dose" selected for any set of circumstances by a process of cost-benefit analysis, using the marginal costs of reducing doses and the benefits of avoiding future detriment, either somatic or genetic. It is shown that this is a more satisfactory basis than a comparison, for any operation or project, of total costs, including detriment, with the overall benefit.

Examples are given showing how risk estimates can be used to suggest values of the "supportable dose" for workers and members of the public. The "justifiable dose" cannot be selected in the general case because it depends on circumstances, but figures much below the supportable dose seem unlikely to be indicated by cost-benefit arguments alone, if dose reductions cost more than a few pounds sterling per man-rad.

151 Oral presentation. Speculated risk to bone and liver from ^{239}Pu .* C. W. MAYS, G. N. TAYLOR, W. S. S. JEE and T. F. DOUGHERTY, Radiobiology Division, University of Utah, Salt Lake City (USA).

The permissible body burden of ^{239}Pu in radiation workers is $0.04 \mu\text{Ci}$. A literature survey indicates that the Pu reaching the circulatory system from occupational exposure may redeposit roughly half in bone and half in liver. For a constant $0.02 \mu\text{Ci } ^{239}\text{Pu}$ in bone and $0.02 \mu\text{Ci } ^{239}\text{Pu}$ in liver, the 50-yr doses to man are 14 and 57 rads, averaged over these respective organs. Probabilities of radiation-induced tumors from these doses are estimated as follows:

	Bone cancers	Liver tumors
Threshold model	0%	0%
Dose-rate model	1%	2%
Lifespan dose model	5%	10%

The threshold model is based on radium-containing

* Supported by USAEC contract.

humans, whereas the dose-rate and lifespan dose models are extrapolated from plutonium-containing dogs. These risks refer to adult, *not* childhood, exposures. The hazards to the lung from inhaled plutonium, and the hazards to wound puncture sites are *not* estimated. Improved estimates of the actual risks are urgently needed.

152 (Withdrawn) See 246

EXPERIMENTAL DATA:
RADIOBIOLOGY I

Discussion Group

153 The metabolism of the radionuclides. L. ARGIERO *et al.*, CAMEN Radioprotection Laboratory, Pisa (Italy).

The values of the maximum permissible concentrations for occupational exposure have been calculated using the exponential or compartment model for retention and elimination from the human body.

In certain cases, it has been observed that the curve of the biological elimination can be represented using an exponential sum model, in which the long half-life components have a greater importance in the occupational exposure, or a power function model,

the biological elimination being an inverse time function.

On the other hand it has not been proved that, in case of acute internal exposures, the biological elimination follows the occupational exposure laws.

Moreover a series of studies have been completed to find the metabolism in the gastrointestinal tract as well as in the breathing system; the results obtained have often been contradictory.

For the above mentioned reasons it is useful to assemble again critically, in a single report, the uniformed retention and elimination curves, obtained by various experimenters with the theoretical curves, to enable the health physicist to determine, with practical dates, in case of nuclear accidents, through an easy procedure, the amount of substances introduced in the body.

154 (Withdrawn)

155 Whole-body ^{90}Sr retention and distribution in trabecular and cortical bone of beagles.* R. J. DELLA ROSA and M. GOLDMAN, Radiobiology Laboratory, University of California, Davis (USA).

The retention of ^{90}Sr in beagles following continual ingestion during their first 1.5 yr of life was measured by routine whole-body counting. Seventy-five dogs from five ingestion levels ranging from 0.1 to 12 $\mu\text{Ci}/\text{day}$ were studied up to 7.5 yr of age. The distribution of ^{90}Sr was also determined in individual bones and teeth from 16 dogs at three ingestion levels. Trabecular bone corings were obtained from femora and/or humeri and from lumbar vertebra of five of these dogs. Cortical bone was obtained from the mid-shaft sections of femora or tibiae. These data were used in constructing a provisional model to describe the ^{90}Sr retention pattern in terms of the weighted effect of differential loss rates from cortical and trabecular bone.

Combination of whole-body counting data and ^{90}Sr determinations from bone samples obtained during and after the feeding period indicated that about 80% of the body burden was in cortical bone which appeared to have an effective half-period of 15 yr. Trabecular bone, accounting for about 15-20% of the skeletal mineral, appeared to lose its ^{90}Sr label with a 1.3 yr half-period while the remaining small fraction of the burden ($\sim 2\%$), ostensibly soft tissue, was lost with a calculated half-period of a few days. The latter estimate is also reflected by the

pattern of plasma and excreta concentration of ^{90}Sr . These data can be utilized in predicting ^{90}Sr hazards to man under conditions of extended contamination in which the relative exchange rates of the skeletal mineral compartments play the major role in determining the local dose rates.

156 Mechanism of deposition of plutonium and americium in tissues.* D. M. TAYLOR and C. J. DANPURE, Department of Biophysics, Institute of Cancer Research, Sutton (UK).

Because of its pronounced tendency to hydrolyse at physiological pH, the distribution of plutonium throughout the body tissues is markedly affected by the physico-chemical form in which the element enters the blood stream. Assessment of the risks to health likely to result from internal contamination with plutonium, and the design of suitable treatment procedures, would be greatly assisted by a clearer understanding of the mechanisms by which plutonium is transported round the body and taken up by cells.

As part of a larger study on transport and uptake mechanisms, we have studied the sub-cellular distribution of plutonium and americium in rat liver after intravenous injection of monomeric or polymeric material. The ultimate location in the liver cell of plutonium administered in either form is in the lysosomes, but the time course of uptake differs for monomeric and polymeric material suggesting that different mechanisms of cellular uptake are involved. Lysosomal association of polymeric plutonium is essentially maximal within one hour of injection and it is suggested that the polymeric particles are taken up directly into phagocytic vacuoles by endocytosis. In contrast, monomeric plutonium, which reaches the liver via the blood as a plutonium-transferring complex, first enters the soluble fraction of the cell where it is bound by a, so far unidentified, protein; the subsequent transfer to the lysosomes occurs after a period of up to 4 days, presumably by an autophagocytotic mechanism. It is not known whether the initial liver plutonium-protein complex is taken up directly by the lysosomes without dissociation.

Essentially similar results have been obtained in studies of the uptake of monomeric and polymeric americium by liver, except that after injection of monomeric material the transfer from the soluble fraction of the liver cells to the lysosomes is more rapid than was seen with plutonium.

Less complete studies on the sub-cellular distribution of plutonium in the testes suggest that the lysosomes are important sites of deposition. However,

* Supported by the US Atomic Energy Commission.

* Work performed under UKAEA Contract.

at all the time intervals studied, a greater proportion of the deposited monomeric or polymeric plutonium is found in the soluble fraction than occurred in the liver.

The association of plutonium with the lysosomes in liver and testes may be of interest in view of the suggestions that lysosomes may be involved in carcinogenesis and of the reported occurrence of hepatic and testicular tumours in animals exposed to ^{239}Pu .

157 The metabolism of thorium and its daughter products in bone. VERONICA KNIGHT, Radiological Protection Service, Belmont, Surrey (UK).

Knowledge of the metabolism of the radium daughter products ^{226}Ra and ^{224}Ra , produced *in vivo* from ^{232}Th in bone is required in order to calculate the absorbed dose from ^{232}Th . Since there is some uncertainty about this data, the retention of ^{232}Th and its daughter products in bone is being investigated in the rat.

A solution of thorium citrate, separated from the radium daughter products of thorium, is injected intraperitoneally into the rat, under conditions which give maximum uptake into the bone. The activities of ^{232}Th and its various daughter products, in the bone, are then measured after different periods of time, up to about 18 months. The ratio of the activities are compared with the corresponding ratios obtained from bones dissected out soon after the initial injection.

The details of the experimental procedure are described and the preliminary results are considered in relation to maximum permissible levels of ^{232}Th in the body.

158 A study of the frequency distributions of ^{226}Ra and ^{228}Th in animal and human bones in relation to daily intake. S. GVOZDANOVIC, MRC Environmental Radiation Unit, University of Leeds, The General Infirmary, Leeds (UK).

This study investigates the extent to which log-normal distributions, as recommended by Schubert (1967) can be used to describe the distribution of the concentrations of ^{226}Ra and ^{228}Th in animal and human bones.

The factors which influence the character of the frequency distribution in bones are discussed. Efforts have been made to correlate the distribution of these elements according to sub-divisions made on such bases as feeding habits, location and age. A comparison between frequency distributions for animal and human bones was also given.

The results of this investigation show that (i) the frequency distribution of ^{226}Ra in a homogeneous

human population is log-normal with the same standard geometrical deviation, s.g. = 1.50 as the frequency distribution of daily intake; (ii) the frequency distribution of the daily intake of food and water is the main factor influencing the character of the frequency distribution in bones; (iii) in relation to ^{226}Ra concentrations in bone, the world population falls into three fairly homogeneous groups which correspond to three already recognized dietary habits.

All these points apply for the case of normal radium levels in food and water.

159 Measurement on natural levels of thorium isotopes in animal and human bones and a comparison with existing metabolic data. D. GVOZDANOVIC, MRC Environmental Radiation Unit, University of Leeds, The General Infirmary, Leeds (UK).

By using a method based on chemical pre-separation and subsequent alpha spectroscopy with a surface barrier detector, measurements of thorium isotopes in biological materials have been made down to concentrations of 2×10^{-16} Ci/g. The following average concentrations of thorium isotopes were found in 7 samples of bovine bones: 1×10^{-13} Ci $^{228}\text{Th/g}$ ash, 0.3×10^{-14} Ci $^{230}\text{Th/g}$ ash and 0.7×10^{-15} Ci $^{232}\text{Th/g}$ ash. Three samples of young bovine bone have shown smaller concentrations; similar variations with age were observed in sheep. Concentrations in bovine liver were much smaller than in bones; it was calculated that the liver burden is 1%, 3.6% and 5.5% of that in the skeleton for ^{228}Th , ^{230}Th and ^{232}Th respectively.

A general agreement was found between the experimental results and values calculated under following assumptions:

1. soil concentration = 5×10^{-6} g $^{232}\text{Th/g}$ soil,
2. accumulation of thorium in grass ash = 0.15,
3. uptake of thorium through gut = 0.0006,
4. fractional deposition in skeleton 0.69 and
5. retention coefficient 0.00014.

The levels of thorium isotopes in two samples of human bones were found to average: 0.8×10^{-14} Ci $^{228}\text{Th/g}$ ash, 0.2×10^{-14} Ci $^{230}\text{Th/g}$ ash and 0.6×10^{-15} Ci $^{232}\text{Th/g}$ ash.

160 Comparison of metabolic kinetics of calcium strontium, barium and radium in rabbits. J. LINIECKI, D. WITKOWSKA and W. KARNIWICZ, Institute of Occupational Medicine, Lodz (Poland)

Short term metabolic kinetics of Ca, Sr, Ba and Ra was studied in 8 months old rabbits after single

intravenous injection of radioactive tracers. It was observed that—as found previously in rats—the sizes of rapidly exchangeable pool and accretion rates of Ba and Ra were both larger than those of Ca and Sr.

The biological retention of single doses of respective tracers on 5th day could be ordered according to a following gradient: $Ra > Ba > Ca > Sr$. The latter correlates well with the order of the ratio:

$$\frac{\text{accretion rate/day 5}}{\text{total excretory/urine, intestines/clearance}}$$

for given four elements.

Long term retention of ^{90}Sr and ^{133}Ba is discussed in light of above observations.

161 The study of hepatic radiocerium deposition.

T. TRNOVEC, A. PLEŠKOVÁ, D. GHORVÁT and J. PETROVIČOVÁ, Institute of Industrial Hygiene and Occupational Diseases, Bratislava (Czechoslovakia).

Blood disappearance of ^{144}Ce intravenously applied in solutions of pH 3 and pH 8 and its organ distribution in rats was studied after reticuloendothelial interference and CCl_4 application. The state of RES has been tested by carbon blood clearance and that of hepatic parenchyma by clearance of ^{131}I -bengal rose.

Three repeated i.v. injections of ferric hydroxide in complex with dextrin stimulated carbon clearance. In rats the blood disappearance of ^{144}Ce pH 3 and pH 8 resp., has not been changed after this treatment. Similarly, there were no changes in 24-hr organ distribution of ^{144}Ce . On the contrary, in mice the blood disappearance of both ^{144}Ce pH 3 and pH 8 was slower and its hepatic initial uptake lower.

After glucan application an enhanced carbon clearance and no changes in ^{131}I -bengal rose clearance have been observed. Repeated glucan administration after ^{144}Ce pH 3 and pH 8 i.v. or intratracheal application had no effect on ^{144}Ce body distribution and its excretion pattern after DTPA administration.

After injections of commercial India ink or the carbon suspension G. Wagner C 11-1431 a resp., a decrease of carbon blood disappearance has been observed. Both agents interfered also with ^{131}I -bengal rose blood disappearance. The ^{144}Ce disappearance from blood has been changed only after commercial India ink application, which had a more pronounced hepatotoxic effect. The 24-hr ^{144}Ce hepatic deposition after previous India ink treatment was low. After the G. Wagner carbon suspension application there were no changes in hepatic deposition of ^{144}Ce . Following CCl_4 application only moderate

changes in carbon clearance have been observed. CCl_4 effected a slowing of ^{144}Ce blood disappearance and a decrease of its hepatic deposition.

It has been shown in these experiments that the state of RES had a little effect upon radiocerium metabolism. On the contrary after disturbing the hepatic parenchyma with CCl_4 or commercial India ink profound changes in radiocerium kinetics were seen.

162 Diffusion deposition of inhaled particles in the upper bronchial tree.

W. JACOBI and D. MARTIN, Hahn-Meitner-Institut für Kernforschung, Berlin (Germany).

The deposition pattern of small radioactive particles (mean diffusion coefficient $2 \times 10^{-6} \text{ cm}^2/\text{sec}$) in a plastic model of the upper bronchial tree was studied. The geometry of the model corresponded with the dichotome lung model given by WEIBEL. The deposition probabilities in the different bronchial regions during inspiration and expiration were measured as function of the air flow rate in the range of 0.1–50 l./min. In addition radioautographs of the exposed lung models were prepared to get information on the microdistribution of the deposited activity.

The results indicate also, that at low flow rate no laminar air stream in the bronchi is reached. Deposition due to turbulent diffusion plays an important role and causes a rather inhomogeneous deposition pattern with maxima at the branchings of the bronchi. The experimental results are compared with the theoretical formulae, which are used till now to estimate the deposition of small particles in the bronchial tree.

EXPERIMENTAL DATA: RADIOBIOLOGY II

Discussion Group

163 A long-term study of the biological effects of inhaled $^{144}\text{CeCl}_3$ in the beagle dog.*

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A study of the long-term effects of inhaled $^{144}\text{CeCl}_3$ in the beagle dog has been in progress for 4 yr.

* Research performed under contract to the US Atomic Energy Commission.

Eighty-two beagles have each been given one short, "nose-only" inhalation exposure to a CsCl aerosol contaminated with ^{144}Ce ; another 17 dogs serve as controls. Twenty-seven dogs whose initial body burdens ranged from 1.5 to 4.4 $\mu\text{Ci}/\text{kg}$ were sacrificed serially during the first 512 days post-exposure to determine normal distribution and excretion patterns for ^{144}Ce inhaled in this form. The remaining 55 dogs were exposed to higher aerosol concentrations so that when ranked on the basis of their retained body burdens at 14 days post-exposure, they could be divided into five groups with mean body burden values of 5.2, 14, 40, 120 and 230 $\mu\text{Ci}/\text{kg}$. Following a sharp drop in the whole-body retention soon after exposure, the remaining ^{144}Ce was retained with an effective half-life similar to the physical half-life. By four days post-exposure, more than 90% of the body burden was localized in the lung, liver and skeleton. As the ^{144}Ce in the lung decreased, a corresponding increase was observed in liver and skeleton. Fifteen dogs in the two highest body burden groups have died to date. Causes of death have generally fallen into three categories: severe hemopoietic depression with associated pancytopenia (8 dogs between 21 and 44 days post-exposure, one at 510 days post-exposure), severe pulmonary fibrosis (3 dogs between 138 and 375 days post-exposure) and hepatic injury (3 dogs between 309 and 874 days post-exposure). Additional clinical information relating to both the survivors and the non-survivors is discussed in relation to the cumulative absorbed radiation doses received.

164 Leukopenia after ^3H -thymidine contamination in mice. CORNELIA DIACONESCU, Radiation Hygiene Laboratory, Institute of Hygiene, Iassy and N. RACOVEANU, Radiation Hygiene Laboratory, Institute of Hygiene, Bucharest (Romania).

The quantity of ^3H -Thymidine able to produce leukopenia in mice has been investigated after several intervals of time (7, 14, 21 and 28 days) using lots of mice that had been intraperitoneally injected 1.5, 3.75 and 7.5 $\mu\text{Ci}/\text{g}$ ^3H -Thymidine.

Leukopenia with evident lymphopenia was noticed after administration of 7.5 $\mu\text{Ci}/\text{g}$ ^3H -Thymidine, the decrease being highly significant statistically 21 days after administration of the labelled substance; on the 28th day a tendency of recovery was observed.

The mechanism of leukopenia and some questions of the distribution of the irradiation in the hemopoietic system during contamination with ^3H -Thymidine are being discussed in the paper.

165 ^{90}Sr -induced osteosarcomas in radiation chimaeras. D. W. H. BARNES, T. E. F. CARR, E. P. EVANS and J. F. LOUTIT, Medical Research Council Radiobiology Unit, Harwell (UK).

ICRP Publication 11, reviewing the radiosensitive tissues in bone, identified 3 especially sensitive tissues—bone marrow, osteoprogenitive cells of the endosteum and epithelium closely adherent to bone in cranial sinuses.

The identity and location of endosteal pro-osteoblasts are uncertain but they are reckoned to be closely adjacent to endosteum. Thus ICRP in considering permissible doses from bone-seeking radionuclides should consider (1) for the avoidance of leukaemia the average dose in red bone marrow, (2) to avoid osteosarcoma the dose close to endosteal surfaces and (3) to avoid cranial carcinoma the dose adjacent to the periosteum.

In theory the stem cells of bone marrow with pluripotentiality for formation of all the circulating blood cells could additionally have osteoprogenitive capacity. In this case the 3 considerations for permissible doses would need restating. The provenance of osteosarcomas induced in mice with ^{90}Sr was therefore investigated in radiation-chimaeras—(1) CBA mice repopulated with CBA.T6T6 bone marrow, (2) CBA.T6T6 mice repopulated with strain A myeloid tissue (foetal liver).

All the osteosarcomas so far investigated by cytological and genetic analysis appear to arise from cells originating in the host and not from the donated bone marrow. Thus the methods of calculation to be used by ICRP seem justified.

166 Studies of liver function tests in radiation workers and changes in liver function tests in rats after total body exposure to lethal doses of X-irradiation. A. M. EL-NAGGAR *et al.*, Medical Unit, Atomic Energy Establishment, Cairo (UAR).

In the first part of the study, about sixty workers occupationally engaged in radiation work for 5 yr are being studied for changes in liver functions. The tests performed are serum bilirubin, serum transaminases, alkaline phosphatase, thymol turbidity, zinc sulphate turbidity, and cephaline cholesterol flocculation. The workers are chosen from groups working at radioactive ore mines, radioisotope production plants and different installations where hazards of external and internal radiation exposure exist. Detailed clinical examination is done prior to the collection of blood samples to exclude any

disease that may cause changes in the tests performed. The radiation exposure doses for the individuals chosen were considered.

The second part of the study deals with the performance of liver function tests in rats after whole body exposure to lethal doses of deep X-rays. Blood samples were collected 4 days after irradiation and studied for serum bilirubin, serum transaminases and zinc sulphate turbidity. A total of forty rats were included in the study; thirty were irradiated and ten served as controls. All animals were weighed before and after irradiation. The dose ranges used were 462, 660, 858, 1056, and 1254 R.

The results of both studies are tabulated, correlated and discussed. The value of liver function tests in eliciting hepatic dysfunction that may occur after internal or external radiation exposure is considered.

167 Test of sensitivity of mice to γ -irradiation with the behavioural response to different colours.

N. KANEKO, Department of Research, Medical School Ground Self-Defence Force, Tokyo and Y. NISHIWAKI, Tokyo Institute of Technology (Japan).

In nuclear radiation facilities the major systems of the switches and dials for safety control are very often distinguished with different colours. Therefore it may be important from the health physics standpoint to study the behavioral response to different colours after irradiation. From these standpoints the authors conducted a preliminary experiment with mice.

In order to test the sensitivity of mice to different doses of λ -ray, the authors examined the behavioral response of mice to different colours with the following method.

A box with a wire-netting ceiling was divided into two compartments with a partition wall at the centre. Each compartment was painted in different colours. In one of the compartments experimental mice were placed. After irradiation, the small door at the central partition wall was opened and the behavioral response of the mice was observed. For this experiment the following combinations of two colours were used: red and white, black and white, green and white, red and blue, and blue and white.

The preliminary results of the experiment may be summarized as follows:

(1) Below 30 R, no significant response due to irradiation was observed,

(2) When one of the compartments of the box was painted blue and the other white, a marked response of mice was observed after irradiation, with a tendency to settle in the blue compartment.

168 Alpha-spectrometric and histological studies on thorotrast-treated rats.* ELVIRA R. DI FERRANTE, EURATOM Joint Nuclear Research Centre, Ispra, and G. GRAMPA, Istituto di Anatomia e Istologia Patologica dell'Università di Milano (Italy).

The distribution of thorium and its effects in the organism of thorotrast-treated rats were studied with the aim to know better the consequences of a thorium dioxide treatment or, more generally, of a radionuclide incorporation in humans.

Rats injected with different amounts of colloidal ThO_2 (thorotrast) were sacrificed at different times. The ^{232}Th content of organs was determined by alpha-spectrometry. The concentrations found seem unaffected by the time elapsed between treatment and sacrifice. The total uptakes in liver vary from 18 to 48% of the injected thorium, in spleen from 5 to 25%, in lungs from 0.05 to 0.5% and in kidneys from 0.03 to 0.09%.

The alpha-spectra obtained revealed also the presence in the tissues of all the descendants of ^{232}Th contributing to the alpha-irradiation dose.

Histological analyses permitted to study the nature of lesions induced in the tissues by the radioactive elements: the existence of a relationship dose-effect is evident. Results of observations made in humans described in the literature are compared with those obtained in the course of this study on rats.

169 Disorders in embryonal development of rats after injection of ^{131}I . A. M. LYAGINSKAYA, Y. D. PARFENOV and S. N. SINITSYNA, Institute of Biophysics, Moscow (USSR).

It has been found that after single injection of ^{131}I to rats at various periods of pregnancy in the dose ranging from 4 to 0.04 $\mu\text{Ci/g}$ foetus death is a function of injected dose level and the period of pregnancy. For all administrated dose ranges it was observed that the later was the period of pregnancy when isotope was injected the higher was foetus death *in utero*. Injection of ^{131}I at later periods caused higher absorption in the foetus.

This effect for ^{131}I differs from that for ^{90}Sr , tritium and ^{241}Am . Injection of these isotopes at earlier periods of pregnancy led to higher levels of foetus death.

The above dependence also exists for the delay in foetus development showing itself in the decrease of foetus weight as compared with the controls. Changes in the weight of placentas are not in dependence of

* Work supported in part by contract with the International Atomic Energy Agency in Vienna.

the period of pregnancy when ^{131}I was injected regardless of various levels of absorbed doses.

Progressive studies showed that main disorders in embryonal development fell within the last third of pregnancy.

170 The protective action of some dietary additives on strontium absorption in pregnant, lactating and suckling rats. K. KOSTIAL, N. GRUDEN, A. DURAKOVIĆ and I. ŠIMONOVIĆ, Institute for Medical Research, Yugoslav Academy of Sciences and Arts, Zagreb (Yugoslavia).

It has been shown previously that the absorption of radioactive strontium from the gut can be reduced by various dietary additives. The best results were obtained by a simultaneous increase of calcium, phosphate and alginate in the diet.⁽¹⁾

The purpose of this work was to evaluate the protective action of this dietary supplementation on radiostrontium absorption in suckling, pregnant and lactating rats, i.e. in conditions of a greatly increased absorption from the digestive tract.

A diet with calcium, phosphate and alginate additives was fed to suckling, pregnant and lactating rats. Tracer amounts of ^{47}Ca and ^{85}Sr were added to their drinking water or milk. The skeletal retention of both radioisotopes was determined in control animals and in animals on special diets.

The results indicate that dietary additives can be used successfully to reduce the absorption of radioactive strontium without interfering with the increased absorption of calcium in special physiological conditions i.e. during pregnancy, lactation and very young age.

1. K. KOSTIAL, T. MAJKOVIĆ, M. KADIĆ, R. MANIŠEVIĆ and G. E. HARRISON, *Nature, Lond.* **215**, 182 (1967).

OPERATIONAL HEALTH PHYSICS III

171 Oral presentation. Hazards in X-ray departments and preventive surveys. M. DAVISON, Department of Clinical Physics and Bio-Engineering, Glasgow (UK).

Radiation surveys have been carried out for many years in the West of Scotland hospital region. The results of checks on radiation levels, equipment performance, and patient dose are summarised and the hazards to staff and patients are put in perspective. It is suggested that dose reductions could be achieved through closer co-operation between manufacturer and physicist, leading to design improvements and standardisation.

172 Oral presentation. Radiation protection in general dental practice. N. J. D. SMITH, King's College Hospital, London (UK).

A recent survey of dental practice in the south of England showed that only 6.5% of the dentists in the sample did not possess X-ray sets.

A total of 114 dentists were visited in 79 practices where there were 88 X-ray sets, an average of 1.3 dentists per X-ray set. It was found that of the 38 sets with variable field size, this control was only used in seven cases, whilst 22 of the X-ray sets had a field size greater than 6.5 cm. There was no added aluminium filtration on 13 of the sets, whilst a further 8 had less than 1.0 mm aluminium filtration. Of the 88 X-ray sets, 85 had clockwork timers and 24 of these had errors of reproducibility of greater than 20% when set for a $\frac{1}{2}$ -sec exposure. The work loads of the X-ray sets were found to be small, only six sets having a work load of more than 10 mA min/week.

Protective aprons for patient protection were present in only six practices, and were used regularly on all patients in only one practice.

The positioning of 25 of the dentists was assessed as unsatisfactory during radiography and 44 dentists admitted to holding films in patient's mouths during the exposure with some degree of regularity. A measurable amount of radiation on the film badges used for monitoring was found among 27% of the dentists. There was a highly significant correlation between the dose received and the dentists whose positioning was regarded as unsatisfactory. It was also found that 17% of the surgery assistants had recordable doses on their film badges.

It is suggested that since the use of radiography during dental treatment is undoubtedly increasing, it is important to see that the dental undergraduate receives adequate training in the appropriate aspects of radiation protection.

173 Oral presentation. Occupational exposure in veterinary radiology in Britain. M. C. O'RIORDAN, Radiological Protection Service, Belmont, Surrey (UK).

The extent and nature of veterinary radiology in Britain and the radiation doses received by personnel as estimated from individual monitoring records will be reviewed. The poor quality of radiation protection in many practices, as determined on survey, will be described and the special features of a new Code of Practice for Veterinary Radiology will be discussed.

174 Oral presentation. A new approach to radiation protection supervision specially suited for universities. N. H. STEIGER-SHAFRIR and S. PAUKER, Department of Nuclear Science and Radiation Safety Unit, Israel Institute of Technology, Haifa (Israel).

The outline of a new approach to radiation protection supervision specially suited for universities and other academic institutes will be presented. Existing laboratory classifications and radiation protection regulations usually applied to nuclear research centres were found unsuitable for university student and research laboratories.

These classifications and regulations are of too general a character. On the one hand they are often too rigid when applied to specific types of radiation work, and on the other hand they are sometimes not rigid enough to enable the use of existing general purpose laboratories and buildings for other types of radiation experiments. Most of the university laboratories used today for radiation work were originally not designed for this purpose but had to be adapted in each case for the specific experiment to be performed.

Furthermore, in contrast to nuclear research centres where, as a result of previous planning, radiation work is concentrated in large specific areas and laboratories, the situation at universities is different. Here, radiation experiments of various types and at various levels are scattered over parts of numerous buildings all over the campus.

In consequence of these remarks, a new kind of classification for radiation laboratories for open sources, sealed sources, and other radiation devices, is proposed. Based on this classification, an integrated system for radiation protection supervision specifically suited for universities has been developed. This system interlinks all the steps and provisions to be taken and the necessary regulations to be issued for most practical types of radiation experiments performed at universities. A suitable computer program for this system has been written and makes it possible to obtain automatically, the information for most radiation protection and supervision problems of general and personal character for each specific case.

OPERATIONAL HEALTH PHYSICS IV

175 Invited paper. Experimental investigations of gamma dosimetry. L. BOZÓKY, National Institute for Oncology, Budapest (Hungary).

In order to develop our radiation protection aspects, it seemed of interest to complete the accurately known data on the primary gamma radiation

and its absorption phenomena with similar relevant data on the far more complicated scattering processes. Owing to the very limited possibility to account for the 12 parameters in question by calculation, the following contributions to the scattering of the gamma radiation have been investigated experimentally:

(1) Dependence of the dose rate from the scattered radiation on the scattering angle and the cross section of the primary gamma beam on lead, iron, concrete and paraffin scatterer.

(2) Dependence of the dose rate on the angle of incidence of the primary radiation and on the scatterer thickness for a radiation scattered at a given angle in the case of various scatterer materials.

(3) Contribution from scattering on the collimator.

(4) Contribution from 4π -scattering, i.e. from the scattering on the walls, ceiling and floor of the premises.

(5) Dose distribution of the scattered radiation within the scatterer.

The measurements were performed with the use of a 250 Ci or 800 Ci cobalt sources. For the experiments an irradiation facility was built, which does not permit the escape of gamma radiation when switched off and thus it lends itself well to the investigation of the inherently low intensity scattered radiation.

For the measurement of the dose rates from the very heterogeneous scattered radiation special condenser ionisation chambers were developed which enable the dosimetry over a dose range of 8 orders of magnitude.

The results of the measurements and the relationships involved are graphically presented.

176 Oral presentation. Radiological protection in the Central Electricity Generating Board. J. A. BONNELL and G. C. DALE, CEGB Nuclear Health and Safety Department, London (UK).

The CEGB is a statutory corporation established by the Electricity Acts of 1947 and 1957 with the objective of producing electricity economically and safely in England and Wales. As part of its electricity generating capacity it owns and operates 16 nuclear power reactors with a total installed electrical capacity of 3400 MW.

The Board's policies are implemented executive through five regions, and in addition advice and guidance on specialist matters are provided by a number of Headquarters departments.

The Nuclear Health and Safety Department has a Chief Officer responsible directly to the Deputy Chairman. He is responsible for the provision of specialist advice to the Board and to its various departments and regions on all matters relating to

nuclear health and safety, and for an advisory, inspecting and approving service in relation to the standards of radiological protection at nuclear licensed sites.

Technical co-ordination is necessary with the various government departments which have a statutory responsibility for radiological health and safety, and who may impose various conditions pertaining to radiological protection. Safety rules applicable to all employees are formulated with the Board and plans are prepared to be used in emergency for the protection of members of the general public living in the vicinity of nuclear sites.

Standards of medical care and supervision throughout the industry are specified and Local Liaison Committees are established at each site in order to inform the representatives of the local population about the power stations and about the plans drawn up for its protection in the event of an emergency.

This paper describes the various aspects of the CEBG's radiological protection policy and how it has been implemented. Operational experience and unexpected problems encountered over the past eight years are discussed.

177 Oral presentation. Health physics experience during the build-up and subsequent removal of activated corrosion products from the Winfrith SGHW Reactor. J. J. CLIFTON, AEE, Winfrith (UK).

Work involving plant modifications and maintenance inside the primary containment of water reactors during shut-downs is often complicated by the presence inside the primary circuit of activated corrosion products (crud). This material, which consists primarily of finely divided iron oxide, containing a number of radionuclides such as ^{58}Co , ^{60}Co , ^{59}Fe , ^{51}Cr and ^{65}Zn , deposits inside coolant pipes, steam drums, pumps and other circuit components. It presents problems when it is necessary to break into the circuit, but more important, the gamma dose rates throughout the area are high enough to require careful control of working times during entry into the containment during shut down.

Health physics problems arising from the build-up of crud in the Winfrith SGHWR, mainly as a result of mal-functioning of the water purification plant during the first months of reactor operation, are discussed. Radiation fields increased during the first 18 months of operation, and dose rates were such as to limit severely working times in certain localities during shut-down periods. The measures taken to control radiation exposure are described.

During a major shut-down after 18 months of operation it was decided to replace some experimental pressure tubes and to decontaminate half of the primary circuit. The health physics aspects of these operations which were very successful are described.

Review of Operational Experience

Rapporteur Presentation

178 An organic cooled reactor and its environment.

J. L. WEEKS, Medical Division, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba (Canada).

The operation of a nuclear reactor imposes certain stresses upon an environment as a whole, and upon the working environment in particular. Such stresses have been studied for many types of reactor, but the organic cooled reactor has so far received little public attention.

The reliability of this reactor system has been demonstrated during a four year operating period. Experience gained during this period in relation to radiation exposure, safety, toxicity of the coolant and the effects of the reactor upon the environment is considered in the paper.

179 Operational experience in heavy water power reactors.

R. WILSON, G. B. KNIGHT and G. A. VIVIAN, Ontario Hydro, Toronto (Canada).

Ontario Hydro has made considerable investment in the CANDU-PHW type of reactor for its growing power requirements. At the moment the committed capacity is in excess of 500 MWe in four stations: NPD, Douglas Point, Pickering and Bruce G.S. NPD and Douglas Point have both been in service for some years, Pickering is under construction and Bruce is in its early design stages.

A brief description of a typical CANDU-PHW is given and of the organizational responsibilities for radiation safety within the company. The program relies heavily on training of individual workers rather than having a separate group of radiation monitors or surveyors.

Radiation doses at both operating stations are reviewed and the program for tritium dose estimation is outlined. Information is given on the airborne contamination level and radiation field levels experienced in working areas for both plants and the system activities associated with the latter are described. Data are presented on the quantities of radionuclides released via the station effluents to the environment and the quantities of radioactive waste produced on the stations.

Some specific problems associated with protective equipment, tritium monitoring and unusual radiological conditions are discussed.

Finally consideration is given to methods of improving radiation protection in the reactors and reducing future radiation doses.

180 Evaluation of personnel exposures in a reactor-fuel recycle facility. E. M. COOK, Argonne National Laboratory, Idaho Facilities, Idaho Falls (USA).

The Fuel Cycle Facility (FCF), associated with Argonne National Laboratory's Experimental Breeder Reactor No. 2 (EBR-II), has had remotely refabricated and pyrochemically refined EBR-II fuel assemblies since 1965. The external radiation exposures received by personnel working in the FCF have been evaluated for the period 1966-1969. Average work-group exposures, total personnel exposure for specific jobs, and percentages of yearly exposures received on primary job assignments are included in the evaluation.

The experimental nature of this reactor-fuel recycle complex made it imperative that the flow of fuel through the FCF be maintained and, therefore, the downtime of failed equipment minimized. This was accomplished by repairing the failed remote-operations equipment manually outside the hot cells, not remotely inside as had been intended. The repair of this equipment, which is highly contaminated with fission products, provided most of the personnel exposure in the FCF. Most of the FCF personnel, except the repair-group personnel, received only a small fraction of their yearly exposures on their primary jobs, the remainder coming from equipment-repair operations. The health physics exposure control procedures devised, successfully allowed the rapid repair of the equipment without personnel exposures exceeding allowable limits.

Personnel not normally employed in FCF operations were used in the equipment-repair operations and are also included in the FCF personnel-exposure evaluation.

181 Radiation protection experience during the commissioning of the Tarapur Atomic Power Station. P. ABRAHAM and D. PATTANAIK, Health Physics Division, Bhabha Atomic Research Centre, Bombay (India).

This paper describes the experiences and problems in radiation protection during the commissioning and operation of the 380 MWe twin-reactor Tarapur Station (BWR type).

The results of the personnel monitoring programme are presented, briefly mentioning incidents which led to significant personnel radiation exposures. Safety aspects of the special operations undertaken, such as entry into the reactor vessels for maintenance work, are detailed. An incident leading to the internal exposure of a few maintenance personnel is described.

Radiation and contamination status obtained in the different areas of the station are given. A study of airborne radioactivity in the Station areas and the stack exhaust is presented.

Reactor water analysis results are summarised. Details regarding the effluent monitoring and area monitoring programme are given and results are discussed in relation to the relevant limits.

182 The occupational exposures to ionizing radiation in Czechoslovakia. J. CHYSKY, Research Institute for Radiation Hygiene, Prague and J. TROUSIL, Institute for Research, Production and Application of Radioisotopes, Prague (Czechoslovakia).

The personal exposure measurements of persons working in Czechoslovak industrial, medical and research institutions are carried out by the National Film Dosimetry Service of the Institute for Research, Production and Application of Radioisotopes in Prague. The exposures are very low in average. During 1964, 1965 and 1966 the annual exposures did not exceed 500 mR at 82%, 84% and 84% of monitored persons respectively. Only several exposures were higher than 5 R.

The results of 1966 indicated that the part of low exposures in the group of industrial institutions is smaller than in medical ones, and this part in medical institutions is again smaller than in research ones. The differences are significant as proved by the Smirnov-Kolmogorov test.

The highest exposures were found among persons employed in gamma-graphy and in medical applications of radium. The exposures of men were higher than those of women in all professional groups. The annual personal exposure decreased in general with increasing qualification of monitored persons and with increasing number of employers at the respective working place. No correlation was found between exposure and length of employment, but exposures of older persons are in average higher than those of youngsters.

During 1966 only 281 monthly exposures exceeded 400 mR and were investigated by the National Hygiene Service. The results of investigation are discussed as well as the results of the annual exposure statistics.

183 Radiation doses received by workers using tritium in industry. B. E. LAMBERT and J. VENNART. Radiological Protection Service, Belmont, Surrey (UK).

In recent years tritium has found more and more commercial use particularly in the luminising industry. Experience over the past 7 yr at the RPS has shown that environmental control alone has not prevented the intake of tritium by workers and the situation has been aggravated by difficulties in implementing advice on the design of good working conditions. Radiological control has, therefore, necessitated frequent biological monitoring of workers for tritium in urine. The results of this monitoring are presented and show that the radiation doses received by some workers are not inconsiderable but can be reduced by improving the working conditions.

The accuracy of estimates of dose depends on the interval between successive samples of urine and the uncertainty concerning the half-period of tritium in the body. Practical cases will be discussed with reference to these parameters. For meaningful estimations of dose under conditions of chronic intake of significant activities of tritium it can be concluded that monitoring must be done at intervals which are unlikely to be considered practicable by the industry. The alternative is to organise the working conditions so that intake of significant activities is unlikely and biological monitoring is then used solely as a check that these good conditions are maintained in practice.

184 Impact of tritium on the watch industry, F. J. BRADLEY, R. BLAIS and A. JONES, New York State Department of Labor, Division of Industrial Hygiene, New York (USA).

Tritium has replaced radium as an activator on self-luminous watches. The great advantage of tritium over other radionuclides in such applications is its low radiotoxicity. This, however, is partially offset by its great propensity for migration. There are five areas or stages of potential large-scale contamination arising in the watch industry. These are to be found at the manufacturing, assemblage, storage, repair and refinishing stages. The manufacturing stage has been studied and reported elsewhere by others and we have studied the storage area problem and reported on it. This study pertains to the assemblage, repair and refinishing stages. The removable surface activity, air activity and tritium activity in urine of workers are being studied in 3 firms over a 12 month period in order to establish new guidelines for radiation safety in such installations. The refinishing industry is just beginning to encounter

tritium since self-luminous watches with tritium are now being returned for surface refinishing, which involves the stripping of the surface paint off the dial by a caustic solution in which the tritium concentrates.

185 University health physics—Its aims and agonies. J. C. COLLINS, University of Manchester Radiological Protection Service (UK).

The unique problem for the university health physicist is to weave his influence into a mesh of academic freedom. He himself may be caught in the process and possibly strangled; he will certainly trip a few times. Success will come to the man with persistence, a keen sense of timing and a measure of luck.

In general, university work must be organised so as to contribute very little to the genetically significant dose of the whole population. Larger numbers of people are at risk and gonadal doses must be minimal. The chronic occupational risks of leukaemia and life-shortening may be estimated to within an order of magnitude or so; their control is by technical administration and instruction in procedures. In X-ray research laboratories the risk of acute foetal damage in women in early pregnancy either must be accepted or the women concerned must work elsewhere. Much of the control of open sources is more for the protection of the experimenter than the experimenter. Levels are generally low, but space is short and cross-contamination is a serious risk.

Most of the radiation workers are initially inexperienced and students are not subject to the usual employment disciplines. In the university environment responsibility for working areas is often diffuse and legal action might result in the witness box becoming crowded with defendants from many parts of the campus. Standards of occupational radiological protection are available but, for their successful application, their need must be understood and the recommended procedures must be adopted.

186 Health physics experience in the use of a ^{252}Cf neutron source in a university. R. L. ZIMMERMAN, Georgia Institute of Technology, Atlanta (USA).

The US Atomic Energy Commission has agreed to loan to the Georgia Institute of Technology approximately 100 μg of ^{252}Cf for evaluation of its use as a source of neutrons for research and instructional purposes. It is anticipated that californium will have widespread application in the future as a replacement for presently used sources such as Pu-Be, Sb-Be, and Po-Be. In some cases californium

may be used in place of small training reactors. A 100 μg source has an output of about 2×10^8 neutrons per second. In the course of the demonstration, the Office of Radiological Safety has developed a radiation safety program to facilitate most efficient use of the source. A source holder was designed to serve three functions: (1) to provide sufficient shielding; (2) to be reasonably portable; and (3) to allow access to the neutrons for use in many experiments and thereby eliminate much of the need for secondary source holders. Instruments which have proven useful in research and teaching applications as well as for radiation safety are described. Problems related to sealed-source leak testing and neutron activation of materials are considered. The health physics program which is described is intended to serve as a model for schools which have not established a formal radiation safety program but are considering the use of a californium neutron source.

187 AURPO survey of safety devices on X-ray crystallography/diffraction sets. RABETTE E. STERN, Radiation Unit, University of Surrey, Guildford (UK).

It is often necessary for a user to design and fix safety devices on X-ray crystallography and diffraction sets. To do this on a "one-off" basis is an uneconomic and sometimes unsatisfactory way of ensuring that these sets are safe to use and that they comply with relevant codes of practice and legislation.

Manufacturers standards of safety design are improving and this survey was undertaken by the Association of University Radiation Protection Officers to assess the present situation.

The results of the survey are reported.

188 Characteristics of radioactive aerosols released by cutting of irradiated fuels. H. YAMAMOTO, H. MATSUI, Y. YOSHIDA and M. KOKURU, Division of Health Physics and Safety, Japan Atomic Energy Research Institute, Tokai-mura (Japan).

Metallurgical tests on irradiated natural uranium fuels of the JAPCO's Tokai Reactor were carried out at the Hot Laboratory, JAERI. During cutting the fuels, airborne fission products in the fuel were dispersed in the cave and were discharged to the exhaust system.

The concentration of airborne fission products in the cave, in the exhaust ducts and in the stack were assessed by the air sampling. The size distribution of airborne particles was also measured using a beta autoradiography.

Collection efficiency of typical airborne fission products for three types of sampling medium, that is, cellulose asbestos filter paper (He-40), charcoal-loaded filter paper (CP-20B) and charcoal cartridge, and also the dispersion factor during cutting in the cave and removal efficiency of the exhaust air filtering system for fission products were obtained. Dispersion factor was $10^{-5} \sim 10^{-3}$ depending on the volatility. Removal efficiency of the exhaust air filtering system was found to be 80% for ^{131}I and 97% even for particulate fission products. The count median diameter of particulate fission products collected on the filter paper was measured to be 2.4 μ .

Problems in estimating the concentration of airborne fission products and in determining the size distribution of radioactive aerosols are also discussed.

189 Oberflächendekontamination mit Hilfe einer Tonsuspension. E. WANDERER, Institut für Strahlenschutz, Reaktorzentrum, Seibersdorf (IAEA).

Das im Untergrund des Reaktorzentrums Seibersdorf anstehende pliozäne Tongestein enthält die ionenaustauschenden Tonminerale Montmorillonit, Illit und Chlorit. Als Suspension auf kontaminierte Oberflächen aufgebracht und eintrocknen gelassen, kann es zur Dekontamination verstrahlter Stellen herangezogen werden.

Dabei werden zweiwertige Radioisotope wie ^{60}Co , ^{90}Sr , U-Spaltprodukte u.a. vernehmlich in das Montmorillonitgitter eingebaut. ^{137}Cs wird irreversibel an Illitpartikeln gebunden. Chlorit kann zwei- und dreiwertige Radioisotope binden.

Die Versuche wurden an verschiedenen Laboroberflächen durchgeführt. Je nach Einwirkungszeit und Art der Kontamination konnten bis über 99% der Aktivität wieder entfernt werden.

Decontamination of surfaces with the help of a clay suspension.

In the subsoil of the Seibersdorf Reactor Centre, there are naturally occurring pliocene clays, the ion exchange clay minerals Montmorillonite, Illite and Chlorite. When applied as a suspension to the contaminated surface and dried, it appeared to assist the decontamination.

Thus bivalent radioisotopes like ^{60}Co , ^{90}Sr , U-fission products were incorporated into the Montmorillonite crystal. ^{137}Cs became irreversibly bound onto Illite particles. Chlorite can bind bivalent and trivalent radioisotopes.

The studies included different laboratory surfaces. With every situation and type of contamination, more than 99% of the activity could be removed.

RADIOECOLOGY II

190 Oral presentation. Inhalation hazard for the population near a contaminated area. S. SALVADOR and E. IRANZO, División de Medicina y Protección, Junta de Energía Nuclear, Madrid (Spain).

The effect of meteorology and farming on the airborne radioactivity within an area with a low soil ^{239}Pu and ^{235}U contamination has been studied using continuously four air monitoring stations. Sampling periods of 24 hr have been taken.

Each sample is studied for long-lived gross alpha contamination and in particular for ^{239}Pu and ^{235}U .

Groups of samples corresponding to periods of 10 days ($\sim 100\text{ m}^3$) are processed using a technique which includes ion-exchange, electrodeposition and alpha spectrometry to evaluate ^{239}Pu contents.

Uranium-235 concentration is determined from the BM nitric solution coming from the ion-exchange resin where plutonium and thorium are fixed, using electrodeposition and solid state alpha spectrometry.

Results show the occurrence of these elements in most of the samples, although the concentrations are far below the MPC in air. Wind velocity and humidity have a great effect on the resulting concentrations.

191 Oral presentation. Radioecological investigations after the B-52 crash in 1968 at Thule, Greenland. A. AARKROG, Health Physics Department, Research Establishment Risø (Denmark).

On January 21, 1968, a B-52 crashed on the ice in Bylot Sound at Thule. By the impact with the ice plutonium from four unarmed nuclear weapons was released to the environment.

In July-August, when the ice had broken up in Bylot Sound, samples of seawater, bottom sediments, seaweed, plankton, crustacea, bivalves, bottom animals, fish, seabirds, seals and walrus were collected and analysed for ^{239}Pu . The results of these analyses will be presented.

192 Oral presentation. Levels of environmental radioactivity in Bikini Atoll. T. F. McCRAW, Division of Operational Safety, US Atomic Energy Commission, Washington D.C. (USA).

A team of experts from the United States Atomic Energy Commission and its contractors, Trust Territory of the Pacific Islands, and the United

States Naval Radiological Defense Laboratory was sent to Bikini Atoll in April-May 1967 to resurvey the islands and to collect data for use in a determination of whether or not the Bikini people might be returned to their homeland. This survey was made at the request of the Secretary of Interior whose department is responsible for the welfare of the Bikini people. The 1967 visit headed by Dr. Edward Held, University of Washington, Seattle, Washington, and sponsored by the Division of Biology and Medicine (DBM) of the US Atomic Energy Commission, was directed primarily toward determining the exposure rates due to external gamma radiation on some fourteen islands and two island complexes. Collections were also made of land and marine plants and animals. An *ad hoc* Committee established by DBM reviewed the survey results. The Committee concluded that exposures to radiation that would result from the repatriation of the Bikini people do not offer a significant threat to their health and safety. The Committee recommended several measures that would reduce exposures. This repatriation consists of removal of scrap material from all the islands of the atoll, clearing of scrub vegetation and replanting coconut trees and other food crops on Bikini and Enyu islands, and building of homes and other facilities on these two islands. The first two of these measures, namely scrap removal and clearing scrub vegetation, have been completed. The next, replanting coconut trees, began with the arrival on Bikini of 18,000 seed coconuts in August and establishment of a nursery for growing seedlings. This rehabilitation program is being carried out through a cooperative effort by the Department of Defense, Department of Interior, and the AEC.

193 Oral presentation. The radiation dose received by plaice in the north-east Irish Sea. D. S. WOODHEAD, MAFF Fisheries Radiobiological Laboratory, Lowestoft (UK).

A large proportion of the radioactive waste discharged into the north-east Irish Sea from the Windscale factory is reconcentrated on to the seabed silt and sediment in the vicinity of the outfall. This results in an extensive environment in which benthic organisms can receive a radiation dose significantly greater than that from the natural background. Calculations based on seabed radioactivity measurements made during routine environmental monitoring surveys indicate that the dose rate to the plaice (*Pleuronectes platessa*), a commercially important species in the area, can range up to 5 mrad hr^{-1} from beta and gamma radiation.

The results of *in situ* measurements made with

lithium fluoride dosimeters which can be combined with the "Petersen disc" tag normally used for marking plaice in population surveys are presented. A total of 3600 fish have been tagged with the combined Petersen disc-radiation dosimeter and released in the vicinity of the Windscale outfall; 2500 in June 1967 and 1100 in April 1968. Recaptures to October 1969 approach 25% and the measured dose rates show substantial agreement with the calculated values.

194 Oral presentation. Transfert et incorporation du tritium dans les constituants de l'herbe et du lait, en conditions naturelles. R. KIRCHMANN, Centre d'Etudes de l'Energie Nucléaire, Mol, J. VAN DEN HOEK, Laboratorium voor Fysiologie der Dieren, Wageningen and A. LAFONTAINE, Institut d'Hygiène et d'Epidémiologie, Bruxelles (Belgium/Netherlands).

Le tritium suscite un intérêt croissant en raison de son importance potentielle comme contaminant radioactif du milieu, liée au développement de l'industrie nucléaire.

Des expériences de contamination volontaire de prairies, par dépôt d'eau tritiée, ont permis de calculer le taux d'incorporation du tritium dans l'herbe et de suivre l'évolution de la contamination après dépôt à différentes saisons. Le taux et la vitesse de transfert ainsi que la répartition du tritium dans le lait produit par des vaches consommant de l'herbe contaminée ont aussi été déterminés; ces données sont comparées à celles obtenues dans le cas de la contamination du lait résultant de l'ingestion répétée d'eau tritiée: il apparaît que l'incorporation relative du tritium dans la matière organique du lait est de 2 à 3 fois plus élevée dans le cas de consommation d'herbe contaminée que dans celui d'eau d'abreuvement contaminée.

Les résultats indiquent un transfert très rapide dans le cas d'ingestion d'eau contaminée, alors que dans le cas d'ingestion d'herbe contaminée le niveau maximum de contamination a été observé au quatrième jour.

Transfer and incorporation of tritium in the constituents of grass and milk in a natural environment.

There is an increasing interest in tritium because of its potential importance as a radioactive environmental contaminant associated with the development of nuclear industry.

Deliberate experimental contamination of grazing land by the deposition of tritiated water has made it possible to calculate the level of incorporation

of tritium into the grass and to follow the pattern of contamination after deposition at different seasons. It was also possible to determine the level and rate of transfer and thence the distribution of tritium in the milk produced by cows eating the contaminated grass. These data are compared with those obtained for the contamination of milk resulting from the repeated ingestion of tritiated water. It appears that the tritium in the organic material is from 2 to 3 times higher in the case of cows fed with contaminated grass than for cows drinking tritiated water.

The results show a very rapid transfer in the case of the intake of contaminated water while, in the case of ingestion of grass, the maximum level of contamination was found on the 4th day.

POPULATION EXPOSURE II

195 Oral presentation. Body burden of ^{137}Cs and the radiation dose of a population group in Finnish Lapland. T. RAHOLA and J. K. MIETTINEN, Department of Radiochemistry, University of Helsinki (Finland).

Higher radionuclide contents in the biota of Lapland than in that of southern Finland and other non-arctic areas have been observed, despite the obviously lower fallout deposition in Lapland. Since 1961 the ^{137}Cs body burden of Finnish Lapps has been estimated by using a mobile wholebody counter. These measurements have been performed every spring but only two times also in the autumn, in 1962 and 1969. A change of seasonal variation is now noticed and reported in this paper.

The average maximum whole-body burden of the highest exposed group of male reindeer herders was found in the year of maximum values, 1965, to be 1.5 μCi , while the highest individual value was about 3 μCi . In the spring 1969 the corresponding values were 0.6 μCi and 1.1 μCi , in September 1969 0.5 μCi and 0.8 μCi . The autumn value of the male reindeer herder group was now 84% of the spring value while it was in 1962 61%.

The annual radiation dose of reindeer herders from ^{137}Cs will be in 1969 about 60 mrem/yr. The integrated dose to the present generation of reindeer herders (1955-1985) is estimated to be about 1 rem/30 yr, if no changes in the fallout situation will take place. The dose from other artificial fallout nuclides will be much smaller than this. For southern Finns the dose from ^{137}Cs is estimated to be 0.025 rem/30 yr. An estimate of the total radiation dose to be delivered to the Lapps between 1955-1985 is given, too. The dose commitment to this population from the natural radionuclide ^{210}Po is also exceptionally high, of the order of 3 rem/30 yr.

It can be noticed that the contribution of the natural radiation sources to the total dose of the present generation will be significantly greater than reindeer breeders.

196 Oral presentation. The assessment of dose commitment for the populations of subarctic regions of the USSR from global ^{137}Cs . A. P. USHAKOVA, I. A. LIKHAREV and P. V. RAMZAEV, Institute of Radiation Hygiene, Leningrad; and A. A. MOISEEV, Central Institute of Post-graduate Medical Studies, Moscow (USSR).

The authors present the assessment of dose commitment for the various national groups of the Far North of the USSR from incorporated global ^{137}Cs .

The calculations were based on *in vivo* measurements of ^{137}Cs burdens in the selected subjects from these groups and demographic data about structures and natural movements of the native populations.

197 Read in title. Environmental γ -radiation dose rate in Finnish Lapland and Southern Finland. T. JAAKKOLA and P. KAURANEN, Department of Radiochemistry, University of Helsinki (Finland).

To make possible the calculation of the total radiation dose from artificial radionuclides and background radiation to the Lapps, measurements were carried out in Finland with an ionization chamber and a battery operated γ -spectrometer equipped with a 5 in. \times 3 in. NaI-detector.

The contribution from the cosmic radiation was determined by performing measurements on two fresh water lakes. The cosmic ray response of the ionization chamber was subtracted from the values obtained at different locations.

The average environmental γ -radiation dose in three communes in Finnish Lapland (Enontekiö, Inari and Utsjoki) was found to be 49, 40 and 21 mrad/yr, respectively. The corresponding value in southern Finland was on the average 83 mrad/yr.

The environmental γ -radiation dose rate was about 10-20% smaller inside the Lapp's houses than outside. The houses were single-storied of wooden construction.

In the γ -spectrometric measurements it was found that the ^{40}K activity was more dominating in Lapland than in southern Finland. The ratio of ^{40}K to ^{232}Th was in Lapland 9.1 and in southern Finland 5.9 on average. The ^{40}K and the ^{232}Th activities were 1.6 and 2.5 times higher in southern Finland than in Lapland. These results were in agreement with those obtained with the ionization chamber. The photo-peak of ^{137}Cs could be observed in a few γ -spectra from Lapland.

198 Oral presentation. On the radiation exposure following ingestion of ^{222}Rn rich water. M. SUOMELA and H. KAHLOS, Institute of Radiation Physics, Helsinki (Finland).

The whole-body counter has been used to determine the elimination rate of ^{222}Rn and its daughters in order to assess the radiation exposure of persons who have ingested radon rich water. The determination of ^{222}Rn is based on the measurement of its gamma-emitter daughter product ^{214}Bi .

Two series of experiments were performed. In the first series the elimination was followed in subjects who had ingested 50-170 nCi ^{222}Rn as a single intake. The elimination rate can best be described by a model of one exponential component. The mean effective half-life of 50 min for radon and its daughters in the body was evaluated with the aid of the elimination rate of ^{214}Bi .

In the second series a group of 14 persons was measured who have daily, for 2 to 7 hr, used radon rich water. Each subject was investigated twice within a few hours meantime in order to detect the radon content in the body. The greatest radon content was 12 nCi in a subject who used water containing 283 nCi ^{222}Rn /litre.

199 Read in title. Measurement of atmospheric radon in and out of doors. B. L. DAVIES and JEAN FORWARD, Radiological Protection Service, Belmont, Surrey (UK).

Measurements of radon concentrations in air out-of-doors together with measurements of some meteorological variables have been made at the Radiological Protection Service, Belmont, Surrey for a number of years. The radon concentrations are fairly well correlated with atmospheric stability and show a lesser correlation with rainfall and humidity. The measured concentrations range from the limit of detection of the method, 10 fCi/l. to 430 fCi/l.

Measurements of radon concentration indoors have been made in five different houses during the evening at weekly intervals for several weeks. The measured concentrations range from the limit of detection 10 fCi/l. to 1.5 pCi/l. In a second series, measurements were made in one house at 30 min intervals for 8 days using an automatic device. In this case the radon concentration, in general, increased during the night, with the indoor concentration rising to a very much greater extent than that of the atmosphere outside. The results are discussed in terms of the exposure of the population to radon and the relation of this to currently recommended values of MPC_{air} for radon.

Oral (See 94)
200 Read in title. The measurement of tritium in the rainwater in Japan. Y. NISHIWAKI, Tokyo Institute of Technology, H. KAWAI, Y. HONDA, H. MORISHIMA, Y. KIMURA and T. KOGA, Atomic Energy Research Institute, Kinki University (Japan).

The results of measurement of tritium in the rain water in Osaka (Japan) for the period from 1965 to 1968 are given in the paper as compared with the data for ^{90}Sr and ^{137}Cs in the same sample. For the purpose of reference, some of the data observed near Tokyo are given. The rain water sample collected every month to be assayed was first distilled and electrolyzed four times to enrich the tritium concentration several hundred-fold. The beta activities of the enriched samples were measured with a liquid scintillation counter. The enrichment factor of tritium for each sample was estimated from the deuterium concentration in the same water sample before and after the electrolysis.

The measured tritium concentration in the samples indicated a seasonal variation; highest in spring and lowest in autumn as reported for other parts of the world. The peak value, however, decreased from the maximum in the years 1963 and 1964 (about 1500 TU) to the value under 200 TU in 1967 and 1968.

^{90}Sr and ^{137}Cs concentration in the same rain water sample as used for tritium measurement indicated also a similar seasonal variation. However, the peak value for ^{90}Sr and that for ^{137}Cs in May, 1963 were observed to be 19.7 pCi/l. and 32.8 pCi/l. respectively, while in April, 1968 1.1 pCi/l. and 0.9 pCi/l. respectively. The decrease rates of peaks for ^{90}Sr and ^{137}Cs were a little larger than that for tritium. The tritium peaks were observed to appear one or two months after ^{90}Sr and ^{137}Cs peaks. These results seem to suggest that some correlation may exist between tritium, ^{90}Sr and ^{137}Cs fallouts.

201 Read in title. Activities of the Medical Internal Radiation Dose Committee (MIRD). E. M. SMITH and R. H. ROHRER, Medical Internal Radiation Dose Committee, Society of Nuclear Medicine (USA).

The MIRD committee of the Society of Nuclear Medicine was formed in 1964 to serve the increasing needs of the nuclear medical community with the best estimates of the absorbed dose to patients who are administered radiopharmaceuticals. In order to achieve this goal, the committee proposed to develop, collect and critically evaluate information in the following areas: (1) Formulae, units and symbols that are consistent for absorbed dose calculations by either manual or computer techniques. (2) Physical

and nuclear decay-scheme data needed as input for the formulae developed. (3) Metabolic data on the distribution and life-times of radiopharmaceuticals for the total body, specific organs, and sub-organ regions, as well as to consider the influence of the patients' age and clinical state on these variables. (4) Chemical, radiochemical and radionuclidic purity and stability and physical characteristics of radiopharmaceuticals when they are apt to affect the absorbed dose to the patient. (5) Accuracy of the calibration methods used for determining the activity of a radiopharmaceutical. (6) Anatomical and physiological data for patients of various ages and body types.

To date the committee has developed and promulgated the use of contemporary methods of computing absorbed dose based upon the absorbed fraction concept. The first three publications contain the recommended methods for calculating the absorbed dose, physical radionuclide data, and extensive tables of absorbed fractions. More recent publications are directed to the estimation of absorbed dose resulting from specific radiopharmaceuticals. The work of the MIRD Committee is open-ended and will continue as long as new radiopharmaceuticals are developed.

The work of the MIRD Committee is supported by the US Bureau of Radiological Health, Environmental Control Administration.

INSTRUMENTATION AND ANALYSIS

Discussion Group

202 K-fluorescence X-rays: A multi-use tool for health physics.* R. L. KATHREN, H. V. LARSON and W. L. NEFS, Pacific Northwest Laboratory, Richland, Washington (USA).

Therapeutic or industrial X-ray generators can be simply and effectively adapted to the production of K-fluorescence radiation by impinging the primary beam onto an appropriate secondary target. The technique of producing a secondary beam of large diameter with virtually any energy below 100 keV is described. Typical spectra show the beam to be composed almost exclusively of K characteristic radiation, with less than one percent of the total flux attributable to scattering or L fluorescence. Calibration is best accomplished with a free air ionization chamber, and dose rates ranging from a few mR/hr to tens of R/hr are available with most common

* This paper is based on work performed under United States Atomic Energy Commission Contract.

X-ray generators, thereby providing levels of interest in the health physics region. The essentially monoenergetic beams have proven extremely valuable for energy dependence studies of dosimeters and detectors of all types, providing a more intensive study of the response in the 8–100 keV_{EFF} region than is possible with conventional X-ray sources. Specific examples cited include a study of a number of available thermoluminescence dosimeters, as well as the evaluation of portable radiation monitoring instruments. Of particular interest is the use of a radiation with Z near 40, which provides a means of imitating the photon spectrum from ^{239}Pu without the necessity of using this highly toxic material. The potential application of this device to radiological standardization is also discussed.

203 Nuclear instrumentation standards: Practical aspects. R. T. HANKINS, Radiological Protection Service, Belmont, Surrey, England.

This paper is intended to detail both the advantages and disadvantages of implementing instrumentation for radiation measurements, conforming to the United States Atomic Energy Commission NIM standard T1D-20893 (Rev. 2). It is proposed to discuss why the ideal of complete interchangeability, rapidly assembled experimental systems, and the freedom to purchase from any manufacturer so as to be able to assemble a mixed system, is often frustrated by a profusion of non-standard plugs and sockets mounted on many rear panels of commercially available modules made to the NIM standard.

A further aim of the paper is to examine the degree of compatibility between the NIM standard and that of the European ESONE standard, CAMAC, and the possibility of incorporating a dataway system in a NIM bin that would be CAMAC compatible.

204 (Withdrawn)

205 Portable instrument for the continuous measurement of tritium surface contamination. H. v. BINSBERGEN, J. MERTON, A. MARTING and E. KOWALSKI, Landis & Gyr AG, Zug (Switzerland).

Tritium surface contamination is difficult to detect because of the low energy of the beta radiation of this isotope. A detector window of 1 mg/cm² itself absorbs about 99% of the beta radiation of the tritium spectrum.

A light, portable instrument will be described, having a windowless gas flow counter in the proportional range as the detector, which continuously measures the tritium surface contamination. The

battery-operated measuring electronics consists of a low-noise preamplifier, a single-channel discriminator, a count rate meter and a high voltage supply. Additional plug-in units extend the measuring possibilities of the instrument. The single-channel discriminator allows for selective tritium measurement, even in the presence of a high energy α - β mixture.

The possibilities of the equipment will be indicated and the measured results discussed.

206 A monitor design for airborne radioiodine. H. FLYGER, A. SØRENSEN and L. BØTTER-JENSEN, Health Physics Department, Research Establishment Riso (Denmark).

The monitoring system is designed for selective measurement of iodine and ^{131}I in the forms of elemental iodine and organic compounds of iodine with special reference to methyl iodide. A continuous air flow is filtered on a bed of impregnated carbon, and the activity in the bed is monitored continuously by a single-channel scintillometer. The output signal is displayed in a logarithmic scale and recorded for determination of the integrated quantity of ^{131}I accumulated in the filter during a certain time. A preset time counting is included for determination of short time mean concentrations of iodine. The importance of variable proportions of the activity associated with elemental iodine and methyl iodide on the output signal is evaluated, and a programme for calculation of the integrated quantity of iodine from the recorder curve is outlined. A discussion of sensitivity and degree of accuracy is included.

207 The assessment of the beta response of beta-gamma survey instruments. I. M. G. THOMPSON, R. G. SHIRTON and Miss J. GOODWIN, CEGR, Berkeley Nuclear Laboratories, Gloucestershire (UK).

In many health physics operations involving mixed beta and gamma radiation fields working procedures are limited by the dose delivered to the skin. A knowledge of the beta response of commercial beta gamma monitoring equipment is therefore vital in making assessments of skin dose. An extrapolation ionisation chamber has been used to measure the dose distribution above a number of beta emitting radionuclides. The beta response of instruments has then been determined from measurements made in these calibrated fields.

To relate these radiation fields characterized in terms of tissue dose to NPL primary standards in rads in air a further extrapolation chamber has been used.

208 The use of miniature electronics in radiation protection. A. R. JONES, Biology and Health Physics Division, Chalk River Nuclear Laboratories, Ontario (Canada).

Many electronic instruments used in radiation protection have requirements not often found elsewhere. They should be light, small, robust, cheap, reliable and operate from batteries for lengthy periods. Also, they should be easy to control, read and interpret.

The advances which have occurred in miniature electronics in the past decade have made this challenge easier to meet. The paper describes examples of such techniques which are now being used in instrument design:

- compact packaging of discrete components,
- digital monolithic circuits using bipolar transistors,
- digital monolithic circuits using field effect transistors,
- linear monolithic circuits which can be designed by the user,
- solid-state displays using light emitting diodes and digital circuits to control them,
- solid-state radiation detectors both with and without internal amplification.

The design and performance of three instruments based on these techniques are also described:

- a very high range gamma survey meter using a silicon junction detector as a solid-state ion chamber. The detector is used as a photo-voltaic device and the current generated is amplified by a miniature low power d.c. amplifier,
- a small alpha monitor using a silicon surface barrier detector and a monolithic pulse amplifier to amplify the pulses produced by the alpha particles,
- a gamma survey meter using an amplifying radiation detector to measure dose rates from 1 mrad/hr to 1000 rad/hr. The output is displayed in digital form by light emitting diodes and the digital circuits use field effect transistors with very small power needs.

209 New solution of input circuit for wide range portable exposure rate meter. M. ŠOBAJČIĆ, S. MUŽDEKA and R. BLAGOJEVIĆ, Boris Kidrič Institute of Nuclear Sciences, Vinča (Yugoslavia).

The paper describes a portable instrument for measuring the exposure rate of gamma radiation which provides linear indication in the range of 1 mR/hr to 1000 R/hr.

A new solution is suggested for a wide measuring range by means of two ionization chambers being permanently built in the instrument without a need to replace them as it is usually done with commercial instruments. The chambers of the volume 990 cm³ and 10 cm³ are air filled. Both chambers are parallelly connected by a special diode in the case of sensitive measuring ranges. In less sensitive ranges, the problems of high impedance input circuit relate to switching off one of the chambers are solved with short-circuiting the collector of the bigger chamber to ground by reed relay. In that case, low reverse current of the diode provides high input resistance from the amplifier input to the ground.

The current measurement is performed with an operational amplifier having high input resistance using insulated field-effect transistors in the input circuit. As feedback elements only two resistors of $3 \times 10^{11} \Omega$ and $3 \times 10^9 \Omega$ are used for six linear measuring ranges. The ranges are: 10 mR/hr, 100 mR/hr, 1 R/hr, 10 R/hr, 100 R/hr and 1000 R/hr.

210 Portable exposure rate meter for wide energy range using integrated circuits. J. HIZÓ and K. ZSDÁNSZKY, National Office of Measures, Budapest (Hungary).

The authors of the paper developed a portable exposure rate meter with which radiation protection measurement can be performed without correction within a wide energy range and even in places near the source of radiation. The detector used by this meter is a special ionization chamber the current of which is measured with the aid of an operational amplifier consisting of integrated circuits.

A new method of compensation has been developed and applied to eliminate the energy-dependence of the ionization chamber. The composition of the uncompensated chamber wall is almost air-equivalent and the thickness of the wall meets the requirement of electron equilibrium up to the energy of ⁶⁰Co. Therefore the sensitivity of this chamber decreases towards the low energy range. It is possible to imagine another chamber that would have a similar shape but a wall thickness being less than or at most equal to the range of secondary electrons at the lowest photon energy applied. If the atomic number of the wall material of this latter chamber exceeds that of the air, the chamber's sensitivity increases symmetrically with that mentioned above towards the low energy range. By selecting the material and the thickness of the thin-walled chamber's wall appropriately it is possible to render the sum of the ionization currents of the two chambers independent of energy. In practice the thin chamber wall may

be a film evaporated on the inside surface of the thick-walled chamber. It is proved that this "double wall" and such a method of compensation, respectively, result in a far better energy independence than any of the known ones.

211 Analysis of air, food and human tissues, for major, minor and trace elements. E. I. HAMILTON, MARGARET MINSKI and J. CLEARY, Radiological Protection Service, Belmont, Surrey (UK).

In radiological protection there has always been an interest in the distribution of elements in man, his diet and his environment since such data can yield information about the possible distribution of radionuclides following their entry into the body. Presently available data has been obtained on relatively few samples. Preliminary results are presented for the concentration of a large number of elements in human blood, bone, diet and air. Methods of sampling, preparation of materials for analysis and methods of analysis are discussed with particular reference to spark and thermal source mass spectrometry, X-ray fluorescence, and neutron activation analysis.

212 Multi-loaded metal salt(s)-ion exchange resins: their preparation and applications. K. WATARI and M. IZAWA, Chemistry Division, National Institute of Radiological Sciences, Chiba (Japan).

At the First International Congress of the International Radiation Protection Association (Rome, 1966), we reported the preparation of *metal salt-ion exchange resins* and their applications to radiochemical analysis. The resins possess both properties of the constituent metal salt and of the ion exchange resin.

As an extension of the study, one or more kinds of insoluble metal salts could be incorporated simultaneously in one ion exchange resin matrix, by utilizing the residual ion exchange capacity of the resin. We named the product *multi-loaded metal salt(s)-ion exchange resin*. Multi-loaded metal salt(s)-ion exchange resins can be classified into two categories: (a) multiloading single metal salt-ion exchange resin, which contains only one metal salt in an ion exchange resin, and (b) multi-loaded composite metal salts-ion exchange resin, which contains two or more different metal salts in a resin. Multi-loaded nickel ferrocyanide-IRA 904 and nickel ferrocyanide-calcium phosphate-IRA 904 are examples of the *resins* of categories (a) and (b), respectively. It was found that the adsorption ability of the former for cesium increased linearly with the number of multi-loaded treatment, and that

simultaneous adsorption of cesium and strontium was possible by using the latter.

This paper deals with the preparation of the *resins* and their applications in the fields of radiochemistry and health physics. Structure of the *resins* was also studied.

213 An automatic system for the estimation of tritium in urine. E. J. MARSH and N. A. TAYLOR, AWRE, Aldermaston (UK).

An automatic tritium in urine analyser has been developed to give improved reliability and to save manpower in the internal contamination monitoring programme at a large atomic research establishment. The system incorporates a continuous distillation of the urine sample stream and liquid scintillation counting of the distillate. The sensitivity of the system is dependent upon the background count rate of the coincidence counting head and is normally better than $1 \mu\text{Ci cm}^{-3}$ of urine. The standard deviation (excluding variance due to counting) is about 5% of the measured value and memory effects are not serious. The sampling rate is eight samples per hour and the instrument can be run continuously for more than 24 hr.

RELEASE OF ACTIVITY INTO THE ENVIRONMENT III

214 Invited paper. La protection sanitaire de l'environnement dans les pays industrialisés. P. RECHT, Commission des Communautés Européennes, Luxembourg.

Deux phénomènes principaux caractérisent actuellement le développement d'un grand nombre de pays. La concentration urbaine et une industrialisation rapide. Les conséquences sociales et sanitaires en sont importantes et, par certains côtés inquiétantes, du point de vue de la santé des individus et des collectivités.

Le milieu naturel et l'environnement social se transforment, parfois d'une façon irréversible. Une des préoccupations majeures des autorités publiques est actuellement d'organiser la sauvegarde des ressources naturelles et de mettre en oeuvre, contre la pollution présente et future de l'air, de l'eau, du sol et des denrées alimentaires, des actions réparatrices et préventives efficaces.

Les difficultés sont nombreuses car les causes sont multiples et la connaissance des effets biologiques est relativement lacunaire; la fixation des normes de protection du milieu est malaisée dans de nombreux cas.

La maîtrise obtenue dans les utilisations pacifiques de l'énergie nucléaire apporte la démonstration d'une unité de conception et d'actions remarquable par ses conséquences dans le domaine de la médecine et de l'hygiène industrielle et de la protection sanitaire.

L'expérience pourrait bénéficier à la lutte contre les autres nuisances du monde moderne.

The maintenance of environmental public health in industrialised countries.

Two principal phenomena are at present characteristic of the development of a large number of countries—urban concentration and rapid industrialisation. Their social consequences and effects on health are important, and in some ways disquieting, from the point of view of the health of both individuals and the community.

The natural environment and social conditions are being altered, sometimes irreversibly. One of the major concerns of public authorities at present is to ensure the preservation of natural resources and to implement effective remedial and preventive actions against the present and future pollution of air, water, soil and foodstuffs.

There are many difficulties because the causes are complex, and our knowledge of the biological effects is relatively incomplete. It is difficult to establish suitable standards for the protection of the environment in many cases.

The control achieved in the peaceful utilisation of nuclear energy provides a remarkable demonstration of the unity of conception and operations in the fields of medicine, industrial hygiene and health protection.

This experience could be of benefit in the fight against other detriments of the modern world.

215 Oral presentation. Nuisance du ^{85}Kr atmosphérique. R. PANNETIER, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

Le ^{85}Kr occupe d'ores et déjà la deuxième place parmi les agents de la radioactivité de l'air. En effet, les ordres de grandeur sont les suivants en pCi/m^3 d'air au niveau du sol: émanations des familles naturelles $\approx 10^5$, $^{85}\text{Kr} \approx 10^4$, $^{14}\text{CO}_2 \approx 10^3$, tous aérosols artificiels et cosmonucléides $\approx 10^2$.

À l'occasion d'une étude sur la répartition mondiale du ^{85}Kr , nous avons tenté de prévoir l'évolution future de sa concentration dans l'air. Dans quelques années le ^{85}Kr prendra la première place parmi les responsables de la radioactivité atmosphérique. Avant la fin du siècle, si on continue la pratique actuelle du rejet dans l'atmosphère de la quasi totalité du ^{85}Kr dans les usines de traitement de combustibles

irradiés, il engendrera, à lui seul, une dose engagée dans l'air supérieure à celle due à la totalité des explosions nucléaires effectuées jusqu'à ce jour.

D'un autre côté, il semble que la valeur de la CMA du ^{85}Kr , actuellement adoptée par la CIPR, soit trop restrictive d'un facteur au moins égal à 6. Mais le problème de l'élimination du ^{85}Kr n'en reste pas moins posé à plus ou moins longue échéance.

Parmi les possibilités d'élimination du ^{85}Kr on propose une solution qui présente, en outre, d'autres avantages du point de vue sanitaire et également économique.

Harm due to ^{85}Kr in the atmosphere.

Krypton-85 already occupies the second place among the radioactive materials in the air. In fact, the orders of magnitude in pCi/m^3 in the air at ground level have the following values: emanations from natural radioactive materials $\sim 10^5$; $^{85}\text{Kr} \sim 10^4$; $^{14}\text{CO}_2 \sim 10^3$; all artificial and natural particulate materials $\sim 10^2$.

During a study of the world-wide distribution of ^{85}Kr , we have attempted to predict the future trend of the ^{85}Kr concentration in air. In a few years, ^{85}Kr will take the first place among the radioactive materials in the atmosphere. If the current practice of discharging to atmosphere essentially all the ^{85}Kr from fuel reprocessing plant is continued, the dose commitment from this source alone will, before the end of the century, be greater than that from all the nuclear explosions which have taken place to date.

On the other hand, it appears that the maximum permissible concentration for ^{85}Kr currently adopted by ICRP is too restrictive by a factor of at least 6. But the problem of the discharge of ^{85}Kr does not become less real because it is more or less long term.

Among possible solutions for removing ^{85}Kr , one is proposed which, in addition, provides advantages from the point of view of both health and economy.

216 Oral presentation. La coordination des rejets aëriiformes radioactifs des différentes installations d'un centre nucléaire. P. CAGNETTI et L. FRITTELLI, CNEN, CSN Casaccia; et A. NARDI, CNEN, Divisione Protezione Sanitaria et Controlli, Rome (Italy).

Le rejet des déchets radioactifs aëriiformes de la part d'un centre moderne de recherches nucléaires implique la solution de nombreux problèmes, liés surtout aux différentes fonctions des installations existantes (réacteurs, installations de fabrication

ou de traitement d'éléments de combustible, etc.), aussi bien qu'aux informations démographiques, écologiques et météorologiques du milieu ambiant autour du centre.

Dans la présente étude on expose la formule de rejet des effluents aëriiformes adoptée au CEN de la "Casaccia", sur la base des recommandations de l'ICRP et des informations dérivées d'une "survey" approfondie du site et des caractéristiques particulières de chaque installation.

La formule ainsi calculée permet de coordonner les modalités de rejet des différentes installations, soit dans les conditions de routine, soit dans le cas d'opérations exceptionnelles programmées.

The co-ordination of the gaseous radioactive wastes from different installations of a nuclear centre.

The discharge of gaseous radioactive wastes from a modern nuclear research centre involves the solution of many problems associated particularly with the different functions of the installations (reactors, fuel element fabrication and treatment plants, etc.), as well as with the demographic, ecological and meteorological information concerning the environment of the centre.

The control formula for the discharge of gaseous effluents adopted at CEN, Casaccia, is discussed in the present study. It is based on ICRP recommendations and on information derived from a thorough survey of the site and of the special characteristics of each installation.

The formula calculated in this way allows co-ordination of the methods of discharge from the different installations, either in routine conditions or in the case of planned special operations.

217 Read in title. Experimental determination of the dispersion of airborne effluent in a complex topographic environment. D. VAN AS, R. C. SHORT and M. VAN DER WESTHUIZEN, Atomic Energy Board, Pretoria (South Africa).

A series of experiments were performed during different meteorological conditions to measure the dispersion of airborne effluent on the site of the South African Atomic Energy Board's nuclear reactor SAFARI 1. The site is surrounded by a complex pattern of hills and valleys. Aerosols of lanthanum and gold were released from a 70 m stack and air samples were collected on filter paper with portable pumps. Lanthanum and gold concentrations were determined by neutron activation of the filter paper samples. Concentration of 10^{-9} - 10^{-10} g/m³ could be measured.

Results are correlated with meteorological parameters of wind speed, wind direction and vertical temperature profile and are compared with theoretical dispersion data. Relationships between air concentration and deposited material were determined.

218 Read in title. Mise au point de méthodes et premiers résultats sur la diffusion atmosphérique à petites et moyennes distances auprès du CSN Casaccia. P. CAGNETTI, CSN, Casaccia (Italy).

L'étude expérimentale de la diffusion atmosphérique reste encore aujourd'hui d'actualité, surtout dans ces cas où les modèles à présent généralement acceptés ne sont pas applicables. La majorité des centre nucléaires italiens se trouve dans cette situation, et ceci à été un peu à la base de la décision prise en Italie de constituer un groupe qui s'occupe spécialement de ces problèmes.

L'auteur expose brièvement les résultats obtenus pendant cette première année d'activité à la suite d'expérimentations de diffusion à petites distances (≈ 100 m), au moyen de la photographie avec pose prolongée (2-4 min) du panache produit par de fumigènes: la méthode employée est celle proposée par Gifford, sur la base de la théorie de l'opacité de Roberts.

Dans le cas de distances jusqu'à quelques kilomètres on a préféré l'emploi de la fluoroscépie comme traceur, suivant l'expérience positive obtenue dans ce domaine par les français (Le Quinio, Doury, etc.) et les américains (Robinson, MacLeod, etc.). La deuxième partie de ce travail concerne la mise au point et les premiers résultats obtenus par cette méthode au CSN Casaccia.

Application of methods and first results of atmospheric diffusion at small and moderate distances around CSN, Casaccia.

The experimental study of atmospheric diffusion is still of current interest, especially in cases where the models generally accepted at present are not applicable. Most of the Italian nuclear centres are in this position and this is to some extent the reason for the Italian decision to set up a group specially concerned with these problems.

The author summarises the results obtained during the first year's work from experiments of diffusion at small distances (of the order of 100 m) using prolonged exposure photographs of the plumes produced by smoke. The method used is that proposed by Gifford, based on the theory of opacity due to Roberts.

Fluorecin is the preferred tracer for distances up to some kilometres, following the practical experience

obtained in this field by the French (Le Quinio, Doury, etc.) and the Americans (Robinson, MacLeod, etc.). The second part of the work concerns the application of the first results obtained by this method to CSN, Casaccia.

219 Read in title. Kriterien für die Emission radioaktiver Abluft aus Kernanlagen. K. J. VOGT, Kernforschungsanlage Jülich (Germany).

Es werden die Grundzüge einer Konzeption zur Diskussion gestellt, die eine Beurteilung der Zulässigkeit radioaktiver Abluftemissionen aus Kernanlagen gestattet. Bemessungsgrundlage zulässiger Aktivitätsfreisetzungen sind die in der Umgebung durch Inhalation kontaminierter Atemluft, Ingestion kontaminierter Nahrungsmittel sowie direkte Strahlung aus der Abluftfahne und von den auf dem Boden abgelagerten Aktivitäten bewirkten Strahlenbelastungen. Ausgehend von den im Normalbetrieb und bei Auslegungsunfällen als tragbar angesehenen Dosislimits und Unfallrichtwerten lassen sich die zulässigen Emissionen mit Hilfe der Ausbreitungsrechnung berechnen. Während bei kurzfristigen (z.B. unfallbedingten) Freisetzungen die aktuellen, bzw. für Planungszwecke die ungünstigsten Wetterbedingungen zugrunde zu legen sind, dürfen bei quasikontinuierlichen Ableitungen die Häufigkeitsverteilungen der meteorologischen Parameter berücksichtigt werden. Für die Ermittlung der in diesem Zusammenhang wesentlichen Diffusionskategorien wurden alternative Bestimmungssysteme entwickelt. Messungen der Ausbreitungsparameter mit Mehrkomponentenwindfahnen haben zu ersten Ergebnissen geführt und werden durch Tracerstudien ergänzt. Ziel dieser Untersuchungen ist eine Neuauflage des bereits vorliegenden Katalogs von Ausbreitungsnomogrammen, Parameter- und Isoplethendarstellungen unter Verwendung neuer, unter realistischen Bedingungen gemessener Ausbreitungsparameter.

Criteria for the emission of radioactive waste air from nuclear plants.

The basic elements of a conception are discussed, to permit a judgment on the admissibility of radioactive waste air from nuclear plants. Breathing of contaminated air in the surroundings, ingestion of contaminated foodstuffs, as well as direct radiation from the plume of waste air and the exposure to radiation from radioactive deposits on the ground, are the bases for assessing the permissible release of radioactivity. The permissible emissions can be estimated with the help of diffusion calculations from the dose limits and emergency reference levels regarded as tolerable in the normal course of events

and in accidents. While, with short-duration releases (e.g. accidents), the current or, for the purposes of planning, the most unfavourable weather conditions are to be taken as a basis, with quasi-continuous discharges the frequency distribution of the meteorological parameters should be borne in mind. For the detection of these diffusion categories which are important in this connection, alternative determination systems were developed. Measurement of diffusion parameters with multivariate weather vanes produced the first results and will be completed by tracer studies. The aim of this research is a new edition of the current catalogues of diffusion nomograms, parameters and isopleths, by applying new diffusion parameters measured under realistic conditions.

220 Read in title. Radiological consequences of accidental and operational releases of radioactivity. R. H. CLARKE, CEGB, Berkeley Nuclear Laboratories, Gloucestershire (UK).

The CEGB is constantly reviewing and updating information of potential value in the siting of nuclear reactors. In this paper, a method of obtaining personal doses in the vicinity of nuclear reactors is presented with an evaluation of risk to a population with a given distribution.

The method gives inhaled doses and γ doses from the composite fission product cloud at any point in space. This involves the calculation of the full fission product inventory in any reactor type under consideration with any given irradiation history. To evaluate the effluent composition, the best available data on release fractions and plate-out and filter efficiencies are used for the fuel involved in the incident. Using standard meteorological techniques, the effluent is dispersed to give concentrations at any point in space. The dose commitments to various organs and tissues are determined and used for a risk analysis coupled to a given population distribution.

A computer program has been written to perform the calculations, with an emphasis on speed of solution so that large survey problems can be solved extremely quickly on the IBM 360/75 computer.

221 Oral presentation. Estimation des risques de contamination interne de l'homme résultant de la pollution radioactive des eaux. R. BIRTEL and G. LACOURLY, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

Parmi les mécanismes de retour vers l'homme de la radioactivité qui parvient dans les systèmes hydrobiologiques du fait des retombées et des rejets d'effluents liquides, il semble que le plus important pour

l'irradiation de l'homme soit l'ingestion, par ce dernier, d'aliments contaminés d'origine aquatique.

L'objet de la présente communication est de proposer un modèle mathématique permettant:

- d'évaluer, en tenant compte des situations locales, la dose délivrée à l'homme du fait de l'ingestion,
- de fournir des éléments de prévision quant aux conséquences de nouvelles implantations nucléaires.

Un certain nombre de paramètres s'introduisent naturellement dans les calculs:

- quantités ingérées, Q
- facteurs écologiques de transfert, F
- facteurs physiologiques de transfert, f
- facteurs R , intégrant les différentes caractéristiques radiologiques et radiobiologiques d'un radioélément et permettant de transposer les données en termes d'énergie effective,
- niveaux de contamination des eaux, x .

La dose délivrée du fait de l'ingestion, D , s'exprime alors par:

$$D = \sum Q \cdot F \cdot f \cdot R \cdot x,$$

la somme Σ étant étendue aux divers aliments et radioéléments envisagés.

Ces conceptions théoriques débouchent sur des aspects concrets, en particulier:

- l'évaluation des doses en fonction de données locales,
- la détermination de conditions critiques,
- la prévision quant aux conséquences de nouvelles implantations et quant à l'évolution vers des situations critiques.

Estimation of the risk of internal contamination of man resulting from the radioactive pollution of waters.

Among the mechanisms by which radioactivity arising in hydrobiological systems from fallout and the discharge of liquid effluents return to man, the most important in terms of the irradiation of man is his ingestion of contaminated foods of aquatic origin.

The object of the present paper is to propose a mathematical model allowing:

- the evaluation of the dose delivered to man as a result of ingestion, taking account of local situations,
- providing material for forecasting the consequences of new nuclear installations.

A number of parameters are introduced in the calculations:

- the amount released, Q
- ecological transfer factors, F

—physiological transfer factors, f

—factors combining the different radiological and radiobiological characteristics of a radioelement and allowing data to be transformed in terms of effective energy, R

—the levels of contamination of the waters, x .

The dose delivered as a result of ingestion, D , is then expressed as:

$$D = \sum Q \cdot F \cdot f \cdot R \cdot x$$

the summation, Σ , being carried over the various foods and radioelements considered.

These theoretical considerations lead to some practical results, in particular:

- the evaluation of doses as a function of local data,
- the determination of critical conditions,
- the forecasting of the consequences of new installations and of the development towards critical situations.

222 (Withdrawn)

223 Read in title. Die Retention von Böden und Sedimenten in der Umgebung des Reaktorzentrum Seibersdorf gegenüber ^{235}U Spaltprodukten verschiedenen Alters. E. WANDERER, Institut für Strahlenschutz, Reaktorzentrum Seibersdorf (IAEA).

Um Grad und Art der Kontamination des Bodens im Umkreis des Reaktorzentrum, wie sie infolge eines Reaktorunfalles auftreten könnte, abschätzen zu können, wurden Filterversuche an verschiedenen Sedimenten und Bodenarten mit ^{235}U Spaltprodukten verschiedenen Alters durchgeführt.

Dabei konnte ein selektives Sorptionsverhalten der monomineralischen sowie polymikten Sedimente in Abhängigkeit von Porosität, Permeabilität sowie Mineralzusammensetzung für ^{235}U -Spaltproduktgemische verschiedener Zusammensetzung und Konzentration bestimmt werden.

Monomineralische Sanfilter aus

Quartz, Feldspat, Augit, Hornblende, Calcit, Aragonit, Bauxit und Zeolithen

wurden ebenso untersucht wie

Löss-Sand, Flußsand, polymikter Ton, alter Humus und Faulschlamm, wie sie im Flußbett des Vorfluters anzutreffen sind.

Die Ergebnisse wiesen für die im Reaktorzentrum anstehenden Sedimente, polymikter Feinschotter, pliozäner Ton, alter Humus, gute Sorptionseigenschaften aus.

Quartz, Feldspat sowie Augit und Hornblende zeigten bei gleichen Versuchsbedingungen eine wesentlich geringere Retention.

The retention of ^{235}U fission products of varying ages by soils and sediments in the vicinity of the Seibersdorf Reactor Centre.

Filtration studies have been carried out with various sediments and soils and with ^{235}U fission products of various ages, to allow evaluation of the level and kind of contamination of the soil in the Reactor Centre that might result from a reactor accident.

From these studies, it is possible to determine the selective absorption and retention of ^{235}U fission product mixtures of various compositions and concentrations by single and mixed minerals and sediments, as a function of porosity, permeability and mineral structure.

Single mineral filter beds of

quartz, felspar, augite, hornblende, calcite, aragonite, bauxite and zeolite

were studied, and also

Loess-sand, river sand, "polymikter" clay, aged humus and sapropel, such as occur in tidal river beds.

The results show good absorption properties for the sediments, "polymikter" fine gravel, pliocene clay and aged humus present in the Reactor Centre.

Quartz, felspar, as well as augite and hornblende, exhibit markedly less retention under almost identical experimental conditions.

224 Read in title. The uptake of ^{137}Cs , ^{89}Sr and ^{60}Co on the soil at the Boris Kidric Institute of Nuclear Sciences, Yugoslavia. L. KNEŽEVIĆ and O. M. JANKOVIĆ, Boris Kidrič Institute of Nuclear Sciences, Vinca (Yugoslavia).

The uptake of microconcentrations of Cs^+ , Sr^{2+} and Co^{2+} on the surface layer soil at Boris Kidrič Institute of Nuclear Sciences near Belgrade was examined on a laboratory scale under batch and dynamic conditions.

The data on the mineralogical composition of representative samples of soil were given. The main criteria for the degree of uptake (or sorption) of Cs^+ , Sr^{2+} and Co^{2+} were the distribution coefficients (K_d); the uptake was investigated in dependence on the pH of solution, initial concentration of a competing macrocomponent as Ca^{2+} and Na^+ ions and contact time. The uptake capacity of soil samples with respect to Na^+ and Ca^{2+} were determined.

METABOLISM IN MAN I

225 Oral presentation. Long-term evaluation of biological half-life of tritium. A. A. MOGHISSI and M. W. CARTER, Bureau of Radiological Health, Southwestern Radiological Health Laboratory, Las Vegas and R. LIEBERMAN, Southeastern Radiological Health Laboratory, Montgomery (USA).

The body burdens of two tritium luminous dial painters have been followed since January 1967. Urine collections began six to ten months after termination of work involving occupational exposure to tritium.

In both cases, an intermediate (T_i) and a long (T_l) half-life component could be observed. One individual exhibited a T_i of 24 days and a T_l of 990 days, whereas the second worker showed a T_i of 30 days and a T_l of 1175 days. A surprisingly high seasonal dependence of tritium body water concentration was observed in one case. This resulted in an increase of tritium concentration in body water in winter as compared to the previous summer.

The consequences of these findings are discussed.

226 Oral presentation. The percutaneous absorption of tritium from contaminated metal surfaces. J. D. EAKINS, W. P. HUTCHINSON and A. LALLY, Health Physics and Medical Division, AERE, Harwell (UK).

This paper describes experiments with volunteer subjects designed to determine the hazard due to handling metal surfaces contaminated with tritium both as tritium gas and tritiated water. Evidence is given for the presence of organically bound tritium in urine after exposure of the skin to tritium gas contaminated surfaces and the significance and chemical form of this organic tritium is discussed. Results are presented which indicate that the hazard due to percutaneous absorption is relatively small and maximum permissible levels for tritium surface contamination are suggested.

227 Oral presentation. A study of radiobiological data obtained from some individuals engaged in plutonium operations. F. A. WARD and R. HESP, Health and Safety Department, UKAEA Wind-scale Works, Sellafield (UK).

A number of cases involving the uptake of plutonium following inhalation or wound contamination are presented.

In the inhalation cases, the amount of plutonium in the chest in each case was determined by X-ray counting using proportional counters, and the amounts transferred to blood were estimated from urinary plutonium excretion. The "in-vivo" measurements showed different phases, and rates, of transfer from the chest for the various forms of plutonium involved in the intakes. Where a significant fraction of the intake was retained in the chest, the long-term retained fraction had a half-life of the order of 100 days. In some cases the urinary excretion data indicated a rapid direct transfer to blood, but in other cases evidence of a delayed transfer to blood, with a half-life of the order of 50 days was observed. A comparison is made between the "in-vivo" measurements and the uptake models indicated by the urinary excretion data.

Four cases are considered involving plutonium contaminated wounds, all the injuries being of a minor nature. Excision was performed in each case and a chelating agent administered by direct intravenous injection.

The amounts of plutonium alpha activity in the wounds were determined by X-ray counting and the amounts transferred to blood were assessed from plutonium excreted in urine.

Although the initial amounts of plutonium in the wounds varied considerably, the amounts of plutonium transferred to the blood were relatively constant.

228 Read in title. Excretion of plutonium following the inhalation of a plutonium-alkaline metal-oxide aerosol. W. N. SAXBY and N. A. TAYLOR, AWRE, Aldermaston (UK).

Two men, of markedly differing ages, stature and habits inhaled accidentally an aerosol of a finely dispersed plutonium-sodium-potassium-oxide complex. This paper describes the incident and discusses the aerosol involved. The excretion patterns found are described and functions which characterise them are derived. The intakes by the two persons were nearly the same and their excretion patterns are remarkably similar. The excretion patterns are compared with the data of Wright Langham and with case data for more conventional plutonium aerosols. The data for the 1st year shows that the daily urinary excretion rate is falling much more rapidly than it does in any other available cases. After the 1st year the excretion pattern tends to follow more closely the data of Wright Langham.

229 Oral presentation. Etude de cas de contamination par l'americium. L. JEANMAIRE et J. BALLADA, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

Deux personnes se sont contaminées avec ^{241}Am en ouvrant une ampoule scellée contenant le radioélément en solution.

L'évolution de la contamination a été étudiée au cours du temps par la méthode directe au moyen d'un détecteur en iodure de sodium et un analyseur multicanaux.

Parallèlement, l'excrétion a été mesurée dans les urines et les matières fécales.

On expose l'étude critique de ces deux méthodes de mesure.

Studies of a case of contamination by americium.

Two people became contaminated with ^{241}Am while opening a sealed ampoule containing the radioelement in solution.

The progress of the contamination as a function of time has been studied by the direct method, using a sodium iodide detector and a multi-channel analyser.

Preliminary measurements were also made of the excretion in urine and faeces.

A critical study is made of these two methods of measurement.

Oral (See 249)

230 Read in title. Uptake of radioactive lead following inhalation and injection. D. V. BOOKER, A. C. CHAMBERLAIN, D. NEWTON and A. N. B. STOTT, Health Physics and Medical Division, AERE, Harwell (UK).

Experiments have been made with human volunteers to determine the fate of ^{212}Pb (ThB) after inhalation. Two subjects inhaled the activity as a submicron aerosol and one also inhaled it as a vapour. The two subjects also received injections of ^{212}Pb in saline solution, so that the levels in blood following the two routes of entry could be compared. Measurements of the activity in excreta were also made.

The activity was removed from the lung with a biological half-life of about 10 hr. At 24 hr after inhalation about three-quarters of the particulate activity initially retained in the lung was found in the blood. The removal from blood to permanent sites of deposition and by excretion was comparatively slow. When a vapour of ^{212}Pb was inhaled, however, there was substantial faecal excretion (37% of the retained dose in 72 hr). This is attributed to activity deposited on the ciliated epithelium of the upper respiratory tract and subsequently brought up and swallowed.

231 Read in title. Internal contamination with ^{60}Co and other radioactive materials. D. NEWTON, Health Physics and Medical Division, AERE, Harwell (UK).

The behaviour of ^{60}Co has been studied in five individuals who became contaminated with this nuclide. Measurements of whole-body radioactivity, and also of activity retained in the chest region, were made over periods of up to 11 yr after accidental inhalation, using sodium iodide scintillation spectrometry; analysis of the gamma-ray spectra by least squares fitting enabled the retention of ^{60}Co to be followed until it had fallen below the nanocurie level. It is concluded that the long-term clearance from the chest may be extremely slow, with observed biological half-lives in the range 1-13 yr, while for the clearance of systemic burdens of ^{60}Co , biological half-lives of up to 6 yr are deduced. Data on the retention of ^{65}Zn and ^{110}Ag in one of these subjects will also be presented.

232 Read in title. Human excretion of ^{210}Po following accidental intake. N. A. TAYLOR, AWRE, Aldermaston (UK).

Excretion and blood concentration data are presented together with estimated retention functions for seven cases of accidental intake of ^{210}Po by human subjects. Entry was by inhalation or through wounds. The majority of these, and other, cases of accidental intake of ^{210}Po yield a single exponential function for excretion and total body retention for periods up to 300 days. The mean effective half-life found for these cases is 36.5 days for transportable ^{210}Po in the human. The mean biological half-life is estimated to be 51 days. The urinary and faecal excretion rates are approximately 0.2% and 1% of the total body content per day respectively.

233 Read in title. The metabolism of inorganic compounds of cobalt in laboratory animals and man. J. G. HOLINS, National Research Council of Canada, Ottawa, G. C. JACK and E. G. LETOURNEAU, Radiation Protection Division, National Health and Welfare, Ottawa (Canada).

ICRP Publication 10 suggests that it is reasonable to represent the retention of cobalt by a single exponential term with a half period of 10 days, although it notes the possibility that a small part of a dose of cobalt may be retained with a longer biological half period. The present paper describes a series of experiments to determine the long-term retention of cobalt in laboratory animals and man. $^{58}\text{CoCl}_2$ or

$^{60}\text{CoCl}_2$ was injected into mice, rats, rabbits, and men, and the retention of the radioactive cobalt was measured by whole body counting. The whole body retention equations obtained for mice and rats are identical and similar to that found for rabbits. These equations have terms with long biological half periods. At early times, the shape of the whole body retention curve for man is similar to that for laboratory animals, but a much larger fraction of the dose is retained.

234 Read in title. The influence of Prussian Blue on ^{137}Cs metabolism. J. W. STATHER, Radiological Protection Service, Belmont, Surrey (UK).

Prussian Blue (P.B.), the common name of ferric ferrocyanide, has recently been shown to bind ^{137}Cs in the lumen of the mammalian gut forming a stable complex and thus stopping the enteral circulation and increasing the faecal loss from the body.

The stability of the P.B.- ^{137}Cs complex in the varying conditions of the rat and human gastrointestinal tract has been shown by oral administration of P.B. at the same time as ^{137}Cs . In rats about 98% of the administered activity was lost within 2 days, whilst in man the corresponding time was about 7 days.

The effect of P.B., fed in drinking water, on the excretion of intraperitoneally administered ^{137}Cs from rats of various ages has also been investigated. An increased rate of loss of ^{137}Cs was found in all rats treated with P.B. but the effect was most marked in young animals. In 4 week old animals the body burden of ^{137}Cs was reduced to 9.4% of that in the controls at 1 week following intraperitoneal injection of the radionuclide, whilst in 19 week old animals the level was reduced to 33.0% of that in controls at the same time. Analysis of tissues has shown that the rate of loss of ^{137}Cs from the body under the influence of P.B. depends upon the turnover rate of caesium in muscle tissue. The turnover rate would appear to decline with increasing age, and this is reflected by a decreasing efficiency of the decontamination procedure.

ACCIDENTS, EMERGENCY PROCEDURES AND LESSONS II

235 Invited paper. Emergency organisation. W. POHL, Oberste Baubehörde im Bayerischen Staatsministerium des Innern, Munich (Germany).

In our country, the assessment of environmental hazards from reactor accidents follows the line of the so called "maximum credible accident" (m.c.a.).

There may be, however, more dangerous (hypothetical) accidents with lower probability. The consequence of an "m.c.a." may not make necessary emergency procedures, hypothetical accidents (e.g. burst of the pressure vessel of a BWR or PWR or failure of containment) would do so.

Safety precautions for the environment, therefore, must be well prepared in emergency plans. An exact alarm-scheme has to be set up. Measurements of volatile release and of environmental contamination must be organized. The district survey in our country would be done in three overlapping phases. The emergency staff and their duties must be defined. Exercises have to be planned and the emergency scheme should be tested regularly.

The paper will give an outlook of the emergency scheme to be followed in Bavaria (Federal Republic of Germany) where some nuclear power plants of the light-water type are operated. The scheme is based on the experience gained by exercise.

236 Oral presentation. Emergencies at nuclear sites of the Central Electricity Generating Board. J. GREGORY and H. C. ORCHARD, CEGB, Nuclear Health and Safety Department, London (UK).

In the event of a major accident at a Central Electricity Generating Board (CEGB) Nuclear Power Station any radiological problems arising would result from the release of fission products, and the actions to be taken would depend on whether the station was operational or not. If the station was operational fresh fission products would be released; if it had been shutdown (e.g. for maintenance) for some weeks the hazard would come from aged fission products.

In the former case the main fresh fission product would be radioactive iodine and emergency actions, such as the issue of stable potassium iodide tablets and the evacuation of the general public in the vicinity of the site, are based on the levels of radioactive iodine likely to prevail.

If the reactor had been shutdown for some time, fission products with a longer half-life than radioiodine, e.g. ^{90}Sr and ^{137}Cs , could be the determining factors in radiological control.

Where the station has a concrete pressure vessel the release of radioactive materials to the atmosphere will be the principal hazard, but at the earlier stations where the reactor is contained within a steel pressure vessel there could be an explosive release of hot carbon dioxide gas. Immediate action on the site will then be necessary to safeguard personnel, rescue and treat any casualties, and provide

protection against physical as well as radiological hazards for the rescue, control and repair teams.

At the CEGB Berkeley Nuclear Laboratories a major accident would be a fire in the cave area or a criticality accident on the experimental pile. These would not be likely to involve persons outside, and radiological injury rather than physical injury is to be expected.

Much of the work in the event of an emergency will fall on the health physics personnel. In addition to monitoring and helping to control the local situation, they will be monitoring the external environment both for immediate effects and later for long term effects on such as herbage and milk, and the assessment of radiation doses incurred by personnel involved in or controlling the incident.

Each site has an Emergency Plan detailing the emergency arrangements and the actions to be taken should a major incident occur, and all personnel are trained and exercised in their respective duties. The main principles of all such plans are that a single person on the site should be in control from a special emergency centre and that adequate communications be established immediately with the police and local authorities, regional and national headquarters, and neighbouring nuclear sites. Advice will be obtainable from the Nuclear Emergency Information Room set up at headquarters, and assistance will be available through this source and from neighbouring nuclear establishments as required, but the overall control of the emergency will rest with the one Emergency Controller on the site itself.

The CEGB is also responsible for the safety of consignments of irradiated nuclear fuel to the UKAEA establishments and its own nuclear laboratories, and emergency plans exist to deal with any accident occurring en route.

Accidents Emergency Procedures and Lessons

Rapporteur Presentation

237 Les moyens d'intervention du CEA en cas d'accident nucléaire à l'extérieur de ses établissements. P. KISSEL, Y. MARQUE et J. VERTUY, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

Depuis sa création, en 1945, le Commissariat à l'Energie Atomique a étudié et réalisé les moyens d'intervention spécialisés qui lui étaient indispensables pour la sécurité de son personnel et de ses installations.

Les moyens d'intervention dont sont équipés les différents Centres du CEA peuvent évidemment être mis à la disposition des autorités publiques ou des organismes extérieurs.

L'objet de cette communication est de présenter l'organisation des interventions du CEA à l'extérieur de ses propres établissements et les moyens d'intervention dont il dispose en insistant sur certains matériels spécialisés.

Procedures for intervention by the CEA in the case of a nuclear accident outside its establishments.

Since its creation in 1945, the Commissariat à l'Énergie Atomique has studied and established methods of specialist intervention which it needs to provide for the safety of its staff and installations.

The facilities for intervention which are provided at each of the CEA centres can of course be put at the disposal of the public authorities and outside bodies.

The aim of this paper is to show the CEA organisation for taking action outside its own establishments and the means of intervention which it has available on request to deal with certain specialised materials.

238 Protective actions for radioiodine in milk. D. E. BERNHARDT, M. W. CLARKER and F. N. BUCK, Bureau of Radiological Health, Southwestern Radiological Health Laboratory, Las Vegas (USA).

This paper presents the concept and history of protective action concerning radioiodine in milk, including planning prior to events and enactment after contaminating events. It is primarily concerned with protective action taken by the Southwestern Radiological Health Laboratory (SWRHL) and the Atomic Energy Commission (AEC) in the Nevada Test Site off-site safety program.

One of the best documented instances of protective action relates to the Pin Stripe Event in April 1966. This study indicated that about 70% of the potential total ^{131}I dose to a child's thyroid was prevented by changing the cows' ration from contaminated to uncontaminated forage at the time of peak ^{131}I milk concentration. This action by SWRHL in concurrence with the AEC was taken at levels below the Federal Radiation Council guides and, although intended primarily as a feasibility study, was a prudent measure for minimizing the potential thyroid dose.

239 Strahlenschutzerfahrungen bei einem größeren Kontaminationszwischenfall. L. A. KÖNIG, Kernforschungszentrum Karlsruhe (Germany).

Bei einem Wasserschaden wurden $\sim 6 \text{ m}^3$ α -kontaminiertes Wasser (Aktivitätskonzentration in der Größenordnung 10^{-1} Ci/m^3 ; Aktivitätsverhältnis $^{241}\text{Am}/^{239}\text{Pu}$ etwa 10:1) über eine Laborfläche von $\sim 800 \text{ m}^2$ verbreitet. Eine geringe Flüssigkeitsmenge gelangte ins Freie. Die im Zusammenhang mit diesem Zwischenfall durchgeführte Kontaminationsüberwachung der Regenwasserkanalisation, der betroffenen Oberflächen und der Raumluft beschränkte sich nicht auf die zur Bekämpfung des Zwischenfalles notwendigen Messungen, sondern versuchte vielmehr die gegebene Gelegenheit dazu auszunutzen, möglichst viele zusätzliche, für die Strahlenschutzüberwachung nützliche Informationen zu gewinnen. Es wird über die Ergebnisse dieser Messungen berichtet.

Experience in radiation protection gained in a major contamination incident.

During flood damage, about 6 m^3 of α -contaminated water (concentration of activity of the order of 10^{-1} Ci/m^3 ; $^{241}\text{Am}/^{239}\text{Pu}$ ratio about 10:1) was spread over a laboratory area of about 800 m^2 . A small quantity of water reached the open air. The monitoring of rainwater drainage, of affected areas and of air in connection with this incident was not limited to the measurements necessary for the control of the incident, but was intended in addition to make the most of this opportunity to obtain as much additional useful information as possible relevant to radiological protection. The results of these measurements are presented.

240 Radiation incidents dealt with by the Scottish Centre of the RPS. P. C. ESCOTT, N. T. HARRISON and G. C. JARDINE, Radiological Protection Service, Scottish Regional Centre, Glasgow (UK).

The paper will discuss interesting and relevant incidents grouping them into categories (e.g. Industrial site or enclosure radiography, Research, Teaching, General) establishing the cause or reason for the incident, the departments involved, the methods of approach to the RPS for assistance and the action taken by the RPS to complete an investigation. Reference will be made to the people directly involved (e.g. classified or unclassified workers, general public, children).

An incident involving ^{226}Ra at a secondary school has been chosen for detailed description since it

involved an excellent cross-section of the types of advice, services and measurements offered by the RPS, e.g. radiation, contamination, radon-in-air, radium-in-air measurements, radon-in-breath measurements, with the subsequent indication of the radium content in the body.

Oral (See 50)

241 A study of overexposure incidents in Texas, January 1963-June 1969. M. G. WUKASCH, Radiation Control Program, Division of Occupational Health and Radiation Control, Texas State Department of Health, Austin, Texas (USA).

Radiation exposure incidents within the State of Texas requiring extensive reporting constitute a large expenditure of time and energy on the part of many people. Evaluational procedures are considered for attempting to estimate actual exposure under unusual circumstances.

An analysis is presented of reportable incidents versus real exposure with exploration of situations commonly leading to overexposure of personnel.

One major result of this investigation shows that the number of incidents reported in Texas has increased in the past years.

Detailed analysis is provided in several cases of particular interest.

242 Reconstitution des incidents de contamination atmosphérique. J. DUPOUX, J. P. PEROTIN et B. WERDERER, Centre d'Etudes Nucléaires de Saclay, Gif-sur-Yvette (France).

Pour estimer l'activité inhalée par des opérateurs exposés à une contamination atmosphérique accidentelle, on se dispose généralement que des résultats des mesures de prélèvements fixes. L'utilisation brutale conduit le plus souvent à une estimation grossièrement erronée.

Des corrections peuvent être apportées, soit en recherchant une corrélation statistique entre les résultats d'un grand nombre de mesures par prélèvements fixes et par prélèvements individuels, soit en supposant une diffusion isotrope et en tenant compte des distances de la source de contamination aux points de prélèvements.

Mais aucune de ces méthodes ne fournit une estimation précise des activités inhalées. Les auteurs proposent une troisième méthode, dite de "reconstitution" de l'incident: on établit d'abord par une enquête les circonstances de l'accident, puis on les reproduit aussi exactement que possible en utilisant un aérosol traceur; par comparaison des mesures effectuées aux emplacements des opérateurs et des appareils de prélèvements fixes, on détermine un

facteur de correction qui permet d'estimer de façon adéquate les activités inhalées.

Les auteurs discutent de deux exemples d'application de cette méthode au moyen d'un aérosol traceur provenant de fumigènes et en déduisent la nécessité d'adjoindre aux prélèvements fixes utilisés en routine des appareils de détermination granulométrique et de disposer d'une gamme d'aérosols traceurs permettant de reproduire en dimension les divers aérosols contaminants rencontrés dans la pratique.

Ils proposent d'utiliser des aérosols de sulfure de zinc et décrivent les matériels de génération, de prélèvement et d'analyse étudiés en France pour les reconstitutions d'incidents de contamination atmosphérique.

The reconstruction of incidents involving airborne contamination.

In general, the only information available for estimating the activity inhaled by workers exposed to an accidental airborne contamination is the result of measurements from fixed samplers. The crude use of these data usually leads to a grossly erroneous result.

It is possible to apply corrections, either by studying the statistical correlation between the results of a large number of measurements of fixed samplers and the results of personal samplers, or by assuming an isotropic diffusion and taking account of the distance of the source of the contamination from the sampling points.

However, none of these methods provides a precise estimate of the inhaled activities. The authors suggest a third method, i.e. the reconstruction of the incident. Having established by enquiry the circumstances of the accident, these are then reproduced as accurately as possible, using a tracer aerosol. A correction factor which allows an adequate estimate to be made of the inhaled activities is then obtained by a comparison of measurements made at the working positions with those of the fixed samplers.

The authors discuss two examples of the application of this method, using an aerosol tracer produced by a smoke generator, and from these show the necessity for adding to fixed routine samplers equipment for particle size determination. They also show the need for a range of tracer aerosols representing the particle size distribution of the various contaminating aerosols encountered in practice.

They suggest the use of aerosols of zinc sulphide, and describe the equipment for generation, sampling and analysis being considered in France for the reconstruction of incidents involving airborne contamination.

243 Analysis of a case of internal contamination with ^{242}Cm . J. P. VAANE and E. M. M. DE RAS, European Institute for Transuranium Elements, Karlsruhe (EURATOM).

During the preparation of targets for the mass spectrometer some ^{242}Cm escaped from the preparation box resulting in a contamination of the laboratory air and of the technician concerned.

Nose wipe tests were taken immediately after the incident. Faecal and urine samples were taken during the week following the incident. Air sampling filters located in three places in the laboratory were changed immediately and then at regular intervals. Autoradiographs of the filter samples were prepared and the size distribution of the particles were calculated. From the results of these analyses the quantity ingested in the respiratory tract was determined using the ICRP Lung Model as a guide. The distribution of the ingested material in the body organs was then estimated from the data in *ICRP Publication 2* (1959).

Although the quantities involved predicted an internal contamination far below the maximum permissible values, this detailed analysis was carried out to make use of the opportunity of testing the lung model in the case of curium. Interpretation and comparison of air filter sampling data with results of nose wipe and faecal tests suggest that the ICRP lung model may serve as a useful guide to estimate the approximate level of an internal contamination after inhalation exposure to ^{242}Cm .

244 Elimination of radioactive cobalt following acute accidental inhalation.* J. SEDLET and W. D. FAIRMAN, Argonne National Laboratory, Illinois (USA).

The elimination pattern of radiocobalt inhaled in the form of metal or oxide is described in four cases of accidental exposure. The isotopes involved were ^{60}Co , from thermal neutron irradiation of cobalt metal, and ^{57}Co and ^{58}Co , from charged particle and fast neutron irradiation of stainless steel.

The results of urine and fecal analyses are presented and discussed. Sampling was generally continued until the activity was too low to detect, between 5 and 63 days after exposure in the four cases. In all instances the excretion was characterized by appreciable and early urinary elimination of the radiocobalt, although the inhaled material should have been quite water-insoluble. This finding is of interest to the problem of monitoring individuals for cobalt

* This work was done under the auspices of the US Atomic Energy Commission.

exposures and in describing the behavior of inhaled cobalt in the body. In some of the cases, the intake was first detected through a routine urinalysis. Urine-to-fecal activity ratios varied from about 0.4 less than one day after exposure, through a minimum of 0.02 after 3 days, to 4 after 60 days.

In three of the cases, where sufficient data are available, the urinary excretion can be described by a power function, although for short time intervals one or two exponential terms is adequate. The fecal excretion was less regular. Some possible reasons for the relatively high solubility of the cobalt activity are discussed.

Oral (see 52)

245 Body radioactivity studies on a series of cases in which ruthenium-106 oxide was inhaled. R. HESP and J. COOTE, UKAEA Windscale Works, Sellafield (UK).

The Windscale Whole Body Counter was used to make *in vivo* measurements of body radioactivity on a series of subjects who had inhaled ruthenium-106 oxide. Most of the inhaled material was cleared via the gut within several days of the day of intake. The remaining material was found to be deposited in the chest, presumably in the lungs. The biological half-time for the long term component of chest retention was found to be in excess of 200 days.

The results of these studies tended to support the recommendations of the Task Group on Lung Dynamics regarding the long term retention of inhaled ruthenium-106 oxide.

Oral (see 152)

246 Histoire d'une contamination interne par du radium. M. DELPLA et R. SCHAEFFER, Electricité de France, Paris (France).

Une femme, contaminée par du radium 226 à l'âge de 48 a, dans un but thérapeutique, a pu vivre jusqu'à 84 a. La charge de son squelette ($10,5 \mu\text{Ci}$) est l'une des plus élevées qui soient connues.

Malgré les lacunes de l'observation, il est possible de retrouver que, selon l'hypothèse la plus probable, cette personne a dû recevoir dans son sang, pendant une dizaine de mois, environ $30 \mu\text{Ci/semaine}$, et que la valeur maximale atteinte par la charge du squelette devait donner, dans les zones du tissu osseux à concentration élevée en radium, un débit d'équivalent de dose de près de 2000 rems/jour, et, en 36 a, plus de 5,000,000 de rems.

Les débits de dose et les doses cumulées dans la moelle osseuse ont atteint également des valeurs considérables.

Cet exemple, certainement trop rassurant, ne doit pas être cité isolément, mais rapproché des autres cas connus qui, pour des doses beaucoup moindres, ont induit des cancers osseux ou épithéliaux.

The course of an internal contamination by radium.

A woman contaminated by ^{226}Ra at the age of 48 yr for therapeutic purposes has survived to 84 yr. The bone burden ($10.5 \mu\text{Ci}$) is one of the highest yet known.

In spite of the gaps in the information, it is possible to establish, at least as the most likely hypothesis, that this person must have received about $30 \mu\text{Ci}/\text{week}$ into the blood in just under a year. The maximum level of the bone burden must have given a dose equivalent rate of about 2000 rems/day to the bone tissue with the highest concentration of radium. Over 36 yr, this amounts to more than 5,000,000 rems.

The dose rates and the total doses in the bone marrow also attained considerable values.

This example, certainly over-optimistic, must not be taken in isolation but must be considered with other known cases where cancers of the bone and the epithelium have been induced by very much lower doses.

METABOLISM IN MAN II

247 Oral presentation. The movement and fate of ^{212}Pb inhaled by man. J. B. HURSH and T. MERCER, School of Medicine and Dentistry, University of Rochester, N.Y. (USA).

Experiments were performed in which 4 human subjects were administered ^{212}Pb by mouth inhalation and by intravenous injection. Blood, urine, and fecal samples were collected. ^{212}Pb inhaled on natural aerosols showed lung depositions of 27–62%, the amount depending in part on well-characterized aerosol size differences. The loss rate from the lung measured by *in vivo* gamma counting (corrected for extra-lung activity in the lung survey field) was exponential with a transport constant to the blood of 0.066–0.060/hr. Twenty-four hour urinary lead excretion after intravenous injection was from 2.6 to 6.6% dose. Fecal collections (34–48 hr) yielded 0.2–2.7% dose. After inhalation exposure urinary excretion accounted for 2.0–2.5% of the deposited activity in 24 hr, and fecal collections (34–50 hr) accounted for 0.05–0.9% of the deposited activity. All activities were decay-adjusted to zero time. Supplementary sacrifice experiments on dogs indicate that inhaled ^{210}Pb is transported from the lung with similar rates and is deposited principally in the red blood cells, liver, and bone.

248 Oral presentation. Skeletal concentrations and metabolic parameters of ^{210}Pb and ^{226}Ra in radium-burdened people.* R. B. HOLTZMAN, Radiological Physics Division, Argonne National Laboratory, Illinois (USA).

The concentrations of ^{226}Ra and its decay product, ^{210}Pb , were determined in 44 bone samples taken from 13 persons who had acquired the radium either as dial painters or under medical treatment. The burdens, carried 4 to 36 yr, ranged from $0.4\text{--}10 \mu\text{Ci}$ ^{226}Ra whole body. The ^{210}Pb was derived almost entirely from the radium in bone, an assumption supported by measurements on radium-injected dogs with short-term exposures of 7–500 days. Despite great differences from sample to sample, such as differing body burdens, exposure times and methods of acquisition, differing bone types (femur, rib, vertebra, etc.), and large differences in ^{226}Ra concentration ($10^2\text{--}10^4 \text{ pCi/g}$ ash), the ratios of ^{210}Pb specific activities to those of ^{226}Ra were fairly uniform with an average of 0.33 ± 0.06 (s.d.). This uniformity and the large variations in radium concentrations within an individual (factors of 10 or more) indicate that little ^{210}Pb was translocated from the site of formation. However, there does appear to be some translocation, as shown by a ratio of 0.7 in one group of 7 samples and the even higher ratios of 1.6–13 in another group of 4 samples. In the latter set, the low values of ^{226}Ra relative to those in other samples from the same subject, indicate either that little radium was taken up initially, or that the bone was resorbed with subsequent preferential incorporation of ^{210}Pb .

The effective half-life of the ^{210}Pb , based on the ^{210}Pb to ^{226}Ra ratio of 0.33, appears to be about $\frac{1}{2}$ that of the radium in an exponential retention model. The dose from the ^{210}Pb (^{210}Po) series appears to be about 10% of that of the ^{226}Ra series over the period of 10–40 yr after acquisition.

(Wiederhalm) See 230

249 Oral presentation. Investigation of correlation of ^{210}Po in hair, blood and urine in the workers exposed to radon and its products of decay. D. PANOV and I. J. NOVAK, Institute of Occupational and Radiological Health, Belgrade (Yugoslavia).

A method of determination of ^{210}Po in hair, blood and urine of uranium mine workers in Yugoslavia (Gorenja Vas and Kalna) has been presented.

Samples of hair, blood and urine were digested by wet-ashing method by nitric acid at higher temperature to mineral residue, then under the determined

* Work performed under the auspices of the US Atomic Energy Commission.

~~conditions deposition was made on a silver foil and alpha activity was measured.~~

~~A total of 152 samples of hair, 146 of blood and 113 of urine were analysed.~~

~~Correlation of ^{210}Po in hair, blood and urine has been discussed, as well as the possibility of assessment of integral contamination of the workers by radon and its decay products.~~

250 Oral presentation. Body burden, distribution and internal dose of ^{210}Pb and ^{210}Po in a uranium miner population. R. L. BLANCHARD and J. B. MOORE, Bureau of Radiological Health, Radiological Engineering Laboratory, Cincinnati, Ohio (USA).

Concentrations of ^{210}Pb and ^{210}Po in tissues from 40 uranium miners and 14 unexposed individuals are reported. The tissues studied were bone, liver, lung, kidney, spleen, testes, heart, muscle, pancreas, lymph nodes, small intestine, stomach, aorta, brain, spinal cord, adrenal gland, prostate, thyroid and blood. Observations relative to individual tissue types are discussed, and comparisons are made between the levels observed in the exposed and unexposed populations.

Relative tissue concentrations and the fractional body burdens of each tissue are determined. The largest amount of ^{210}Po and ^{210}Pb in the body was observed to be in the skeleton, about 78%, while the important soft tissue reservoirs were the lung, liver, muscle, lymph nodes, kidney and blood. Body burdens of the miners were 4-50 times those of the non-miners, approaching 33 nCi ^{210}Pb and 23 nCi ^{210}Po ; the latter being 76% of the maximum permissible body burden. The dose calculated for ^{210}Po to bone assuming an RBE of 10 exceeded in some cases the maximum permissible dose-rate of 5 rems/yr, however, the doses to soft tissues were in all cases below the maximum permissible limits set by ICRP.

251 Oral presentation. Fate of iodine radioisotopes in infants and adolescents and resulting radiation exposure. L. R. KARHAUSEN, J. P. PAGES and A. M. ERMANS, Laboratoire de Médecine Nucléaire de l'Université Libre de Bruxelles and CEA, France.

Iodine kinetic studies were performed on two groups of subjects: 40 infants 0-2 yr of age and 40 adolescents 10-15.

A three-compartment model was used to determine the amount of ^{131}I in the thyroid as a function of time in case of single or chronic contamination.

Four models were established, one for each of the following age classes: 0-6 months, 6 months-1 yr, 1-2 yr and adolescents 10-15 yr.

Finally these theoretical results were validated by careful studies on 30 subjects within the same age classes. Thyroid activities were watched during 3 to 4 weeks. Plasma radioiodine and protein-bound iodine were measured and serial determinations of urine specific activities were made.

Exposure doses resulting from absorption of an iodine radioisotope and the inferred maximal permissible quantities were determined.

OCCUPATIONAL MEDICINE I

252 Oral presentation. Lymphocytes with nuclear alterations as a biological dosimeter.* N. RACOVEANU, Institute of Hygiene, Bucarest, F. FARKAS, Centre of Industrial Toxicology, Bucarest and CORNELIA DIACONESCU, Institute of Hygiene, Iassy (Romania).

Starting from the papers of Ingram and Dobson we focussed our investigations on the occurrence of binucleate lymphocytes in persons exposed to ionizing radiations, by means of lymphocyte concentrates.

We observed more frequently five types of nuclear alterations which were classified into the following categories of lymphocytes: binucleate, with two superposed nuclei, with bilobate nucleus, with lobate nucleus, and with micronucleus.

The investigations of these modifications carried out on three human control lots, nine lots of persons exposed to ionizing radiations, and an additional lot of persons subjected to a high electromagnetic field, evince a statistically significant increase of the number of anomalous lymphocytes; the increase is slightly proportional to the type and the presumed magnitude of exposure. We noticed a higher occurrence of lymphocytes with nuclear alterations after internal contamination (uranium miners, workers who handle radioactive luminizers, etc.).

We followed the same modifications in rats exposed experimentally both to external irradiation of 5, 10, 15, 20, 30, 40 and 80 R and to internal contamination with ^{191}Au , ^{59}Fe , ^{123}I , and ^3H -Thymidine. Even in these conditions there still remains a minor proportional dependence—number of anomalous lymphocytes vs. dose—the phenomenon prevailing in internal irradiation.

We suggest the possibility of using the lymphocytes with nuclear alterations as a biological dosimeter especially in internal contamination.

* The work was partly supported by the IAEA.

253 Oral presentation. Dose estimation for workers exposed to ^{222}Rn inhalation and an investigation of chromosome aberrations in their peripheral blood lymphocytes. J. POHL-RÜLING and E. POHL, Research Institute Gastein of the Austrian Academy of Science, and P. FISCHER and N. K. SAHU,* Cancer Research Institute, University of Vienna (Austria).

At the well known spa in Badgastein, Austria, a new form of treatment has been used for about 20 yr. Patients are conveyed into a disused gold mine. They remain in various therapeutic stations for two hours. The mine's atmosphere contains a mean of 2,5 nCi/l. ^{222}Rn , its short-lived decay products are 70–90% in equilibrium. Air temperatures in the therapeutic stations reach 41°C, with up to 90% relative humidity. A spa house with treatment rooms is connected to the mine entrance, and the atmosphere here also contains a considerable concentration of ^{222}Rn and daughters.

In order to estimate the radiation load to the individual workers, we have investigated the various components of external radiation in the atmosphere of the mine and spa house for many years. These components are: (a) ^{222}Rn , ^{220}Rn and their daughters as well as long-lived alpha-emitters. The concentration of these varies with barometric pressure and degree of ventilation according to the weather. (b) The gamma radiation from the rocks and of Rn daughters in the air, and their deposit on the walls.

On the basis of our preliminary investigations [e.g. E. POHL and J. POHL-RÜLING, *Strahlentherapie* **136**, 738 (1968)] we have established that the main radiation dose is caused by the inhalation of ^{222}Rn , ^{220}Rn and its daughters; external gamma irradiation and the incorporation of the long-lived alpha-emitters contribute little. We have calculated the radiation dose in various organs for persons who stay in the mine every day for some hours. The loads exceed the maximum permissible dose for the lungs and kidneys (15 rem/y) but are below for red bone marrow gonads and other organs (5 to 15 rem/y resp.). The lung dose delivered to a patient during a cure does not exceed 0.9 rem/y.

Peripheral blood cultures have been undertaken on all persons occupied in the mine and spa house. Blood samples were repeated on two and in a few cases on three occasions. Results indicate an increase in the number of chromosomal aberrations in the

lymphocytes of these persons. The aberrations observed were mainly acentric fragments. Dicentric chromosomes were present in two cases (the caretaker of the spa house and his son); no ring chromosomes were seen.

An intensive investigation of these persons as well as of members of the general population of Badgastein is at present being conducted in order to establish whether this increase in aberrations is related to dose levels or not. The preliminary investigation was financially assisted by a grant from the World Health Organisation. Present work is being supported by a research contract from the International Atomic Energy Agency, Vienna, Austria.

254 Oral presentation. Clinical and laboratory data of persons professionally exposed to low-level chronic radiation. T. PREDMERSZKY and I. LOVANYI, Frédéric Joliot-Curie National Research Institute for Radiobiology and Radiohygiene, Budapest (Hungary).

Over several years, various clinical and laboratory examinations were performed on a large group, including over 1000 individuals, professionally exposed to low level radiation. Results were compared with data obtained on unexposed controls of about the same number. Correlation was investigated between the effect of intermittent low level chronic radiation and clinical and laboratory data registered.

We concluded that there are several clinical and laboratory results which differ significantly from the values obtained for the unexposed groups. These signs, when studied in their progress as well as in their combined occurrence, may prove useful in the evaluation of the chronic radiation effects.

255 Oral presentation. Reticulocyte counts on radiation and non-radiation workers at the Reactor Centrum Nederland, Petten, The Netherlands. W. J. M. CARPAIN, Health Protection Department, Reactor Centrum Nederland, Petten (Netherlands).

At a low dose (rate) ionizing radiation is assumed to act as a stimulus on the bone marrow. In case of a low stimulus the reticulocytes are the only immature cells which will appear in the circulating blood.

On the basis of these assumptions one could expect a higher number of reticulocytes in the circulating blood of radiation workers as compared to a control group (non-radiation workers) (Radiation worker defined here as an employee regularly working in a controlled area).

* Rajendra Medical College, Ranchi, India; presently Austrian Government Research Fellow in Pathology.

During one year period, reticulocyte counts were performed on 989 male individuals, 392 radiation and 597 non-radiation workers. All examinations were done by the same medical technician.

The mean of the radiation group is 5.03 (s.d. 2.71) and of the control group 4.55 (s.d. 2.63). (The number of reticulocytes/thousand erythrocytes is given.)

This difference is statistically significant at a 5% level. Detailed analysis to reveal correlations between the number of reticulocytes and the radiation dose is clearly necessary.

256 Oral presentation. An assessment of medical requirements for workers in nuclear installations. A. N. B. STOTT, Health Physics and Medical Division, AERE, Harwell (UK).

A review is made of the experience of 20 yr of routine medical examinations (including blood counts) at AERE, Harwell. The reasons for initiating medical surveillance are described and examined in the light of this experience. Illustrative cases are described showing that exclusion from radiation work would not prevent the development of various illnesses, and the statistical probabilities relating to the development of such illnesses are also explored.

Although there has been a trend away from the more intense form of medical examination, ICRP recommendations are still equivocal. Since legislative requirements will be based on existing medical practice, no alteration in these can be expected until the medical advisers themselves show that there is no need for continued medical surveillance of radiation workers.

ACCIDENTS, EMERGENCY PROCEDURES AND LESSONS III

257 Oral presentation. Teilkörperbestrahlung mit ^{192}Ir -Stab und Folgeerscheinungen. B. CHONÉ, Universitäts-Strahlenklinik, Heidelberg (Germany).

Darstellung von Unfallhergang, Entstehungsmechanismus und Ablauf eines Strahlenunfalls, der von arbeitsmedizinischer Seite besonderes Interesse verdient. Es handelte sich um eine akute Strahlenexposition auf einer Großbaustelle, die sich durch die versehentliche Deposition eines ^{192}Ir -Strahlers in einer Rohrleitung am 18.9.68 ereignete und von der ein Bautruppp von 6 Arbeitern betroffen war. Sichtbare Kontaktschäden und Folgeerscheinungen traten nur bei einem Beteiligten auf, der in Unkenntnis

der Zusammenhänge den Strahler mehrere Stunden in seiner Jackentasche aufbewahrte. Unter Berücksichtigung der Strahleraktivität (5,8 Ci), Formgebung (punktförmige Quelle von $2 \times 2 \text{ mm } \emptyset$), des Zeitfaktors und der durch die Art des Körperkontaktes gegebenen Begleitumstände war eine hohe Teilkörperdosis im Becken- und Oberschenkelbereich anzunehmen (physikalische Schätzdosis 4000–8000 R). Daraus ließ sich eine Ganzkörperbelastung zwischen 100–200 R ableiten. Die Nominalwerte standen in Einklang mit den nachfolgenden lokalen Reizerscheinungen an der Hantoberfläche und den Fernwirkungen im Gonadenbereich. Die morphologisch faßbaren Rückwirkungen auf das hämatopoetische System waren nur diskret, konnten aber durch zytogenetische Paralleluntersuchungen im Ausgewert erhöht werden. Die Tragweite der permanenten Sekundärschäden—vor allem hinsichtlich der Gonadenfunktion—ist zum gegenwärtigen Zeitpunkt noch nicht abzusehen. Dasselbe gilt für die bestehende Kontaktschädigung der Haut, die inzwischen ein Ausmaß erreicht hat (Strahlenulcus von $4 \times 4 \text{ cm } \emptyset$), daß eine plastische Wunddeckung erfolgen muß. Dieser Tatbestand bedingt zusätzliche versicherungsrechtliche Konsequenzen.

Partial irradiation with ^{192}Ir rod and consequent effects.

Account of the occurrence and course of a radiation accident, which is especially interesting from the practical medical point of view. It concerns an acute exposure to radiation in a large building area. This happened on 18.9.68 as a result of the inadvertent placing of a ^{192}Ir radiation capsule in a pipeline. This caused injury to a party of six workers. Noticeable injuries and other effects incurred by contact appeared only in the case of one man who had, in ignorance of the possible effects, carried the capsule around in his coat pocket for several hours. Considering the activity of the capsule (5.8 Ci), its form (point source $2 \times 2 \text{ mm dia.}$), the time factor and the method of physical contact, a large dose of (partial body) radiation in the pelvis and upper thigh was to be expected (estimated physical dose 4000–8000 R). From this an overall body dosage of 100–200 R was deduced. These estimated values agreed with the subsequent local appearances of irritation on the surface of the skin and subsequent effects in the testes. The morphological reactions on the haematopoietic system were only slight, but more significant conclusions could be drawn from parallel cytogenetic examinations. The extent of permanent secondary injuries—above all with regard to the function of the

testes—cannot be foreseen at the present time. It is also difficult to assess the extent of permanent injury to the skin through contact, which has meanwhile attained the following proportions (radiation ulcer, 4×4 cm diam.), so that a plastic surgical dressing is necessary. This fact occasions additional legal insurance consequences.

258 Oral presentation. Radiation accident prediction at the AES. O. P. BOBBOVNIKOV, N. G. GOUSSEV and V. F. FEDOULOV, Institute of Biophysics, Moscow (USSR).

In connection with a large programme of building AES in the vicinity of densely populated centres, much attention is given to the problem of radiation accident prediction at the AES. Therefore the working out of methods to predict accidents at the AES has become of great importance.

This report introduces a probability-time characteristic of the arising of emergencies at the water-cooled reactors $W(q, t)$, based on the analyses of experimental data on inert radioactive gas releases collected during the whole operation period of the AES.

The mathematical expression for $W(q, t)$ is

$$W(q, t) = \phi(q)U(t). \quad (1)$$

In this formula $U(t)$ is the time characteristic of the AES operation; $\phi(q)$ —the probability of accidental release, determined from the radio

$$\phi(q) = \int_{q_0}^{q_{ac}} f(q) dq, \quad (2)$$

where q_0 , q_{ac} are designed and accidental releases respectively, curie per time unit; and $f(q) dq$ is the density of accidental release probability from q to $q + dq$.

The function $W(q, t)$ is obtained from the treated data on releases, which had been measured systematically several times a day for 4.5 yr.

The suggested model makes it possible to predict radiation accidents at the AES of any type within the period of 1-2 months to several years.

The results of this method can be also applied for prediction of radiation situation at any area in case of an accident.

This paper continues the studies reported at the IAEA Symposium on Radiation Accident Planning (Vienna, May 1969) and at the International Congress on Radiation Protection (Saclay, November, 1969).

259 Oral presentation. Safety standards for nuclear power reactors and the calculation of the ensuing radiological risk. G. D. BELL, UKAEA, Authority Health and Safety Branch, Risley (UK).

The knowledge that a nuclear power reactor contains many millions of curies of radioactive fission products has led to the conscious imposition of severe safety standards by designers and operators. Consequently the release of a significant fraction of the total radioactivity is so unlikely as to be deemed incredible by normal engineering judgment. Nevertheless it is useful to attempt to define the spectrum of acceptable releases in a numerical manner so that achievement of the safety criteria can be assessed in as quantitative a manner as possible. The criterion proposed by Farmer, which defines the acceptable frequency of releases of a given magnitude has been used in the United Kingdom Atomic Energy Authority for design and assessment of reactor systems.

If a release of activity occurs, the consequences to the surrounding population will depend upon the size of release, the weather conditions at the time, the direction of the wind, the height of the release and the relationship between dose received and the probability of biological damage. If, as is usual, the release of radioactive iodine is the dominant hazard, then the radiological consequences will be an enhanced rate of incidence of cases of cancer of the thyroid gland.

It is possible, by suitable mathematical techniques, to evaluate the distribution spectrum of such cases resulting either from a reactor conforming exactly with the safety target spectrum or from a reactor whose release spectrum has been derived by safety assessment techniques. Examples of such spectra for typical reactor sites will be presented and compared with the risks arising from some hazards, both natural and man-made, to which we are all inevitably exposed. It is concluded that the standards of safety proposed for nuclear power reactors are adequately conservative.

260 Oral presentation. Quelques considérations sur la courbe de confiance d'une installation nucléaire en relation au site. P. CAGNETTI, L. FRITTELLI and A. NARRI, CSN Casaccia, Rome (Italy).

Le risque auquel est exposé la population du site environnant une installation nucléaire, à la suite d'un rejet accidentel, peut être évalué en termes de probabilité à partir de la courbe de confiance de l'installation (probabilité d'occurrence d'un reje-

accidentel en fonction de sa gravité), de caractéristiques météorologiques et démographiques du site et des relations "dose-effet" généralement acceptées.

Par cet exposé on propose une méthode de calcul qui permet, après avoir fixé une certaine valeur pour le niveau du risque acceptable, de déterminer d'une manière quantitative la meilleure courbe de confiance d'une installation nucléaire en relation aux caractéristiques du site environnant.

Some considerations on the reliability curve of a nuclear installation in terms of its site.

The risk to which a population near the site of a nuclear installation is exposed following an accidental release can be assessed in terms of the probability, based on the reliability curve of the installation (probability of occurrence of an accidental discharge as a function of its severity), the meteorological characteristics and population distribution of the site and the dose effect relationships generally accepted.

In this paper, methods of calculation are proposed for determining in a quantitative way the best reliability curve for a nuclear installation in relation to the characteristics of the surrounding area and on the basis of a certain selected value for the level of acceptable risk.

DOSIMETRY

Discussion Group

261 The dosimetry of radionuclides which decay by electron capture. M. E. WRENN, I. HAIR and GWYNETH PARRY HOWELLS, Institute of Environmental Medicine, New York University Medical Center, N.Y. (USA).

Calculations of radiation dose from nuclides which decay by electron capture have been conventionally performed by assuming that the resultant X-rays are absorbed in a "beta like" fashion. However, Auger electron emission is more probable than X-ray emission for most elements of biological interest. The energy associated with the Auger process is conventionally included with the X-ray energy in calculations of dose ($\Delta E/\Delta M$). Since the range of an Auger electron is many times smaller than the mean free path of the equivalent X-ray, conventional calculations of dose result in grossly inaccurate estimates whenever the dimensions of the biological object of interest is small compared to the mean free path of the X-ray. Since many elements are known

to localize in subcellular structures (e.g. iron in ferritin aggregates) accurate dose calculations for electron capture nuclides are of great biological interest.

To rectify the error inherent in conventional dose calculations for electron capture nuclides, a general theory has been developed to predict dose from a knowledge of the energy of the Auger electron as a function of the Z of the emitter, the fraction of the total decay energy which is emitted in the form of Auger electrons, and the Z of the absorbing material.

Irradiation of biological systems with electron capture nuclides should provide a powerful tool to investigate radiation effects, and most particularly the adequacy of our present concepts of dose at the cellular and subcellular levels.

262 Estimates of dose to red bone marrow from monoenergetic sources of photons in lungs and other organs.* MARY J. COOK, Health Physics Division, Oak Ridge National Laboratory, Tennessee (USA).

Estimates have been published⁽¹⁾ of the absorbed fraction (AF) of energy for 22 target organs when a monoenergetic source of photons is distributed uniformly in 16 different source organs. However, "marrow" as reported there includes both red and yellow; since the two types are fairly well localized in different portions of the skeleton, an average dose to marrow of both types may differ significantly from an average for red marrow. In this paper estimates of AF for red bone marrow are obtained, both as an average and for portions of the active marrow which are close to the source organ and, hence, might have a higher dose, e.g., dose to red marrow in the ribs from a source of photons in the lungs. The phantom used in the Monte-Carlo-type calculations has a skeletal system consisting of arm and leg bones, ribs, spine, pelvis and skull, and these have approximately the shape, density and composition of the corresponding portions of the skeleton. The phantom has been modified to include scapulae and clavicle. Distribution of red bone marrow has been estimated from a variety of sources; the computer then estimates a weighted dose as average for red bone marrow. The source has been assumed to be uniformly distributed in lungs and has energy ranging from 10 keV to 4 MeV. Besides an average dose, an estimate is given for certain portions of marrow,

* Research sponsored by the US Atomic Energy Commission under contract with Union Carbide Corporation.

e.g., in ribs, which might be expected to have a higher dose. Plans are under way to use a source in other organs, e.g., gastrointestinal tract, bladder, etc.

1. W. S. SNYDER *et al.*, MIRD Pamphlet No. 5, *J. nucl. Med.* **10**, Suppl. No. 3, August (1969).

263 Estimation of dose to gonads from gamma emitters present in the body.* W. S. SNYDER, MARY R. FORD and G. G. WARNER, Oak Ridge National Laboratory, Tennessee (USA).

Using the Monte Carlo technique, Snyder *et al.* have calculated the absorbed fraction of photon energy for 16 choices of source organ, 22 target organs, and 12 different photon energies ranging from 10 keV to 4 MeV. The phantom is anthropomorphic, and the organs have approximately the size, shape, density and composition of the body organs they represent. The results, as tabulated in MIRD Pamphlet No. 5, sometimes fail to give a statistically reliable estimate, particularly when the gonads are the target organ and when the energy is low. A variety of techniques are used in the same phantom to obtain reliable estimates; these include using a target region much larger than the gonads but positioned so that gonad dose is comparable; using a surface and calculating energy flux across the surface, thus obtaining better statistics; and using the reciprocity theorem in certain cases. The results are successful in providing estimates for most of the blank entries for gonad dose in MIRD Pamphlet No. 5 and will be presented and discussed in this paper.

264 Estimation of the energy W per ion pair in liquids using ionization chambers. J. HACKE and W. JACOBI, Hahn-Meitner-Institut für Kernforschung Berlin (Germany).

The mean absorbed energy W per ion pair in gases can easily be determined from the saturation current in a suitable gas-filled ionization chamber. In liquids however saturation cannot be reached on account of the initial recombination of ion pairs in the tracks of ionizing particles.

In this paper a method is presented to estimate the initial recombination probability and the W -value in γ -irradiated nonpolar, dielectric liquids from measurements of the radiation induced conductivity in liquid-filled ionization chambers. The method of

evaluation is based on Onsager's theory of ion recombination in compressed gases. The results indicate that the W -values for liquids are within the limits of error of the same magnitude as the W -values in corresponding gases.

265 (Withdrawn)

266 Radiation doses from diagnostic studies with ^{75}Se -selenomethionine. KATHERINE A. LATHROP, Argonne Cancer Research Hospital, Chicago, R. E. JOHNSTON, Division of Nuclear Medicine and Biophysics, Vanderbilt University, Nashville, Tenn., and M. BLAU, Division of Nuclear Medicine, Roswell Park Memorial Institute, Buffalo, N.Y. (USA).

Limitations on the clinical dose of a radiopharmaceutical can be realistically estimated only from actual human data. The public health hazard may be assessed and controlled from knowledge of excretion patterns. Risk to the patient may be judged from wholebody retention and organ distribution data. Such estimates for ^{75}Se have been made by the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine using both published and unpublished data from a single intravenous administration of ^{75}Se -selenomethionine. Using several computer programs, calculations have been made of the absorbed radiation doses within and from the various sites of localization. Available information includes quantitative urinary and fecal excretion data during the initial period of maximum rate and up to 289 hr in six subjects, exhalation losses in two subjects until undetectable at 60 hr, epithelial losses during the measureable period to 280 days, per cent of retained dose up to 930 days for 24 subjects determined from whole-body counting, and tissue concentrations for eleven organs from 0.5 hr to 361 days assayed on surgical or autopsy specimen from 22 patients.

267 Scanning electron microscope investigation of human trabecular bone. E. D. DYSON, UKAEA Health and Safety Branch, Harwell and W. J. WHITEHOUSE, Health Physics and Medical Division, AERE, Harwell (UK).

Spongy or cancellous (L. cancelli, lattice-work) bone has long been known to be significant in the radiation dosimetry of bone-seeking nuclides, because in it the osteogenic and haemopoietic cells are in close proximity to the bone. This bone has traditionally been assumed to consist of short rod

* Research sponsored by the US Atomic Energy Commission under contract with Union Carbide Corporation.

(L. Trabeculum, a little beam) or of small plates. It is not at all easy to distinguish between these alternatives when examining thin sections by normal microscopic techniques. The distinction is, however, important, because the relation between the volume of bone and the surface area of bone will be quite different in the two cases. The bone volume is more significant in the dosimetry of γ -rays and hard β -particles, while the surface area of bone is the dominant factor in the dosimetry of α -particles. The ICRU model, based upon plates, leads to quite unrealistic values for the relative volume of bone in the tissue.

It is therefore important to obtain a knowledge of the actual arrangement of the bone, in three dimensions. For this purpose low magnification ($\times 10$ – 100) scanning electron micrographs were taken, of the trabecular bone in a lumbar vertebral body. A special technique was developed for polishing the bone surface under liquid nitrogen, using the hard-frozen marrow to preserve the bone from damage. The photographs of the bone, after removal of the marrow, give most vivid impressions of the bone structure in depth, and at the same time show an accurately defined cross-section. It is found that the bone structure varies in a remarkable manner from one part of the vertebral body to another, sometimes consisting predominantly of rods, sometimes entirely of twisted bony plates, but most often of a mixture of the two.

Measurements of the relative area and of the perimeter of the polished bone surface were made on two sections at right angles. Both quantities were approximately constant across the vertebral body, in spite of the varied appearance of the structure. From these figures for area and volume one can calculate the proportion by volume of bone in the tissue (13%) and the area of the bone-marrow interface (28 cm² per ml of trabecular bone). These figures agree with our previous chemical analysis of childrens' bones, and with a number of independent measurements on thin microscope sections.

268 New methods of radiation dosimetry in bone.

F. W. SPIERS, MRC Environmental Radiation Unit, General Infirmary, Leeds (UK).

Considerations of the location and radiosensitivity of tissues in bone are given which indicate that the tissues relevant to long-term radiation effects are those within the marrow spaces in trabecular bone. Theoretical and experimental methods of determining the absorbed dose to tissues in trabecular bone from bone-seeking radionuclides are then described.

The theoretical method is based on the assumption that ionizing particles cross the marrow spaces in approximately straight lines and the energy lost by a particle as it traverses linear paths of different length is calculated. Assumptions as to the geometrical shape of the cavities are avoided by measuring, with a scanning microscope, the distributions of path lengths through the trabeculae and through the marrow spaces of post-mortem bone specimens. Monte Carlo calculations are then used to determine the dose to bone marrow from β -emitters ranging from ³⁵S to ⁹⁰Sr + ⁹⁰Y.

Experimental methods have been developed in which the marrow in a given bone specimen is replaced by fine-grain lithium fluoride as an internal dosimeter. Results have so far been obtained for bone irradiated externally by X-rays and for animal bone containing ⁹⁰Sr. Further work is in progress to make exact replicas of specimens of trabecular bone; radionuclides can then be incorporated uniformly in these replicas or deposited as surface contamination on the trabeculae. The dosimetry of any β emitter, deposited in replicas of human bone, can then be investigated experimentally.

269 Mensuration of trabecular bone for dosimetric purposes.

P. J. DARLEY, MRC Environmental Radiation Unit, General Infirmary, Leeds (UK).

Characterisation of the highly complicated structure of trabecular bone is one of the main problems in the calculation of radiation doses to the critical soft tissues contained within it. Early methods of calculation, which assumed regular geometry, were seriously hampered by the difficulty of identification and measurement of formalized geometrical parameters in the case of actual bone samples. A new approach to the problem however, specifies the structure of the bone in terms of linear paths which ionizing particles can take in traversing both the marrow cavities and the trabeculae. This method has the advantage that such path lengths can be easily and unambiguously measured and conveniently expressed in terms of probability distributions.

To provide such mensuration data an automatic scanning system has been developed which can rapidly measure and analyze path lengths on microradiographs of thin bone sections. Scans in different directions and sectioning planes have confirmed the presence of symmetries in the trabecular structure which enable a general distribution to be generated for particular bones. Typical distributions and other parameters of interest which can be obtained by the above method will be discussed.

270 Monte Carlo calculation of β particle dose in trabecular bone. JOAN R. WHITWELL, MRC Environmental Radiation Unit, General Infirmary, Leeds (UK).

The dose effects of β particles in trabecular bone have been calculated by a Monte Carlo method. The physical dimensions of the trabecular structure of a given bone are described by distributions of linear path lengths through both the marrow cavities and the bone trabeculae. A random path through the bone, weighted according to the distributions, is then formed, and the dose contribution to a particular cavity, from every trabecula within a distance equal to the range of the particle from the cavity is calculated. The variation of LET along the particle track is allowed for by using the range-energy formula $R = AE^m$ (A and m constants, $m > 1$).

Calculations are made for mono-energetic particles, and the results for a given radionuclide are derived by a weighted summation over the β particle energy spectrum, giving the mean dose in any cavity surrounded by bone of the structure characterized by the distributions.

271 Measurement of mean marrow dose in pig bone containing ^{90}Sr . G. D. ZANELLI, MRC Environmental Radiation Unit, General Infirmary, Leeds (UK).

Thermoluminescence methods of dosimetry have been used to determine the mean marrow dose in specimens of trabecular bone of a pig which had been fed on a diet containing ^{90}Sr . The final amount of $^{90}\text{Sr}/\text{g}$ of wet bone has been estimated at $0.154 \mu\text{Ci}$.

The bones were first cut into sections having either fine or coarse trabeculation and the marrow was washed out using pressurized warm water. Thermoluminescent grade LiF of mean grain size $2.5 \mu\text{m}$ was shaken into the marrow spaces and left there for 10-12 days. The LiF was then removed by vibrating the bones at high frequency in acetone and subsequently dried. The light emitted per unit weight was determined using a commercial TLD reader. Previous calibration with ^{60}Co γ -rays enabled the mean marrow dose in rads/day to be derived.

The ^{90}Sr content of the specimens was determined by dissolving small amounts of bone in concentrated nitric acid and counting in a calibrated well-type GM tube. This allowed the results to be reduced to a common basis of $1 \mu\text{Ci}/\text{g}$ of bone.

272 The dosimetry of α -emitting bone seekers. G. C. BUTLER, N. T. GRIDGEMAN and R. S. MCCULLOUGH, Division of Biology, National Research Council of Canada, Ottawa (Canada).

"The available biological data suggest that induction of malignant change should be regarded as the limiting factor in considering maximum permissible levels for bone . . ." (opening statement of *ICRP Publication 11*). Because of the short range of α -particles in tissues and the highly localized deposition of some α -emitters (thorium and plutonium on endosteal surfaces), doses must be determined with more precision than "the average dose to the whole skeleton." There is developing a consensus that osteogenic sarcomas induced by bone-seeking radionuclides arise in a thin layer of cells lining endosteal surfaces of bones (see, for example, *ICRP Publication 11*). Therefore this paper will present calculations of the doses to these cells resulting from the uptake to blood of ^{226}Ra , ^{228}Ra , ^{232}Th , ^{228}Th and ^{238}Pu . Calculations for the first and last of these radionuclides are straightforward with the equations provided by C. W. Mays. Complications arise in the case of the other three radionuclides because of their radioactive daughters and the different patterns of deposition for radium and thorium; for this reason a simple three-compartment model is used to assist in the formulations.

The radiation doses estimated as described above have been used to evaluate the relative toxicities of bone-seeking radionuclides.

273 Some attempts at estimating the microdistribution of doses in the organism of radioactively contaminated animals, by means of thermoluminescent dosimetry and autoradiography. N. RACOVEAU, H. HERSCOVICI, N. IONESCU-GALBENI and GEORGETA MARINESCU, Radiation Hygiene Laboratory, Institute of Hygiene, Bucharest (Romania).

In the case of internal contamination, the microdistribution of doses is of primary importance for the biological effects which result from local irradiation with alpha and low energy beta rays.

To achieve a better estimation, the microdistribution of doses in artificially contaminated animal tissues and phantom organs has been comparatively studied by means of quantitative autoradiographic techniques and thermoluminescent dosimetry.

The size of storages that were found by using both methods, as well as the sensitivity and versatility of the methods are being analysed in the paper; some applications are being made to the estimation of the

dose in the bronchial epithelium after inhalation of ^{222}Rn and daughter products as well as of bone dose, intestine dose, and doses in other organs after contamination with ^3H -Thymidine and other radionuclides.

274 The dosimetry of radioisotopes incorporated in bone using cavity ionization theory. T. E. BURLIN and R. J. SNEELING, Department of Mathematics and Physics, The Polytechnic, London (UK).

Various approaches have been adopted in estimating the absorbed dose to the soft tissue inclusions in bone, in which β and γ emitting isotopes are incorporated. In essence, the problem is identical with that met in dosimetry with ionization chambers, where the dose in the cavity must be related to the dose in the surrounding wall. In the past, theories of cavity ionization have been valid only for cavities with linear dimensions very much smaller than the range of the directly ionising particles, but a recent theory removes this restriction and can therefore be used to determine the absorbed dose to soft tissue inclusions in bone. The average dose and the dose distribution in the soft tissue inclusion is calculated by cavity theory for bone containing β and α emitters. The results are compared with those of earlier workers.

RADIATION PROTECTION POLICY AND ADMINISTRATION II

275 Invited paper. Professional responsibilities of the health physicist in relation to the medical profession. B. LINDELL, National Institute of Radiation Protection, Stockholm (Sweden).

The medical uses of ionizing radiation and radioactive substances cause the highest present man-controlled exposures of both workers and members of the public. These applications might therefore seem to constitute a forgotten area in the field of radiation protection, until one recalls that the present high standards of protection in general have gradually developed from a platform already provided by the medical physicist before the days of nuclear energy and artificial radioactivity.

As an individual, the health physicist may or may not carry a responsibility also in the medical field. It is a matter of local administration whether a medical physicist considers himself also a health physicist, and whether it is one and the same or different authorities which look into the protection problems within and outside medical establishments.

As a representative of the discipline health physics or radiation protection, however, the health physicist belongs to a group which is influencing policy and decisions through numerous organizations and institutions. The discipline as a whole will always carry part of the responsibility for good protection standards also in the medical field.

Health physics in relation to the medical profession has often been identical to medical physics applied to radiotherapy and, more recently, to the diagnostic uses of radioactive substances. With the exception of supervision and advice given by certain competent authorities dealing with inspection and regulations, however, little assistance has been given by the medical physicist/health physicist as regards the diagnostic uses of X-rays.

A review is given of the present situation with regard to actual and potential exposure of personnel and patients in various medical procedures. Some new developments and interesting trends are discussed and special consideration is given to problems relating to the protection of the patient. The advantages and disadvantages of some measures which have frequently been suggested for dose reduction are presented and appraised. An attempt is made to answer the question which has often been raised: Do the current medical uses of ionizing radiation involve unacceptable exposures?

276 Oral presentation. Radiation recordkeeping in the United States: a central repository. C. F. EASON, Assistant for Workmen's Compensation and Radiation Records, US Atomic Energy Commission, Washington D.C. (USA).

Employers using sources of radiation in the United States have accumulated quantities of occupational radiation exposure information. How much of this information should be kept, for how long and for what purposes is subject to varying views. It is argued that conservatism in recordkeeping procedures is justified where legal considerations are involved. Others point out that while radiation exposure records provide useful information as to protection practices, most personnel monitoring results are not accurate indicators of dose to the body or to the critical organs of the body. Assuming that there is a need for maintaining certain radiation exposure records and for encouraging uniformity in recordkeeping, is there merit in including within the system a central repository? What would be its value with respect to evaluating radiological health and safety programs; in indicating the need for remedial action where trends and experience in increased radiation exposure suggest ineffective

control; in considering and developing modifications to existing radiation protection standards and procedures; and in providing an index of identification and exposure information which could be of value to both employees and employers in tracing an individual's occupational radiation exposure history? Would such an index be of importance to employers and others in view of the growth of services utilizing transient labor? Finally, how does the central recordkeeping system work in the United States; who is participating; and what has been the experience of the AEC to date in the operation of its central repository?

Training

Rapporteur Presentation

(Withdrawn)

277 Radiation protection training. D. A. WATSON, T. J. MOSS and R. WILSON, Ontario Hydro, Toronto (Canada).

This paper describes the radiation protection training program implemented at nuclear power stations operated by Ontario Hydro, a public utility providing electrical power to the Province of Ontario. At present there are two operating stations—NPD-2 (25 MWe) and Douglas Point (200 MWe) with two under construction, Pickering (4-500 MWe units) and Bruce (4-750 MWe units).

The radiation protection program is administered by two groups within Ontario Hydro—the Medical Services Division and the Operations Division. The Operations Division establishes the radiation protection procedures and carries out the field work in radiation protection. The Medical Services Division has an overall responsibility for radiation protection, establishes policy, approves procedures, provides dosimetry services and carries out training of personnel. The program relies on training of each person to recognize and cope with radiation hazards. Access to the station and work limitations are dependent on the level of training completed.

Personnel are given lectures on atomic structure, radiation theory, radiation exposure, biological effects of radiation and radiation measurement. Lectures are supplemented by films, laboratory experiments, demonstrations and assignments. Examinations are written to qualify for access and working rights. The practical aspects of radiation protection are taught in the classroom and in the field with emphasis on use of protective clothing and equipment, contamination control techniques, operation of instruments, emergency procedures, detailed operating procedures and field assignments. This training involves about 170 man-hr.

~~This radiation protection program has been followed for eight years and involves several hundred atomic energy workers.~~

~~The effectiveness of such a program may be judged by the ability of trained staff to control their external and internal radiation exposures within prescribed limits and minimize their total man-rem by dealing competently with radiation hazards encountered in their day-to-day tasks.~~

278 Training courses on radiological health and safety. D. L. O. HUMPHREYS, Radiological Protection Service, Birmingham Regional Centre, Queen Elizabeth Hospital, Birmingham (UK).

Specially arranged courses on radiological health and safety are held at Birmingham for various groups of personnel, e.g. industrial radiographers, factory safety officers, dental staff. The aim of the courses is to acquaint each group with the Regulations and/or Codes of Practice with which they are concerned and to deal thoroughly with individual problems; the lecturers are drawn from the staff of the Radiological Protection Service and every effort is made to pass on relevant information and experience gained by the staff whilst carrying out radiological surveys, investigating accidental exposures etc., in various types of establishment.

The paper discusses briefly typical programmes of various courses and gives details of the questions and problems most commonly posed.

279 Training in radiological protection for reactor health physicists. J. R. A. LAKEY, Royal Naval College, Greenwich (UK).

This paper describes a new course, the Nuclear Radiation Protection Course provided by the Nuclear Department of the Royal Naval College, Greenwich to meet the standards of the Veale Committee and to prepare the health physicist for work with Pressurised Water Reactors. The Nuclear Department was founded in 1959 with the terms of reference to "Establish a centre for Naval Nuclear education and training of officers and to provide the necessary academic courses in Nuclear Science and Technology." Most candidates for the course are graduates (exceptionally medical officers) and the minimum entry qualification is the Higher National Certificate. Half of the lectures are foundation subjects including atomic and nuclear physics, reactor physics, reactor engineering, reactor materials and radiochemistry. The reactor engineering section is designed to give the student an understanding of the principles of reactor plant information; reactor

plant operation and safety is taught with the aid of a reactor simulator. The remaining lectures cover the normal topics in radiation protection but give special attention to instrumentation, reactor shielding dosimetry calculations, the study of reactor accidents and their management. A sequence of standardised practicals is followed by an experimental project occupying one-third of the time on the 12-week course. Projects undertaken by the students included ^{41}Ar monitoring, alpha spectrometry and monitoring of fission products escaping to the atmosphere during a reactor accident. The Department uses a 10 kW JASON research and training reactor, health physics and radiochemical laboratories, and is well equipped for radiation dosimetry. Visiting lecturers and visits to nuclear establishments are arranged to give the student a view of the field of health physics in the United Kingdom. Students sit two 3-hr papers, present a written thesis on their project and are examined orally. Although the addition of reactor engineering to the syllabus of health physics training produces an intensive course, the students leave with some useful practical experience and can be rapidly accepted into the operating team of a nuclear reactor.

280 A new 2 yr part-time modular M.Sc. course in health physics at the University of Salford. B. BROWN, Department of Pure and Applied Physics, University of Salford (UK).

Commencing in September 1970, the Department of Pure and Applied Physics of the University of Salford is offering a 2 yr part-time course in Health Physics. The course is oriented towards the needs of industry, hospital boards and local authorities and will be of interest to industrial safety officers, hospital physicists, public health inspectors, etc.

To provide the flexibility necessary to meet the particular interests of individual students the course is arranged on a modular basis, each module occupying three full weeks. Eight modules will be offered, two of an introductory nature and six further self-contained courses as follows:

1. Detection and Measurement of Ionising Radiations
2. Radiobiology
3. Control of Occupational and Environmental Radiation Hazards and Radioactivity
4. Human Acoustics and Noise Control
5. Dust Control and Prevention
6. Heating and Lighting Control.

Each module may be taken in isolation as a short single course on a particular aspect of health physics. However by satisfactorily completing five modules, together with a project a student will be eligible for

the award of the M.Sc degree of the University. The three-week modules are being offered one per term over the two years with the exception of the two introductory modules which are being offered in September and October each year in order to enable students to begin the course each year. Students will be provided with a suitable reading list to assist their private study in between attendance at the University.

Candidates for the M.Sc degree will be required to pass examinations appropriate to their choice of subjects.

281 Two British M.Sc. courses in radiation. B. BROWN, Department of Pure and Applied Physics, University of Salford, and BABBETTE E. STERN, Radiation Unit, University of Surrey, Guildford (UK).

The aims of these courses are to give graduates an appreciation of technical, organizational and research aspects of radiation protection.

Both courses are based on the Veale Committee's recommendations on "Training in Radiological Health and Safety" which was concerned primarily with the provision of adequate numbers of suitably trained radiation safety personnel. A radiation protection officer must be trained in radiation physics, radiobiology and a number of other radiation subjects and consequently he will also be competent to undertake radiation work other than protection.

We accept graduates in any relevant discipline and include some introductory subjects so that the lectures are intelligible to all. The courses are essentially practical ones, aimed to produce useful people.

Although the mixture of disciplines brings problems in teaching, we believe that students with different backgrounds learn much from each other. This applies also to students from different countries. We are fortunate in having had students from Africa, Australia, the Americas and Asia as well as Europe, and a purpose in reading this paper is to learn from our overseas colleagues their views on this type of course for senior radiation workers.

282 Field training for graduate students in health physics, radiological health and related disciplines.* C. B. MEINHOLD, Health Physics Division, Brookhaven National Laboratory, Upton, N.Y. (USA).

Brookhaven National Laboratory (BNL) has conducted field training for qualified graduate

* Research carried out at Brookhaven National Laboratory under contract with US Atomic Energy Commission.

students for over 15 yr. This paper will describe the present program with emphasis on its relevance to operational health physics. It is felt that the program can provide exceptionally broad experience upon which a student willing to expend the effort can confidently begin a professional career in health physics.

During the first two weeks the student visits each of the major areas of health physics interest. By the use of informative tours and discussions, the responsible staff health physicist imparts a knowledge of the basic philosophies, procedures, and instrumentation he employs in discharging his responsibilities.

At the completion of this orientation phase, the students are individually assigned to a specific health physicist. This creates a "home" for the student with the relationship of that of a junior staff member. The work may range from routine monitoring to assisting in applied research (hopefully a combination of these two).

Concurrently, the students participate in assigned "laboratory-like" health physics projects and experiments throughout the Laboratory on a rotating basis. This is done to insure that every student will become familiar with the equipment and methods of health physics investigations, surveys, and research.

We believe that a very vital part of our program is the student seminar. The daily get-together of the 20 or so students from the various universities and interested members of the BNL staff invariably produces lively and enlightened discussions.

OCCUPATIONAL MEDICINE II

283 Oral presentation. Bronchopulmonary lavage: a means for the removal of inhaled radionuclides.*
R. C. PFEGER, D. H. SESLINE, J. W. HARVEY and R. O. McCLELLAN, Fission Product Inhalation Program, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico (USA).

The use of bronchopulmonary lavage with an isotonic saline solution or a calcium chelate of diethylenetriamine pentaacetic acid (DTPA) in saline solution for the removal of inhaled radionuclides from the lung is described. Eighteen beagle dogs were exposed via inhalation to a $^{144}\text{CeCl}_3$ aerosol with an activity median aerodynamic diameter of 1.2 to 2.8 μ . A group of six dogs received no lavage treatment. The left lungs of 12 dogs were lavaged; 2 with saline and 2 with DTPA on (a) day 0 (the day of exposure), (b) day 5 post-exposure, or

(c) day 0 and 5 post-exposure. Profile scanning of the dogs was used to evaluate the change in lung burden with time. The lung burden at sacrifice (28 days post-inhalation exposure) as percent of the total initial lung burden was 68% for the unlavaged control animals, 60% for the saline lavaged dogs and 31% for the animals lavaged with DTPA. The dogs that were lavaged on the day of exposure had a relatively lower lung burden of ^{144}Ce than those lavaged on day 5 post-exposure; suggesting a greater effect of lavage when the treatment is performed soon after exposure. The results indicate that a bronchopulmonary lavage with a chelating agent in the medium may be an effective means of reducing a lung burden of individuals that have accidentally inhaled a radionuclide in a relatively soluble form. The removal of the radioactive material would reduce the radiation exposure to the lungs and the potential for radiation-induced disease.

284 Oral presentation. Metabolic behaviour and toxic side effects of chelating agents. V. VOLZ, A. SEIDEL and M. VLADÁR, Institut für Strahlenbiologie, Kernforschungszentrum Karlsruhe (Germany).

The calcium chelates of ethylenediaminetetraacetic and diethylenetriaminepentaacetic acids (EDTA and DTPA) belong to the most effective means after internal contamination by radioactive substances in man, although in several cases complications were observed.

Since recent investigations with ^{14}C -labelled chelating agents suggest their metabolic degradation *in vivo*, the toxic side effects might be due to their metabolites, too. Detailed turnover studies indicate, however, that only a small fraction of the chelates might be metabolized, but this would be masked by radioactive impurities and/or products of radiolysis present in the injection solutions. Comparison of the plasma disappearance curves after injection of labelled calcium-, yttrium- and chromium-EDTA suggest the influence of the chelated metal ion on the distribution space of EDTA.

The results of haematological and chemical screening tests with rats after intraperitoneal injections of calcium-EDTA, calcium-DTPA and zinc-DTPA at an acute toxic dosage can be interpreted as indicating a non-specific dehydration which occur upon an intraperitoneal exudation. The disturbance in the blood picture suggest a conditional specific injury, since, on the one hand, they appear in this form in the course of a stress reaction, though, on the other hand, they can be well correlated to the nature and dose of chelates. A masking of specific reactions by non-specific reactions seems possible.

* Research performed under contract with the US Atomic Energy Commission.

285 Oral presentation. The influence of bone remodelling on the effectiveness of DTPA therapy for chelation of ^{239}Pu . A. C. JAMES and N. F. KEMNER, Department of Medical Physics, Royal Free Hospital School of Medicine, London (UK).

Data is presented illustrating the role of local bone resorption in the removal of ^{239}Pu deposited in the bones of immature rats following intravenous exposure. The effects of various treatments with DTPA on the activity of plutonium deposits on bone surfaces undergoing various types of remodelling have been studied. Chelation of plutonium bound in the bone matrix can occur effectively only if the plutonium is first liberated into soft tissue by osteoclast action in the process of bone resorption. The proportion of the total bone surface area undergoing resorption during DTPA therapy thus dictates the efficacy of delayed therapy (commenced after the completion of skeletal plutonium uptake) in reducing the skeletal burden. The effectiveness of promptly administered DTPA is largely due to the chelation of plutonium in the blood, thus preventing skeletal deposition. The results of measurements of the alpha particle dose to the osteogenic cells under the various conditions of remodelling activity and DTPA treatment are also presented. The relevance of this data to the problem of human therapy is discussed.

286 Oral presentation. Rationale for the use of DTPA in the treatment of plutonium contaminations in humans. A. M. FREKE and G. W. DOLPHIN, UKAEA Health and Safety Branch, Harwell (UK).

Plutonium complexed with proteins and smaller molecules in the blood mainly becomes deposited in the bone and liver. However, a small fraction between 5 and 10% of the total amount in the blood is excreted daily in the urine. As plutonium deposited in the body organs is retained for long periods, successful treatment of contaminated humans is based on increasing the urinary excretion and consequently diminishing the amount deposited in the bones and liver. To this end DTPA (Diethylenetriaminepentaacetic acid) has been used in a number of cases where internal contamination of workers has occurred.

Since the therapeutic application of DTPA may become more widespread the authors have attempted to produce a rationale for its use. The mode of entry of plutonium into the body is by wound or inhalation but in both cases there is considerable variability in the amount and rate of transfer of plutonium to the blood. Although external counting over the lung or wound may indicate the total amount at the site of entry, the amount and rate of transfer to the blood will depend upon the physico-chemical state of the

plutonium. The DTPA regime depends more on the rate of transfer to the blood rather than the amount present at the site of entry.

As DTPA injections are known to clear the blood of complexed plutonium, it is possible to investigate the rate of transfer of plutonium from the site of entry to the blood by measurement of the urinary excretion following a planned series of DTPA injections. Several initial DTPA injection regimes have been tested in a simple model with the object of establishing an optimum regime for evaluating the rate of transfer of plutonium to the blood and its variation with time. The indications for continuous DTPA treatment are discussed.

287 Oral presentation. A review of the use of DTPA in the treatment of internally deposited plutonium. G. B. SCHOFIELD, UKAEA Windscale Works, Sellafield (UK).

Attempts have been made over the years to immobilize internally deposited or circulating plutonium by the use of chelating agents. These have included EDTA, zirconium malcate, sodium citrate, desferrioxamine, penicillamine and DTPA. This latter has proved to be the most effective agent and has for many years been the only therapeutic compound used at the Windscale Works of the Atomic Energy Authority in the treatment of cases of internally deposited plutonium.

This paper reviews the efficiency of treatment by this compound in 17 people who have been internally contaminated during the period 1963-1969. These patients include six with plutonium contaminated wounds, ten inhalation cases and one whose internal contamination was of unknown origin. It is further suggested that DTPA may be used as a diagnostic as well as a therapeutic agent, since any resulting enhancement of plutonium urinary excretion will indicate the presence of circulating and available plutonium.

RADIATION EFFECTS IN MAN II

(Withdrawn)

288 Oral presentation. Dosimetric and cytogenetic studies in Brazilian areas of high natural activity. T. L. CULLEN, Instituto de Física, Pontificia Universidade Católica, Rio de Janeiro and J. C. CABRAL DE ALMEIDA, Instituto de Biofísica, Universidade Federal, Rio de Janeiro (Brazil).

In Guarapari the population of 6000 lives in a radioactive environment approximately 10 times normal levels. After radiation levels were mapped, lithium fluoride dosimeters were randomly distributed and 340 were recovered. The air was measured for radon, thoron and long lived content, and food

Capillary changes in radiation workers. L. VASKOV (Bulgaria)

~~and water were radiochemically analysed. A random sample of 107 people living in the area for at least 10 yr were chosen for a cytogenetic study and compared with a control group of 82. From the exposed population 7711 metaphases were scored for chromosomal aberrations and compared with 6091 metaphases from the control group. The results showed no statistically significant difference.~~

289 Oral presentation. Incidence des leucémies tardives survenant chez les cancéreux irradiés. S. SIMON, Centre Anticancéreux de l'Université de Bruxelles (Belgium).

Étude portant sur des malades ayant reçu une irradiation totale au cours d'un traitement par rayons X ou par radium et ayant eu une survie supérieure de 5 a. Les traitements ont été effectués entre 1925 et 1962.

L'enquête porte sur 1438 cas de cancers utérins traités par radium, 2042 cas de cancers du sein traités par rayons X, 1356 cancers de la tête traités par appareils moulés radifères et 1064 cancers de la tête traités par curiepunkture. Comme élément de comparaison, nous disposons de 1464 épithéliomas superficiels de la face traités par radiothérapie à bas voltage n'entraînant aucune irradiation générale.

L'ordre de grandeur des doses reçues en irradiation totale est calculé pour les quatre catégories.

Le relevé des "seconds cancers" observés dans les différents groupes, après un délai minimum de 5 a, montre que les leucémies apparaissent en nombre significativement supérieur à la normale dans les trois premiers groupes; le dernier groupe et les témoins n'ont pas présenté de leucémie. Il semble donc qu'il y a un seuil d'action qui n'est pas atteint lorsque l'irradiation totale résulte d'une curiepunkture au niveau de la tête; dans ce cas, les doses sont comprises entre 1 rem et 6 rem au niveau du pubis et 5 rem et 30 rem au bord supérieur du sternum. Les autres modes d'irradiation donnent des valeurs d'irradiation totale plus élevées.

L'étude du groupe fort important des "seconds cancers" localisés dans le tube digestif ne montre aucune différence entre les cinq groupes envisagés, et donne des valeurs équivalentes à celles fournies par les statistiques belges de mortalité, pour les tranches d'âge correspondantes.

Incidence of delayed leukaemia in irradiated cancer patients.

Study of patients who have received total irradiation in the course of X-ray or radium treatment and

having survived for more than 5 yr. Treatment was carried out between 1925 and 1961.

The investigation deals with 1438 cases of uterus cancers treated with radium, 2042 cases of breast cancers treated with X-rays, 1356 cancers of the head treated with moulded apparatus containing radium and 1064 head cancers treated by curiepunkture. As a comparison factor, we have available 1464 surface epithelial cancers of the face treated with low voltage radiotherapy involving no general irradiation.

The order of magnitude of the doses received in total irradiation is calculated for the four categories.

The records of "second cancers" observed in the different groups, after a minimum period of 5 yr, show that leukemias appear in numbers that are significantly higher than the normal in the first three groups; the last group and the controls have not exhibited leukemia. It would appear that there is a level of activity which is not reached when total irradiation results from a curiepunkture at the head level; in this case, the doses are between 1 rem and 6 rem at the level of the pubis and between 5 rem and 30 rem at the top edge of the sternum. The other methods of irradiation give higher total irradiation levels.

The study of the very important group of "second cancers" located in the digestive tube shows no difference between the five groups considered and gives values equivalent to those furnished by Belgian mortality statistics, for the corresponding age groups.

290 Oral presentation. Observation of radiation induced cancers in an exposed environmental population. G. W. DOLPHIN, UKAEA Health and Safety Branch, Harwell (UK).

Risks of radiation induced cancer have previously been evaluated by the author in studies of data from exposed groups such as radiotherapy patients and atomic bomb survivors. On the assumption of a linear dose effect relationship the risk of cancer induction was found to be $100/10^6$ man-rads. The validity is discussed of using this risk value at doses lower than 10 rads in estimating the number of induced cancers in an environmental population following an accidental release of radioactivity from a nuclear installation. Calculations have been made at several dose levels to show the size of an environmental population in which the radiation cancers may be observed as a statistically significant increase over the natural incidence. The effect of other factors on the detection of radiation induced cancers in a population are also discussed.

291 Oral presentation. Radioactive iodine and cancer of the thyroid in Norway. P. OFTEDAL, Norsk Hydros Institute for Cancer Research, Montebello, Oslo (Norway).

Radioactive iodine contamination from fall-out has been measured in Norway since 1956, mainly by the Norwegian Defense Research Establishment.

On the basis of the ^{131}I content in milk in the various parts of the country, growth of the human thyroid during childhood and adolescence, and standard values for milk consumption, doses absorbed in the thyroid gland have been calculated for the various age cohorts. Maximum thyroid doses appear to have been received by those born in 1956-58 and amount to about 2 rads. Mean thyroid dose for all born in 1945 to 1962 is about 1.2 rads. For those born in 1945 the mean dose is about 0.5 rads.

Using the most conservative estimates of thyroid sensitivity to cancer induction (a total of 100×10^{-6} cases per rad for children, and 40×10^{-6} cases per rad for adults), and for ^{131}I radiation RBE (equal to 1.0), it may be calculated that an increase of about 5 cases/yr should be found in the relevant groups.

According to the data from the Norwegian Cancer Registry, thyroid cancer frequency has been increasing during the last 10 yr. The increase is found in age cohorts below 49 yr, and predominantly in women. The total increase is about 15-20 cases, which is approximately a doubling of the number of cases below 49 yr of age.

The data will be presented and possible explanation will be discussed.

292 Oral presentation. Risks of chromosomal diseases due to small parental exposures. H. B. NEWCOMBE and J. F. MCGREGOR, Biology and Health Physics Division, Atomic Energy of Canada Ltd., Chalk River (Canada).

Conditions such as mongolism and Klinefelter's syndrome, which are due to additions or deletions of whole chromosomes or major parts of chromosomes, affect nearly 1% of live born humans and could perhaps constitute a major component in the genetic damage appearing in the first generation following radiation exposure. Although large doses of ionizing radiations undoubtedly cause such chromosome changes, it is not known whether low doses do, and the shape of the dose-effect curve at its low end is unlikely to be determined from human epidemiological studies. The required comparisons are necessarily laborious, even when carried out on lower organisms, because of the increasingly large numbers of progeny that must be examined to detect the effects of progressively lower radiation doses.

Data bearing on assessment of the human risk of chromosomal disease which have been obtained from studies of gross malformations of trout embryos and hatchlings from irradiated sperm will be discussed.

RADIATION PROTECTION STANDARDS III

293 Oral presentation. A mathematical model for establishing the benefit vs. risk criterion on diagnostic radiology.* E. A. PORT and H. CEMAER, Technological Institute, Northwestern University, Evanston, Illinois (USA).

This paper describes the development and application of a decision theory model for radiological procedures. A multistage decision model has been constructed with payoff matrices and experimental costs based upon medical judgment. Conditional probabilities are continually updated to keep pace with changing conditions. The model can be applied by any physician who has access to relatively low-powered computer facilities; and can be used to determine whether a specific radiological procedure is indicated. The structure of the model, the evaluation of parameters and an application pertinent to the chest roentgenology of children will be given.

294 Oral presentation. La protection radiologique des individus du public: discussion des problèmes posés, solutions actuelles et perspectives futures. G. LACOURLY, Département de la Protection Sanitaire, CEA, Fontenay-aux-Roses (France).

La protection radiologique repose sur l'établissement de normes de protection et sur une surveillance permettant de s'assurer que les normes fixées ne sont pas dépassées.

Les normes de base s'expriment en doses maximales admissibles pour les personnes professionnellement exposées et en doses limites pour les personnes du public.

Pour les premières, la surveillance peut s'exercer directement sur les personnes, et les doses d'irradiation reçues sont évaluées d'une façon relativement sûre. Pour les secondes, la surveillance pouvant difficilement s'exercer directement sur les personnes est réalisée soit sur la source, soit sur le milieu récepteur ou encore sur certains vecteurs de la contamination. La dose délivrée au groupe de population critique est alors évaluée au moyen de calculs reposant sur un certain nombre d'hypothèses et mettant en jeu un grand nombre de paramètres.

* Supported by a training grant from the US Public Health Service.

Pour la commodité de la surveillance, on a cherché à établir des niveaux-limites ou des niveaux-guides, applicables au milieu récepteur, puis au rejet lui-même.

Lorsque la dose d'irradiation a pour origine plusieurs radionucléides émanant de plusieurs sources, l'établissement de niveaux-limites doit tenir compte, d'une part, de la contribution relative à la dose des différents radionucléides et des différentes sources de pollution, et, d'autre part, de la capacité d'acceptation du milieu pour ces radionucléides.

Pour l'hygiéniste, l'expression des niveaux-dérivés en pourcentages de la dose-limite fixée pour les individus du public est la plus pratique, car elle permet une application facile et immédiate des conséquences des différents rejets et de leurs effets cumulatifs.

Pour l'exploitant, qui a besoin de savoir quels sont les niveaux-limites des différents radioéléments, qu'il ne doit pas dépasser, l'activité par unité de temps reste la meilleure expression des niveaux-guides de rejet.

Tout le problème consiste donc à établir, pour chaque rejet, une table de correspondance entre les deux systèmes d'unités.

Radiological protection of individual members of the public: discussion of the problems, current solutions and future perspectives.

Radiological protection rests on the establishment of protection standards and on monitoring to confirm that these standards are not exceeded.

The basic standards are expressed as maximum permissible doses for persons exposed in the course of their work and dose limits for members of the public.

For workers, monitoring can be carried out directly on the person and the doses received are assessed in a reasonably sure way. For the public, direct monitoring is difficult and monitoring is therefore carried out either at the source or in the receiving medium or in certain contamination vectors. The dose delivered to a critical population group is then evaluated by calculations which involve a number of hypotheses and a considerable number of parameters.

To make the monitoring convenient, one tries to establish limiting levels or guide levels applicable to the receiving medium or even to the discharged waste itself.

When the dose originates from several radionuclides emitted from several sources, the establishment of limiting levels must take account on the one hand of the contribution to the dose from those different radionuclides and different sources and on the other hand, of the capacity of the environment to accept these radionuclides.

The most practicable solution for the hygienist is to express the derived levels as percentages of the dose limit for members of the public, since this allows a simple and immediate assessment of the consequences of different discharges and their cumulative effects.

For the operator, who needs to know the levels of different radioelements which he must not exceed, the activity per unit time in the discharge remains the best form of guide level.

The whole problem thus reduces to the establishment of a table of correspondence between the two systems of units for each discharge.

295 Oral presentation. Standards for prosthetic devices containing radionuclide power sources. M. L. SMITH, McDonnell Douglas Astronautics Co. and G. CROOK and R. MOORE, Hanford Environmental Health Foundation, Richland, Washington (USA).

The eventual use of radionuclide power sources in prosthetic devices such as pacemakers and nerve stimulation units will require national and international regulations to ensure protection of the public. These regulations must be based on standards that do not make ownership and use of these devices unnecessarily difficult. The standards required may also fall under more than one Government agency. A brief summary of areas which must be considered are as follows:

1. Maximum radiation and heat fluxes to be permitted at the interface between the device and tissue, and the total that may be released to the body;
2. Marking of the device and identification of the user;
3. The standards that must be met in recovery of the devices, and the inherent problems related to posthumous handling of the patient;
4. Standards for minimum times for integrity of the radionuclide encapsulation;
5. Accident survival criteria for the device and standards for meeting these criteria.

The text of this paper suggests the basis for standards in these and other areas.

296 Oral presentation. A proposal to quantify the design of engineered safeguards for the protection of personnel against high intensity radiation sources according to the extent of the potential hazard. R. E. HOLMES and L. CAVE, Atomic Power Constructors Ltd., Sutton (UK).

At the present time there exists no agreed standard of design of the engineered safeguards to protect

personnel against accidental exposure from high intensity radiation sources. The provision of safeguards such as dose rate alarms, interlocks and operating instructions are usually provided according to the subjective judgement of the designer or operator. Wide variations in the actual degree of protection exist for comparable hazards. In this paper it is proposed that engineered safeguards be provided in accordance with the extent of the degree of risk. A quantitative scale of probability of overexposure according to the extent of physiological damage which would result from the overexposure is utilised to propose a scale of integrity of engineered safeguard against potential personnel dose.

ENVIRONMENTAL MONITORING

Discussion Group

297 Environmental radioactivity monitoring of Argonne National Laboratory. J. SEDLET and F. S. IWAMI, Argonne National Laboratory, Illinois (USA).

The environmental monitoring program at ANL is described and discussed. The principal purposes of the program are to measure the natural radioactive content of the ANL site and its environment and to determine the origin, identity and magnitude of any radioactivity not naturally present. The sampling and radiochemical analytical program designed to accomplish these objectives is presented. The program concentrates on water and air as the most common media for dispersing radioactivity, although other types of materials are also collected and analyzed regularly and are important in understanding the environmental radioactivity and in evaluating environmental contamination.

Methods are described for the determination of total alpha and beta activities, normal and enriched uranium, tritium, thorium, plutonium, ^{41}Ar , a number of fission products and other radionuclides in various environmental materials.

A summary is given of the significant results obtained since the program was initiated in 1948. This includes the range of natural radioactivity in the Argonne environment together with the activity contributed by fallout, Argonne operations and other non-natural sources. It has generally been possible to distinguish between fallout, naturally-occurring activity, activity from Argonne and activity from other localized sources by making the proper choices of kinds and locations of samples and types of radiochemical analyses.

* This work was done under the auspices of the US Atomic Energy Commission.

298 The experience of the Central Electricity Generating Board in monitoring the environment of its nuclear power stations. J. K. JONES, G. LEWIS, H. C. ORCHARD, M. J. OWERS and B. W. SKELCHER, CEGB, London (UK).

The establishment of an environmental monitoring programme for the Central Electricity Generating Board's gas-cooled, graphite-moderated nuclear power stations is described, together with the changes in policy and technique which have been made in the light of operational experience over a period of ten years.

The initial land environmental monitoring programme was based on the collection and analysis of milk, herbage, root-mat and soil samples and gamma dose-rate measurements. The aquatic environmental monitoring programmes mainly comprised gamma dose-rate measurements on shore together with the analysis of various samples depending on the materials available at individual stations. These programmes are considered with particular reference to statutory requirements, and monitoring programmes then existing in the United Kingdom. District survey laboratories were set up close to each nuclear power station for initial sample preparation and gross alpha and beta analysis; analysis for specific nuclides was in general carried out at the Central Radiochemical Laboratory which was established in London.

By the mid-1960s it was clear that with the exception of milk, agricultural samples were far from ideal for radiological monitoring purposes. Two alternative sampling systems were chosen for experimental investigation: the deposit gauge (a large "rain-gauge") and the "tacky shade collector" (a wire lamp-shade frame covered with resin impregnated muslin cloth which acts as a collector of atmospheric radioactivity when suspended in the open air). Field trials of the two systems were carried out, the results of which led to the selection of the tacky shade collector as the better all-round collector system for use in the environmental monitoring programme.

The new land environmental monitoring programme and the additional food chain sampling and analysis which would be required if the tacky shade collectors were to show any release from a station, are described. The occurrence of certain site conditions have afforded the opportunity to compare the performance of tacky shade collectors with measurements made on milk samples, which in this instance confirmed in practice that the tacky shade collectors are capable of detecting discharges with good sensitivity.

299 Environmental radiological surveillance in Texas.

M. C. WUKASCH, J. M. LONG and L. M. COOK, Division of Occupational Health and Radiation Control, Texas State Department of Health, Austin (USA).

With Texas having the third largest licensing program, and the largest geographic area among the several Agreement states, the burden of measuring hazards incident to the protection of both public and radiation worker health is very extensive. Legal responsibility for the program is vested in the Texas State Department of Health.

The establishment and maintenance of various environmental surveillance networks for detection of radioactive material is an important part of this mandate. Specific purposes for instituting a program in Texas range from obtaining baseline information for use during radiation accidents to monitoring the environmental vectors during nuclear testing.

In addition to the collection of air, water, milk and diet samples for the Nation-wide programs, state networks were established for the collection of water, milk and oysters. Other radiological sampling programs have been utilized for specific projects such as the Nuclear Ship Savannah activities and a nuclear laundry facility in Galveston harbor, surveillance of environment factors around existent research reactor facilities and an extensive water examination program in cooperation with The University of Texas.

The amplitude of each sampling network and selection of individual sampling points are dependent, to a great extent, upon the unique geographical and climatological characteristics found in Texas. Other criteria, not unique to Texas, are the location of centers of high population density and the availability of personnel to collect samples. A healthy development pattern dictates maintenance of current network programs with greatly expanded concentration on selected local sites.

300 Multiparametric measurement of environmental radioactivities. S. MUŽDEKA, A. KORUROVIĆ and D. STOJANOVIĆ, Boris Kidrič Institute of Nuclear Sciences, Vinča (Yugoslavia).

The paper deals with the problems of elements and organisation of a measuring system used for multiparametric measurements of environmental activities.

The problems of structure of such a measuring system as well as the possibility to form a measuring net by the use of this system are discussed.

Details are described of the system which includes sources of analogue: direct-current and pulse signals, and enables necessary elementary interpretation of

obtained data and their registration or transmission in the digital form.

The presented measurement results have been obtained by a continual observation of the low gamma radiation activity, the concentration of the long-lived radioactive aerosols and the meteorological parameters at one point during the month of January 1969.

The D.C. system for measurements of low-gamma radiation activity has the sensitivity of $0.4 \mu\text{R}/\mu\text{r}/\text{mV}$. The continuous control of radioactive aerosols is realised by an anticoincident circuit with high sensitivity such as 1 pulse/min for $5 \times 10^{-14} \text{ Ci}/\text{m}^3$.

301 Survey networks: a new statistical treatment.

G. G. MASTINU, G. ZUCCARO LABELLARTE, Laboratorio Radioattività Ambientale, CSN Casaccia, Rome (Italy).

A statistical treatment of the data yielded by survey networks over a given country has been developed.

The statistical method consists in the evaluation of the correlation line referring to many couples of measurements performed in two different points. The variances of the mean values and of the regression line slopes are then evaluated. These variances result to be substantially equal for different couples of points at the same distance, and to vary smoothly with the distance. As a consequence of these facts, the distance can be considered to represent the average effect of the various factors (physical, geographical, meteorological) which are normally difficult to be taken into account.

The aforesaid analytical procedures led to the preparation of a nomogram for current use, which is also included. The method, when applied to the radioactive surveillance networks, can give an estimated value of the contamination referring to any area of the country. This method allows also the determination, when establishing new networks, of the optimum density of the sampling points in order to achieve a predetermined reliability of the values to be obtained.

This treatment has been successfully tested on the Italian radioactivity survey networks of air and milk. The results obtained confirm the sound quality of this procedure.

302 The influence of diet composition on radioactive contamination in a selected population group. J. SMEETS and E. VAN DER STRICHT, Commission of the European Communities, Luxembourg (EURATOM).

A comparative study was carried out in the European Community, covering the period September

1965–December 1967, concerning the radioactive contamination of the total diet of adolescents. The programme was organized by the Directorate for Health Protection of the European Communities in cooperation with the Member States.

Ten institutes, geographically widespread, participated in this study, i.e. four in Germany, three in Italy, one in France, one in Belgium and one in the Netherlands.

The purpose was to find out to what extent differences in food habits within the Community influenced the intake of radionuclides.

During the period concerned, samples, representing all types of meals, drinks, etc. were taken *every month* for a *whole week* and examined in order to establish the presence of concentrations of ^{90}Sr , ^{137}Cs , stable strontium, calcium, potassium, ^{226}Ra and uranium.

It was possible to establish a significant difference in contamination between institutes, particularly if milk and grain form an important proportion of the food consumed.

The mean values of $\text{pCi } ^{90}\text{Sr/gCa}$ for the various institutes appear to differ by less than factor two, and the intake seems to deviate very little from the mean value for the whole population.

303 Cesium-137 body burden of children in selected institutions in the United States, 1966–1968. A. A. MOGHISSI, Bureau of Radiological Health, Southwestern Radiological Health Laboratory, Las Vegas and R. LIEBERMAN, Bureau of Radiological Health, Southeastern Radiological Health Laboratory, Montgomery (USA).

Since the establishment of the Institutional Total Diet Sampling Network Program by the US Public Health Service, the concentration of a variety of radionuclides in the food of children residing in several children's homes located in the continental United States has been determined. Starting in 1966, urine samples from eight stations were collected. To establish the validity of a 24-hr sample, the volume, pH value, specific gravity, creatinine content and osmolality of the samples were determined.

Cesium and potassium analyses in food and urine were carried out by gamma spectroscopy.

The body burden of children was estimated by the comparison of Cs/K ratio in food and urine, by the relationship between cesium content of urine and the biological half-life of cesium in children, and by a model based on intake.

The differences between results obtained using each of these techniques are discussed.

304 Strontium-90 and ^{137}Cs diet–urine relationships in India. I. S. BHAT and P. R. KAMATH, Environmental Survey Laboratory, Tarapur Atomic Power Station, Boisar, Maharashtra (India).

Urine/diet observed ratios in case of $^{90}\text{Sr}/\text{Ca}$, $^{137}\text{Cs}/\text{K}$ are proposed to be used in estimating dietary intake of ^{90}Sr and ^{137}Cs from urinary excretion estimations. $^{90}\text{Sr}/\text{Ca}$ ORs reported for different parts of the world vary to a great extent. In this study diet–urine relationship in case of $^{90}\text{Sr}/\text{Ca}$ and $^{137}\text{Cs}/\text{K}$ pairs has been established with the co-operation of some volunteers at Tarapur nuclear power station site.

A day's diet and two days urine samples have been collected from about 15 volunteers (adults between 22 yr to 40 yr). These have been assayed for ^{90}Sr , ^{137}Cs and Ca, K by standard methods.

OR values of 0.3 to 0.6 for $^{90}\text{Sr}/\text{Ca}$ and of 0.5 to 1.0 for $^{137}\text{Cs}/\text{K}$ have been obtained in these cases. Use of these OR values has been discussed.

305 Recent measurements relating to the Concorde in-flight radiation warning meter in actual and simulated stratospheric environments. I. J. WILSON, AWRE, Aldermaston (UK).

Measurements were made to investigate potential further developments of the present hybrid detection system of the dose-equivalent ratemeter for the SST Concorde, such as a reduction in the mass of the neutron moderator, and a more direct indication of the Tissue-Star component.

Radiation situations at Concorde cruising altitudes (17–20 km) due to solar proton flares were simulated approximately. Actual stratospheric situations due to cosmic radiation encountered during slow ascents by balloon to ~35 km from Aire sur l'Adour (France), and synthetic situations produced by the partial shielding of high energy accelerator radiation, were used to obtain radiation distributions having a range of quality factors. The measurements made in these simulations related to the directly ionizing, neutron and Tissue-Star components of dose-equivalent rate.

306 Ge(Li) gamma-ray detectors for environmental activity measurements. G. V. WALFORD, Radiation Unit, University of Surrey, Guildford (UK).

Gamma-ray counting with Ge(Li) detectors is now widely established. Their excellent energy resolution and relatively good timing characteristics make them ideal for many applications. However, their low efficiency (when compared with scintillators), the

unavoidable use of cryostats, and high cost, often makes their choice controversial.

This paper evaluates the significant gamma-ray spectrometer parameters, using the minimum detectable activity as the main criterion. An expression for minimum detectable activity has been derived which shows also the significance of the various counting parameters (i.e. energy resolution, efficiency, background, etc.). This expression has been verified experimentally in our laboratory for various Ge(Li) detectors. Sensitivity limits have been successfully predicted for a given spectrometer.

Experimental data is presented to show how sensitivity is affected by coincidence and anti-coincidence counting, pulse shape discrimination and passive shielding.

In appropriate conditions, activities of 10 pCi may be counted routinely with 30 cc detectors. The extent to which the semiconductor spectrometers can be used to monitor environmental levels has been examined. Although sample reduction by ashing can improve sensitivity, it is not always feasible. The variation of sensitivity limits between large and small volume samples has been investigated.

307 Mesure de la radioactivité des eaux par floculation électrochimique. G. DERRIE et P. DE MONTAIGNAC, Centre d'Etudes Nucléaires de Saclay, Gif-sur-Yvette (France).

La mesure de la pollution radioactive des eaux fait appel en général aux principes suivants:

- Mesure par un détecteur immergé,
- Mesure par concentration: évaporation ou production d'aérosols secs,
- Mesure sur lame d'eau par compteur proportionnel.

Le limite de sensibilité de ces procédés est de l'ordre de 10^{-7} Ci/m³ et le débit du liquide contrôlé est toujours très faible.

Nous avons pensé à utiliser le principe de floculation rencontré dans de nombreux procédés d'épuration des eaux. Le floculat produit par addition de produits chimiques dans l'eau à traiter piège les impuretés en suspension ou en solution, un filtrage simple sépare l'eau traitée du floculat chargé. Dans le procédé exposé, le floculat est produit continuellement par électrolyse du liquide à analyser avec des électrodes de cuivre. Le floculat d'hydroxyde

de cuivre piège les impuretés et en particulier les éléments radioactifs. Il est amené à flotter en surface de l'eau où la radioactivité est facilement mesurable par exemple avec un compteur proportionnel. On rassemble ainsi sous une couche mince environ 80% des éléments radioactifs contenus dans l'eau ce qui permet de contrôler facilement un important échantillon de liquide.

Le débit de l'appareil est adaptable à l'installation; il peut aller de quelques litres/heure à plusieurs centaines de litres/heure.

L'expérimentation actuelle permet d'espérer obtenir une sensibilité environ 20 fois supérieure à celle des appareils actuellement en service.

Measurement of the radioactivity of water by electrochemical flocculation.

The measurement of radioactive pollution of water is based on the following general principles:

- measurement with an immersed detector,
- measurement by a concentration process: evaporation or the production of dry powder,
- measurement of a thin layer of water by a proportional counter.

The limit of sensitivity of these methods is of the order of 10^{-7} Ci/m³ and the rate at which samples can be measured is always very small.

We have thought of using the method of flocculation used in many procedures for purifying water. The floc produced by the addition of chemicals to the water to be treated collects the impurities in suspension or in solution, and a simple filtration separates this floc from the treated water. In the method discussed, the floc is produced continuously by electrolysis with copper electrodes of the liquid to be analysed. The copper hydroxide floc traps the impurities and in particular, the radioactive elements. The floc is made to float on the surface of the water, where its radioactivity is easily measured, for example with a proportional counter. One thus collects about 80% of the radioactive elements contained in the water in a thin layer, which thus permits the easy monitoring of a large sample of liquid.

The rate of flow of the equipment can be adapted to suit the particular installation; it can run from several litres/hour to many hundreds of litres/hour.

The current research gives an expectation of a sensitivity about twenty times higher than that of the equipment presently in use.

AUTHOR INDEX

(Numbers refer to the order in which the abstracts are published)

- | | | |
|--|--|---|
| <p>A. AARKROG 191
 P. ABRAHAM 181
 J. G. ACKERS 10
 Z. M. ALVI 40
 R. AMAVIS 27
 A. L. ANDERSON 14
 A. ANDRÁSI 9
 L. ARGIERO 153
 R. A. ARNOLD 60
 D. VAN AS 127, 217
 M. AVARGUES 47
 J. BAARLI 28, 39
 G. L. BABCOCK 65
 M. E. BAINS 5
 W. J. BAIR 22
 J. BALLADA 229
 R. BARDINA 111
 R. N. BARKHODAROV 129
 D. W. H. BARNES 165
 J. BARTHE 55
 J. R. BEATTIE 49
 G. D. BELL 259
 E. I. BELOVA 145
 R. BERNER 33
 D. E. BERNHARDT 238
 M. A. BEUVE 8
 I. S. BHAT 304
 F. BILLARD 75
 K. BINGO 122
 H. v. BINSBERGEN 205
 J. BIRÓ 126
 R. BITTEL 221
 R. BLAGOJEVIĆ 209
 R. BLAIS 184
 D. BLANC 55, 75, 113
 R. L. BLANCHARD 250
 M. BLAU 266
 O. P. BOBROVNIKOV 258
 B. B. BOECKER 163
 P. BONÉT-MAURY 114
 J. A. BONNELI 176
 H. E. BOOK 17
 D. V. BOOKER 6, 230
 M. DE BORTOLI 128, 135, 143
 L. BÖTTER-JENSEN 206
 C. R. BOWMAN 95
 L. BOZOKY 175
 F. J. BRADLEY 184
 G. BRANCA 27
 F. BREUER 27</p> | <p>V. M. BRIGANINA 129
 R. BRNOVIC 147
 A. BRODSKY 7
 B. BROWN 280, 281
 J. M. BROWN JR. 112
 L. D. BROWN 70
 R. S. BRUCE 48
 H. BRUNNER 15
 R. T. BRONSKILL 3, 62, 82
 PAMELA M. BRYANT 49
 F. N. BUCK 238
 G. BURGER 99
 T. E. BURLIN 274
 S. C. BUSHONG 37
 G. C. BUTLER 272
 J. C. CARRAL DE ALMEIDA 288
 P. CAGNETTI 216, 218, 260
 R. D. CALDWELL 23
 M. CANCE 8
 W. J. M. CARPAJ 255
 T. E. F. CARR 165
 M. W. CARTER 225, 238
 P. N. CASBOLT 97
 L. CAVE 50, 296
 H. CEMBER 293
 A. C. CHAMBERLAIN 230
 A. CHAPIUS 75
 K. H. CHEUNG 98
 T. L. CHIFFELLE 163
 W. D. CHISWELL 30
 B. CHONÉ 257
 D. CHORVÁT 161
 L. S. CHUANG 98, 134
 V. K. CHUMAK 129
 J. CHYSKY 182
 A. A. CIGNA 27, 130
 R. H. CLARKE 220
 J. CLEARY 211
 G. F. CLEMENTE 130
 J. J. CLIFTON 59, 177
 F. J. COLEMAN 43
 J. C. COLLINS 185
 L. COMMANAY 55
 E. M. COOK 180
 L. M. COOK 299
 MARY J. COOK 262
 J. COOTE 245
 P. COURVOISIER 90
 F. M. COX 60
 G. CROOK 295</p> | <p>T. L. CULLEN 288
 F. DABURON 132
 G. C. DALE 176
 C. J. DANPURE 156
 P. J. DARLEY 269
 B. L. DAVIES 199
 M. DAVISON 171
 C. DEAN 45
 G. DEBRIE 307
 H. J. DELAFIELD 123
 R. J. DELLA ROSA 155
 M. DELPLA 2, 119, 246
 P. A. DELWAIDE 11, 125
 J. A. DENNIS 123
 CORNELIA DIACONESCU 164, 252
 J. DOCHERTY 67
 G. W. DOLPHIN 21, 286, 290
 T. F. DOUGHERTY 151
 M. DOUSSETT 106
 L. D. DUBOVA 129
 J. L. DULCINO 125
 H. J. DUNSTER 150
 J. DUPOUX 242
 A. DURAKOVIĆ 170
 E. D. DYSON 267
 J. D. EAKINS 226
 C. F. EASON 276
 M. EISENBUD 117
 A. EL-NAGGAR 166
 B. W. EMMERSON 19
 G. W. R. ENDRES 56
 A. M. ERMANS 251
 P. C. ESCOTT 240
 E. P. EVANS 165
 W. D. FAIRMAN 244
 F. FARKAS 252
 V. F. FEDOULOV 258
 I. FEHÉR 126
 Y. FEIGE 121
 ELVIRA R. DI FERRANTE 168
 A. J. FINKEL 84
 P. FISCHER 253
 D. W. FLEETWOOD 31
 H. FLYGER 206
 J. FONTAN 75
 MARY R. FORD 263
 JEAN FORWARD 199
 H. O. FOURIE 127
 H. FRANÇOIS 55
 A. M. FREKE 286</p> |
|--|--|---|

- J. FRITTELLI 216, 260
 H. FUJIMORI 140
 Y. FUKANO 63
 S. FUKUDA 78
 P. GAGLIONE 128, 135, 143
 ARLETTE GARNIER 93
 F. A. GIFFORD JR. 89
 W. B. GILBOY 30
 F. G. GIORCELLI 130
 E. P. GOLDFINCH 19
 M. GOLDMAN 155
 J. GOODWIN 207
 R. L. GOTCHY 94
 N. G. GOUSSEV 258
 G. GRAMPA 168
 J. LE GRAND 92
 J. GREGORY 236
 N. T. GRIDGEMAN 272
 R. V. GRIFFITH 14
 N. GRODEN 170
 F. GRÜNAUER 99
 P. GUILLLOT 12
 D. GVOZDANOVIC 159
 S. GVOZDANOVIC 158
 B. GWIAZDOWSKI 51
 J. HACKE 264
 I. HAIRR 261
 D. HAJDUKOVIC 136
 C. D. HALLETT 59
 P. HALLIDAY 50
 J. HAMARD 106
 E. I. HAMILTON 139, 211
 R. T. HANKINS 203
 R. HANOUT 132
 N. T. HARRISON 72, 240
 J. R. HARVEY 66, 73, 118
 J. W. HARVEY 283
 R. J. HASTERLIK 84
 K. HATA 120
 A. HEDGRAN 149
 H. HERSCOVICI 273
 H. HERZOG 15
 R. HESP 131, 227, 245
 C. R. HILL 133
 J. HIZÓ 210
 J. VAN DEN HOEK 194
 M. HÖFERT 28
 B. HOLLIDAY I
 J. G. HOLLINS 233
 R. E. HOLMES 296
 R. B. HOLTSMANN 248
 Y. HONDA 140, 200
 J. R. HORAN 16
 GWYNETH PARRY HOWELLS 261
 J. R. HOWLEY 112
 W. H. R. HUDD 73
- R. K. HUKKOO 13
 A. P. HULL 26
 F. HUMBEL 80
 D. L. O. HUMPHREYS 278
 J. B. HURSH 247
 L. D. HUTCHINGS 50
 W. P. HUTCHINSON 226
 N. IONESCU-GALBENI 273
 E. IRANZO 190
 F. S. IWAMI 297
 M. IZAWA 212
 T. JAAKKOLA 197
 G. C. JACK 233
 W. JACOBI 162, 264
 D. G. JACOBS 95
 J. JAGIELAK 51
 A. C. JAMES 285
 OLGA M. JANKOVIC 224
 G. C. JARDINE 240
 L. JEANMAIRE 229
 W. S. S. JEE 151
 M. JEREMIC 88, 147
 H. JOFFRE 91
 W. S. JOHNSON SR. 96
 R. E. JOHNSTON 266
 A. JONES 184
 A. R. JONES 208
 J. K. JONES 298
 R. K. JONES 163
 H. KAHLÖS 198
 B. KAHN 29
 T. KAHN 114
 P. R. KAMATH 304
 N. KANEKO 167
 L. R. KARHAUSEN 251
 W. KARNIEWICZ 160
 R. L. KATHREN 56, 202
 D. S. KATOCH 13
 J. KATOH 79
 P. KAURANEN 197
 H. KAWAI 200
 N. F. KEMBER 285
 I. B. KEVRIM-MARKUS 104, 105, 110
 H. KIEFER 53
 M. KILIBARDA 88
 Y. KIMURA 140, ~~200~~ 200
 R. KIRCHMANN 194
 P. KISSEL 91, 237
 I. KNEŽEVIĆ 224
 A. KNIGHT 41
 G. B. KNIGHT 179
 VERONICA KNIGHT 157
 G. F. KOCH 125
 L. F. KOCHER 56
 O. A. KOCHETKOV 104, 105
 T. KOGA 200
- M. KOKUBU 188
 L. A. KÖNIC 239
 K. KOSTIAL 170
 G. KÖTEL 9
 A. KOTUROVIC 300
 E. KOWALSKI 80, 205
 S. KRISHNAMONY 76
 P. N. KRISHNAMOORTHY 74
 M. KUNZLE-LUTZ 8
 I. KURCZ-CSIKY 146
 Y. KUROKAWA 18
 G. LACOURLY 221, 294
 M. LADU 111
 A. LAFONTAINE 194
 J. LAFUMA 24
 J. R. A. LAKEY 279
 A. LALLY 226
 B. E. LAMBERT 183
 W. A. LANGMEAD 3
 H. V. LARSON 202
 KATHERINE A. LATHROP 266
 S. Y. LAU 134
 C. LAUNAY 87
 R. M. LEDGERWOOD 131
 R. LEIMGRUBER 15
 E. G. LETOURNEAU 233
 G. LEWIS 298
 R. LIEBERMAN 225, 303
 I. A. LIKHTAREV 196
 C. L. LINDERKEN 14
 B. LINDELL 149, 275
 J. LINECKI 160
 G. S. LINSLEY 72
 B. A. J. LISTER 20
 J. M. LONG 299
 A. LOPEZ 75
 J. F. LOUTIT 165
 I. LOVÁNYI 254
 T. H. LU 98
 J. W. LUCAS 141
 A. M. LYAGINSKAYA 169
 R. C. MCCALL 65
 R. O. MCCLELLAN 163, 283
 T. F. MCCRAW 192
 R. S. MCCULLOUGH 272
 J. F. MCGREGOR 292
 A. S. MCLEAN 150
 G. MADELAINE 75
 K. MAEKAWA 63
 S. MAKRA 107
 G. MARBLE 87
 A. N. MAREI 129
 GEORGETA MARINESCU 273
 Y. MARQUE 91, 237
 E. J. MARSH 213
 M. MARSHALL 67

- T. O. MARSHALL 41
D. MARTIN 162
A. MARTINC 80, 205
E. W. MASON 72
G. MASTINU 301
J. MATHIEU 113
H. MATSUI 188
C. W. MAYS 151
C. B. MEINHOLD 282
C. MELANDRI 81
V. B. MENON 76
T. MERCER 247
J. MERTON 205
H. METIVIER 8
J. K. MIETTINEN 195
L. MIJATOVIĆ 136
A. J. MILLER 38
C. E. MILLER 84
Y. MINAGAWA 18
MARGARET MINSKI 211
I. MIRIĆ 103
P. MIRIĆ 103
A. A. MOGHISSI 225, 303
A. A. MOISEEV 145, 196
R. H. MOLE 83
P. DE MONTAGNAC 307
J. B. MOORE 250
R. H. MOORE 295
H. MORISHIMA 200
F. MORLEY 25
R. H. MOSS 60
T. J. MOSS 277
I. E. MUKHIN 145
Y. MURAYAMA 63
S. MUŽDEKA 209, 300
K. NABA 63, 120
E. NAGEL 90
A. NARDI 216, 260
M. NARITOMI 78
W. L. NEES 202
J. NEUFELD 108
H. B. NEWCOMBE 292
D. NEWTON 230, 231
M. NICOLAE 100
Y. NISHIWAKI 63, 101, 120, 140,
167, 200
D. NOLIBE 8
L. NOVAK 249
N. J. NOVIKOVA 129
G. M. OBATUROV 104, 105
M. ODEVRE 142
P. OFTEDAL 291
H. C. ORCHARD 236, 298
M. C. O'RIORDAN 97, 173
T. OSHIMA 63
M. J. OWERS 298
- O. PAAKKOLA 144
H. PACKER 60
J. P. PAGES 251
R. PANNETIER 215
D. PANOV 147, 249
Y. D. PARFENOV 169
J.-P. PATAU 113
D. PATTANAİK 181
H. W. PATTERSON 109
S. PAUKER 174
C. O. PEABODY 5
M. PELLICIONI 111
J. PENSKO 51
J. P. PEROTIN 242
K. E. G. PERRY 58
R. PERRY 141
E. PETROCHILLO 87
J. PETROVIČOVÁ 161
È. V. PETUKHOVA 129
R. C. PFLEGER 283
J. A. PICKRELL 163
E. PIERSCH 53
R. A. PIKE 5
J. PLANET 92, 142
A. PLĚŠKOVÁ 161
E. POHL 138, 253
W. K. POHL 235
JOHANNA POHL-RÜLING 138, 253
ELISABETH POLGÁR 146
C. POLVANI 128
V. I. POPOV 110
E. A. PORT 293
T. POTTER 23
J. PRADEL 75, 91
T. PREDMERSZKY 254
H. E. PRESTON 58, 59
V. PRODI 81
Z. A. PROKOVIEVA 104
N. RACOVEANU 164, 252, 273
R. RADOVANOVIĆ 136
B. RAGHUNATH 76
T. RAHOLA 195
D. RAMSDEN 5
P. V. RAMZAEV 196
E. M. M. DE RAS 243
P. RECHT 214
H. C. REDMAN 163
D. REGULLA 68
A. RICOURT 106
G. K. RIEL 148
C. ROBRINS 112
M. ROCCELLA 111
R. H. ROHRER 201
N. J. ROSENTAL 121
J. T. ROUTTI 109
R. S. RUSSELL 48
- W. L. RUSSELL 44
N. K. SAHU 253
A. SALO 144
S. SALVADOR 190
D. SASHIN 7
P. F. SAUERMAN 42
S. SAVIĆ 88
W. N. SAXBY 57, 228,
G. SCARPA 61
R. SCHAEFFER 2, 119, 246
W. SCHÄFER 42
K. J. SCHLAGER 124
G. B. SCHOFIELD 287
H. SCHÖNBACHER 39
H. SCHRAUBE 99
J. SEDLET 244, 297
A. SEIDEL 284
D. H. SESLINE 283
H. E. SHARONOV 145
R. G. SHIPTON 207
R. C. SHORT 217
G. SILINI 46
S. SIMON 289
I. ŠIMONOVIĆ 170
S. N. SINITSYNA 169
B. W. SKELCHER 19, 298
J. SMEETS 302
E. E. SMITH 86
E. M. SMITH 201
M. L. SMITH 295
N. J. D. SMITH 172
R. J. SNELLING 274
W. S. SNYDER 263
M. ŠOBAJČIĆ 209
A. SØRENSEN 206
F. D. SOWBY 116
W. G. SPARKE 123
F. W. SPIERS 268
H. SPIESS 85
Z. SPURNY 54
J. W. STATHER 234
N. H. STEIGER-SHAFFRIR 174
L. D. STEPHENS 38
J. STEPHENSON 4, 32, 77
B. E. STERN 187, 281
D. C. STEVENS 32, 77
N. G. STEWART 20
G. E. STIGALLI 29
D. STOJANOVIĆ 300
A. N. B. STOTT 230, 256
E. VAN DER STRICHT 143, 302
E. G. STRUXNESS 95
A. H. SULLIVAN 39
A. R. SUNDARARAJAN 76
M. SUOMELA 198
F. SUTER 34

- M. SUZUKI 18
G. K. SVENSSON 65, 102
C. S. SWINEHART 60
B. TAGG 82
M. TAKAGI 120
M. TAKAHASHI 63
S. TASHIRO 35
H. TATSUTA 122
B. T. TAYLOR 6
D. M. TAYLOR 156
G. N. TAYLOR 151
L. S. TAYLOR 115
N. A. TAYLOR 213, 228, 232
J.-L. TEYSSIER 55
D. C. THOMAS 43
R. H. THOMAS 109
I. M. G. THOMPSON 207
S. TOWNSEND 66, 73
T. TRNOVEC 161
J. TROUSIL 182
T. TSURUTA 101
V. I. TSVETKOV 104, 105
A. URBÁN 137
- A. P. USHAKOVA 196
G. UZZAN 92, 142
J. P. VAANE 243
C. VALLEE 87
D. VELIĆKOVIĆ 103
J. VENNART 183
J. VERTUT 237
E. VIRÁGH 137
G. A. VIVIAN 179
M. VLADÁR 284
K. J. VOGT 219
V. VOLF 284
M. VUKOTIĆ 136
Y. WADAGHI 35, 36
G. V. WALFORD 306
D. M. WALLACE 64, 71
E. WANDERER 189, 223
F. A. WARD 227
G. G. WARNER 263
K. WATARI 212
D. A. WATSON 277
C. L. WEAVER 29
J. L. WEEKS 178
- B. WERDERER 242
M. VAN DER WESTHUIZEN 217
D. F. WHITE 57
W. J. WHITEHOUSE 267
J. T. WHITTON 118
J. R. WHITWELL 270
I. J. WILSON 305
R. WILSON 179, 277
D. WITKOWSKA 160
C. Y. WONG 134
D. S. WOODHEAD 133, 193
M. E. WRENN 261
M. C. WUKASCH 241, 299
H. YAMAMOTO 188
H. YAMASHITA 140
S. S. YANIV 7
H. YASUNAKA 36
Y. YOSHIDA 138
G. D. ZANELLI 271
R. L. ZIMMERMAN 186
V. G. ZOLOTUKHIN 104, 105
K. ZSDÁNSZKY 210
G. ZUCCARO LABELLARTÉ 301