ENVIRONMENTAL RADIATION MONITORING IN THE CONTEXT OF REGULATIONS ON DOSE LIMITS TO THE PUBLIC

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INTRODUCTION

Environmental radiation monitoring is performed for the purpose of assessing the dose to the general public from a nuclear or radiological facility, usually to demonstrate compliance with regulations that limit the allowable dose to the public from manmade sources. Measurements are often made at the property line of the facility or further off-site. Monitoring may be performed by the operator of the facility, and in some cases by government regulatory authorities. Assessment of the total effective dose to the public requires modeling of all source pathways. Wherever possible, input to such models should include measurements of appropriate parameters. For example, measurements at plant vent monitors and meteorological data may be required to make projections of the dose to populations at various locations. In addition, monitoring of air, soil, water, and biota may be required to determine the internal dose, and direct measurements may be required to determine the external dose. This paper focuses only on measurements of the external component of the total dose. Considered is the application of current and proposed public dose limits in the context of the natural radiation background, current measurement technology, appropriate quantities, and the development of standards for the determination of external dose.

ICRP PHILOSOPHY ON DOSE LIMITS FOR THE PUBLIC

In most countries, regulations on radiation dose to the public reflect the basic philosophy of the International Commission on Radiological Protection (ICRP). Wherein, it is assumed that stochastic effects occur with a probability (rather than a severity) that is a function of dose, with no threshold. In determining an acceptable dose limit for the public, ICRP report 26 (1) describes an approach that allows for a risk for fatal cancers to be comparable to risks that are accepted for other aspects of everyday life, such as public transportation. The Commission found that this risk would correspond to a whole body annual dose of 1 mSv (100 mrem). However, they recommended that it would be sufficient to set a whole body dose equivalent limit of 5 mSv y^{-1}, applied to the mean dose received by a "critical group", that is a set of individuals most highly exposed.

ICRP report 60 describes an alternative approach, which is to consider variations in the dose from natural background radiation. Consistent with both approaches, the Commission currently recommends a limit to the general public of 1 mSv y^{-1} (effective dose) (2). The ICRP further specifies that, under special circumstances, a higher effective dose may be allowed in 1 year as long as the average over 5 years does not exceed 1 mSv per year. These limits refer to the whole body dose (mean effective dose to a critical group) from all sources and all pathways, except that from natural background radiation, medical applications, and radon.

NATIONAL REQUIREMENTS AND IMPLICATIONS FOR EXTERNAL DOSE LIMITS

Current and proposed regulations from a few countries are summarized in Table 1. While most national regulations are designed to be consistent with ICRP-26 or ICRP-60, the specific requirements may vary from country to country. For example, the limits may be defined in terms of a maximally exposed individual, rather than the mean dose to a critical group, or there may be additional separate limits for gaseous or liquid effluents. Perhaps the aspect most open to local interpretation is how to allow for the potential exposure from more than one source. ICRP 26 states that consideration must be given to the possibility that some individuals may belong to more than one critical group. ICRP 60 also notes the potential need for source-specific constraints, but does not make quantitative recommendations on this subject. In contrast, the U. S. National Council on Radiation Protection and Measurements (NCRP) recommends a single source limit of 0.25 mSv to the maximally exposed individual, unless an assessment is performed to ensure that the dose from all manmade sources does not exceed 1 mSv (3).

The approach used in the Netherlands is to assume that any individual has the potential to be exposed to 10 sources (4), so that the dose limit from a single source is one tenth of the recommended annual dose. In their current regulations, the Netherlands goes further than the ICRP in setting the annual limit at 400 μSv, with a 40 μSv limit at the fence line of any single facility where the public has access. However, the regulations do allow for higher doses if the site is not in an occupied area, and there is a proposal to increase the annual limit to 1 mSv, with the corresponding limit per source of 100 μSv.

In the U. S. there are three government agencies that have oversight over nuclear and radiological facilities. The Environmental Protection Agency (EPA) is responsible for establishing generally applicable standards for the protection of the public from radioactive material. The Nuclear Regulatory Commission (NRC) is responsible for

Table 1. Summary of National Regulations on Dose to the General Public.

Country (document referenced)	Annual Limits on Total Effective Dose (mSv)	Additional Specifications
United States EPA 26FR9057; 40CFR190&61 59FR66414	5 1[a,d]	0.25 mSv[d] U fuel cycle, 0.10 mSv airborne effluents
NRC 10CFR20.1301 59FR43200[a]	1	0.50 mSv[d] external component 0.15 mSv[a] decommissioned sites
DOE 10CFR834[a]	1[a]	0.30 mSv[a,d] for single site
Netherlands ORS[b]	0.4 1[a]	0.04 mSv for single facility 0.10 mSv[a]
Poland National Atomic Energy Agency March 31, 1988	1	___
Denmark National Board of Health Order No. 821 Dec. 7, 1990	1	___
Germany[c]	0.3[d]	___
England Ionizing Radiation Regulations, 1985, Schedule 1	5	___
Spain Royal Decree 53/1992	5	___
France Journal Office de la Republique Francaise, No. 88-521 (Article 4) May 6, 1988	5	Limits on intake of specific radionuclides

[a]Proposed
[b]Omgaan met risico's van straling, Tweede Kamer 1989 Kamer 1989-1990, 21 483 nr 2; SDU The Hague 1990
[c]Allgemeine Verwaltungsvorschrift § 45 Strahlensschutzverordung, Ermittlung der Strahlenexposition durch die Ableitung radioaktiver Stoffe aus kerntechnishen Anlagen und Einrichtungen » of 21 February, 1990.
[d]Dose to maximally exposed individual

licensing commercial nuclear power reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the disposal of nuclear materials and waste. The Department of Energy's (DOE) responsibility currently includes its uranium separation facilities, nuclear production and research reactors, nuclear weapons assembly and disassembly facilities, tritium recovery facilities, nuclear materials storage vaults, and high energy particle accelerators. Both the NRC and the DOE set specific restrictions on facilities under their jurisdiction to ensure that they meet the EPA's general requirements for protection of the public. The DOE is moving towards codifying its requirements, previously specified as internal DOE orders, which means that they will be enforceable through civil penalties and allow for greater public review, as is the case for NRC and EPA requirements.

The current EPA regulations (5) set the annual whole body dose limit at 5 mSv, but proposed new guidance (6) would change this to 1 mSv y^{-1} and would recommend that additional source-specific limits be established to "take into account the present and future potential for doses from other sources". For example, an earlier EPA regulation (7) set such a source-specific limit for the "uranium fuel cycle" at 0.25 Sv annual whole body dose, and another (8) limits the dose from airborne emissions from DOE facilities to 0.10 mSv y^{-1} to the general public.

The proposed DOE regulations (9) would set the annual whole body dose limit at 1 mSv, and specify that the potential of exposure from other sources need be taken into consideration if the dose to the public from the DOE site exceeds 0.30 mSv. The current NRC regulations (10) limit the dose to the public to 1 mSv y^{-1}. They also state that compliance may be demonstrated by showing that the external dose for an individual continuously present in an unrestricted area would be <0.5 mSv in a year if other requirements for liquid and gaseous effluents are met.

In the U. S., a related topic of increasing importance is the assessment of dose to the public from facilities that have been decommissioned in order to verify that the site can be released for unrestricted use. Currently, about 20 commercial nuclear power reactors and 130 DOE sites are in the process of being decommissioned. As some of the larger facilities reach the end of their useful lives in coming years, the clean up issues are expected to become more complex with an estimated 2000 sites eventually requiring decommissioning. The NRC is in the process of revising its regulations to include explicit criteria for decommissioning. Their proposed criteria specify that radioactivity from decommissioned sites be as low as reasonably achievable below the level that would result in a 0.15 mSv y^{-1} dose from all pathways to the average individual in a critical group (11). The intention of the NRC is to provide a margin of safety below the annual 1 mSv limit to allow for potential exposure from other sources and the fact that there are no controls once a site is released for unrestricted use.

Most of these examples of current and proposed regulations on public dose do not explicitly state a separate limit on the external component, so what is acceptable in a particular situation will depend on the magnitude of the internal component. (An exception being the NRC limit of 0.5 mSv y^{-1}). In any case, the measurement of an external dose on the order of 1 mSv y^{-1} (about 114 nSv h^{-1}) or less from manmade sources must include consideration of the natural background radiation field which is on the same order.

REVIEW OF EXTERNAL DOSE FROM NATURAL BACKGROUND RADIATION

Spatial Variations

The background radiation field is due to terrestrial and cosmic sources. Photons and beta rays from primordial radionuclides in the soil, mainly ^{40}K and the ^{238}U and ^{232}Th decay chains, make up the significant terrestrial component. Due to the low penetrating power of beta rays, they are not as significant as gamma rays for dose from natural background. Because of weapons tests in the 1950s and 60s, a small contribution from ^{137}Cs may now be considered part of the radiation background. The terrestrial component varies with geography, depending on the relative concentrations of these radionuclides. The external dose equivalent from terrestrial sources can typically range from 0.1 mSv y^{-1} to 1.4 mSv or more per year depending on the local geography. Some localized areas have been identified with higher levels. The worldwide average annual effective dose is estimated to be 0.46 mSv from terrestrial sources (12).

At ground level, the cosmic component mainly consists of high energy muons, photons, and electrons. The cosmic dose at any given location depends on the altitude, about 0.3 mSv y^{-1} at sea level and about twice that at elevations of 1.6 km. There are also smaller variations on the order of a few percent with latitude because of effects of the earth's magnetic field; the dose is about 10% lower near the equator than near the poles.

Temporal Variations

Measurement of a potential manmade dose component is complicated because the natural background radiation dose levels are not constant in time. Figure 1 illustrates some of the well-known natural variations in background radiation that are associated with diurnal and precipitation effects. (The original measurements were of exposure. For this report the exposure data was converted to absorbed dose in air (1 R/8.7 mGy) and the UNSCEAR recommended factor for environmental radiation was used to convert to effective dose (0.7 Sv Gy^{-1}).) The diurnal effects are related to temperature changes and the accompanying atmospheric turbulence. Radon gas exhaled from soil during the night stays near the surface of the earth while the air there is relatively cold, with the gamma emitting progeny causing an increase in the radiation background level during this time. As the air grows warmer during the day, vertical diffusion reduces the radon concentration and the ground level radiation decreases. Diurnal effects can be on the order of a few percent to as much as 10% where the radon exhalation rate is very high.

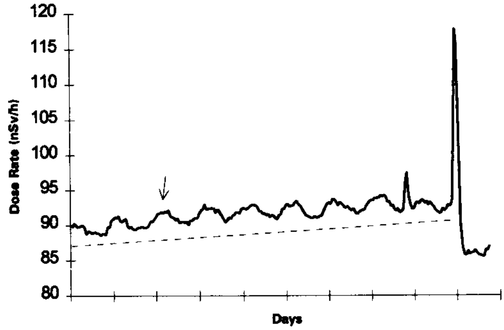
Precipitation also plays a major role in natural variations in background radiation. For example, rain or snow can scavenge airborne radon progeny causing an increase in radiation levels by up to a factor of two (or in rare cases three) for several hours. Subsequently wet ground or snow deposited on the soil surface attenuates the terrestrial component causing radiation levels to drop below the previous baseline after the precipitation stops. Other possible natural variations are related to seasonal influences on the exhalation rate of radon from the ground, such as frozen soil allowing less of the gas to escape.

The cosmic-ray component does not vary as much as the terrestrial component on a day to day basis, but the 11-year solar cycle can result in variations on the order of 10% from the average value. On occasion, solar flares have been observed to produce measurable increases up to a factor of 3 in the ionizing component at sea level.

QUANTITIES TO BE MEASURED

For environmental monitoring, the use of the operational quantities "ambient dose equivalent" and "directional dose equivalent" is recommended in ICRP 60 as reasonable approximations to the effective dose and the equivalent dose in the skin (see ICRU 51 for precise definitions). For field measurements it would seem logical to use measurable physical quantities rather than dose equivalents, thereby avoiding complications that arise with ongoing developments in radiation biology. However, since the purpose of such measurements is to verify compliance with dose limits, they ultimately have to be related to the quantities specified in regulations. To convert between physical and dose equivalent quantities requires knowledge of the nature and energy of incident radiation. Since the radiation field may not be known, the ideal detector would have a flat response with energy for the quantity of interest.

A typical photon energy distribution from terrestrial sources based on calculations for reasonable soil and source distribution parameters (13) is shown in Figure 2. For comparison, the photon fluence, air kerma rate, and ambient dose equivalent quantities are shown. It is important to note that though most of the fluence (~70%) is due to gammas of energy <500 keV, these low energy photon components do not contribute as much to the air kerma or ambient dose equivalent as the higher energy photons. Most of the total ambient dose equivalent (~70%) is from



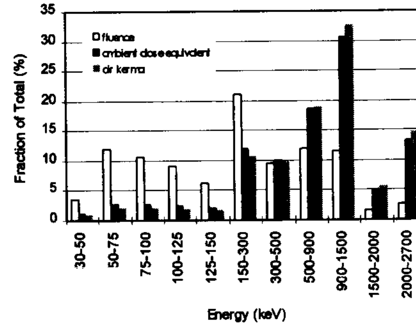


Figure 1. Short-term variations in natural background external dose rate due to temperature and precipitation effects, as measured with a PIC. Arrow indicates changes related to daily temperature effects on radon. Dashed line indicates gradual increase in dose rate due to soil drying out after rainfall. Large peak corresponds to rain scavenging of atmospheric radon progeny.

Figure 2. Approximate energy distribution of typical background terrestrial gamma rays at height of 1 m. Derived from data in Beck (13) using ICRU 47 (1992) factors to convert from fluence to ambient dose equivalent. Average factor for each energy range was used.

photons with energies >500 keV. Comparison of the overall energy distribution in terms of the physical quantity air kerma and the operational quantity ambient dose equivalent shows there is very little difference. This is because above about 30 keV the energy response of air and the ICRU sphere is essentially the same. Photons below about 30 keV are weakly penetrating and do not make a significant contribution in environmental radiation monitoring.

INSTRUMENTS FOR DIRECT MEASUREMENTS OF EXTERNAL DOSE

Pressurized Ionization Chambers, Geiger Mueller Tubes

Figure 1 shows data obtained with a pressurized ionization chamber (PIC). Similar data can be obtained with Geiger Mueller (GM) tubes. Both types of instruments are good for providing a detailed time record of the dose rate. Current models are sensitive to changes on the order of 0.6 nSv h^{-1} and typically allow measurements every minute or less and can store over 1 month of data unattended. It is important that they be appropriately calibrated for the environmental spectrum encountered, with consideration given to the relative sensitivity to cosmic and terrestrial components.

Spectrometers

Sodium iodide and germanium detectors (which have superior energy resolution) record the energy of incident gamma radiation and can therefore be used to identify sources. With appropriate calibration, they can also be used to quantify the concentrations of radionuclides to provide *in situ* soil analysis and to distinguish the terrestrial component of the dose (14). This technique has been used for the study of global fallout, and for assessment after the Chernobyl accident. Because of a spectrometer's high cost and more extensive operating requirements (higher voltage biased supply, amplifier, liquid nitrogen in the case of Ge detectors), they are usually not left at a site unattended for long periods for routine environmental monitoring. But for site characterization and final status surveys for decommissioning or where dose limits are very low, the technique of *in situ* gamma spectrometry can be particularly useful, as explained below.

To assist in the interpretation of environmental radiation measurements, it is often useful to combine results from more than one instrument. For example, the increase in radiation levels due to precipitation, as illustrated in Figure 2, could look like an accidental release. Denmark's "early warning system" (15) established after the accident at Chernobyl uses a sodium iodide detector to assess fluctuations of 10% or more in PIC measurements of the ambient background level in order to separate natural events from possible manmade releases. Likewise, precipitation data from a weather station can be applied for the same purpose. As another example, the terrestrial component of the dose rate determined with a spectrometer can be compared to the reading of a PIC or GM detector as a quality assurance check on both instruments, or to correct for the PIC or GM detectors' differing sensitivities to the cosmic and terrestrial components.

Passive Environmental Dosimeters

Passive detectors provide an integrated measure of the total dose. While this information is limited in comparison to that provided by PICs, GM detectors and spectrometers, it is often adequate for environmental monitoring purposes, as will be illustrated below. While film and electrets are occasionally applied, the most widely used integrating dosimeters for environmental monitoring are thermoluminescent dosimeters (TLDs). Though the laboratory instruments used to process a TLD can be costly, the TLDs themselves are inexpensive, reusable, and rugged, and can therefore be deployed in locations that are remote or subject to potential loss from such factors as vandalism or environmental insults.

To monitor the external dose to the public, nuclear installations may use a few PICs or GM detectors at the fence line, and many more TLDs at the fence line and beyond to provide coverage off site. There are presently over 17,000 sites on earth being monitored with TLDs (16). In the hours immediately following the accident in the U. S. at the Three Mile Island nuclear power plant in 1979, TLDs were the only environmental monitors in the field and they provided significant data about dose since plant vent monitors had reached their upper range limits (17). In the U. S. (partly as a result of this) the NRC established its own network of TLD sites around all power plants, in addition to those used by the private utilities. The NRC's network consists of 13 to 48 monitoring stations around 75 facilities, and typically covers standard windrose sectors circling the site boundary, as well as 3 km from the site, with additional stations 8 km or more from the site, including major population areas (18).

Recently developed TL materials provide increased sensitivity, and have been shown to be capable of measuring daily background doses, i.e., on the order of 2 μSv (19). Some TLD materials such as LiF, $Li_2B_4O_7$, and BeO are nearly tissue equivalent. The differing spectral sensitivity of other materials and the use of additional filters has been exploited to perform crude spectrometry (20). This can be especially useful to monitor for such things as a 6 MeV gamma ray from ^{16}N produced in nuclear power plant, or low energy photons from ^{133}Xe releases.

DISTINGUISHING DOSE ABOVE BACKGROUND LEVELS

While all of the detectors described above are sensitive enough to measure absolute dose levels on the order of the current and proposed limits for public exposure, distinguishing a potential manmade component from the naturally varying background is a more complex problem. The relevant question to address is: Can the available instruments provide data on external dose that would be useful to measure compliance with public dose limits?

To address this question it is useful to look at data from the long-term monitoring of natural background radiation. The Environmental Measurements Laboratory (EML) has been monitoring radiation exposure (and other conditions) at a rural location with no local sources of pollution and undisturbed soil (21). Figure 3 shows PIC and TLD data from 14 years of simultaneous monitoring. The PIC data were obtained with EML designed ionization chambers. The TLD data are from dosimeters consisting of 15 ^{7}LiF:Mg,Ti phosphors ("chips") deployed within about 1 m of the PIC during each calender month (22). While the TLDs measure the total dose, a mean dose rate is obtained by dividing by the field deployment time. This can then be compared with the average dose rate measured by the PICs during the same time period. For the PIC data, each point represents the average of thousands of readings, and the associated statistical uncertainty is small (<<1%). For TLD measurements, the uncertainty tends to be much higher (~5-10%) due variations between chips and possible changes in reader conditions, as well as the expected poorer statistics resulting from averaging over a small number of chips per dosimeter. This is the probable reason for the somewhat larger variations observed in the TLD results.

Figure 3 shows good agreement between the TLD and PIC data, and it illustrates that while the monthly average background dose rate can vary by as much as almost 40%, the yearly average tends to be more stable, varying only a few percent from year to year. The largest monthly variations are low dose rates corresponding to winter months with greater snow cover. The overall PIC average is 87 nSv h^{-1}, and is marked with a solid line in the figure. The dashed lines show the hourly dose rate levels that would correspond to an additional dose, above the PIC average, equal to that of some of the annual public dose limits shown in Table 1.

The dashed lines show that an additional external dose corresponding to an annual dose of 1 mSv (i.e., 114 nSv h^{-1}) above the average background dose would be clearly beyond the range of natural measurement variations, and, therefore, easily detectable. The same is true of the current NRC annual external dose limit of 0.50 mSv. The single source limits being used by EPA (0.25 mSv) and proposed by DOE (0.30 mSv, not shown in Figure 3), are both well above the maximum data variation also. However, the 0.10 mSv limit being considered in the Netherlands and applied to airborne emissions in the U. S. is approaching the measurement variation, as is the 0.15 mSv limit currently proposed by the NRC for decommissioned facilities. As these limits should include internal dose components, the type of TLD and PIC measurements shown here may not be sufficient and additional information would likely be required.

In the case of facilities undergoing decommissioning, it is usually known what contaminant radionuclides could be present. The NRC is in the process of determining specific soil concentrations for various nuclides that would result in a total effective dose below the proposed 0.15 mSv limit ("release criteria") (23). These concentrations are calculated using a dose modeling code (24) that considers various source transport and exposure pathways and

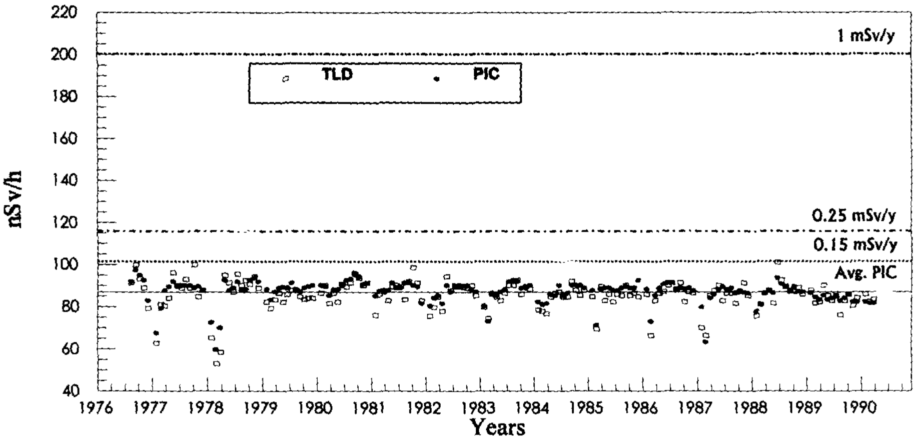


Figure 3. Fourteen years of monthly TLD and PIC environmental monitoring data at a rural site in the U. S. with no local sources of pollution.

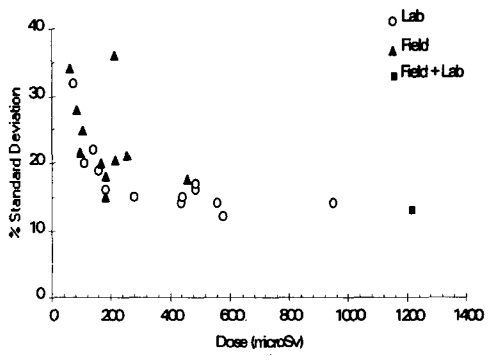
land-use scenarios. To demonstrate compliance, it may be sufficient to show that residual soil contamination does not exceed the release criteria. It is interesting to note that while an additional external dose on the order of 0.15 mSv y^{-1} (17 nSv h^{-1}) may be difficult to detect in monthly averages, the corresponding allowable concentration of a specific nuclide can be measurable by the *in situ* gamma spectrometry technique. For example, the release criteria estimated in the current working draft for ^{238}U in soil is about 0.3 Bq g^{-1} (7.8 pCi g^{-1}), or more than 10 times the natural background concentration of uranium (23). For another example, the release criterion for ^{60}Co is about 0.1 Bq g^{-1} (3 pCi g^{-1}).

However, it must be emphasized that the modeling code is being refined and the release criteria have not been finally determined. The calculated value depends on the input parameters used for such things as soil permeability, and the water situation for the modeled site. Such factors are more important for nuclides with a significant internal dose pathway, and the final values for the release criteria could be much different. For these reasons, it would be useful to make measurements of the external dose to verify the assumptions made in the modeling code. It is also worth noting that because the proposed limit applies to the mean dose to a critical group rather than the maximally exposed individual, depending on how the occupancy and shielding factors are determined, an external dose at a field site greater than 0.15 mSv may be allowed. Also, any external dose from a decommissioned site should be static, and a determination would be made based on comparison with a reference site that is not contaminated, in which cases TLD or averaged PIC measurements may yet be adequate for some cases.

Many environmental monitoring programs presently use a quarterly monitoring cycle, which should result in a lower range of variations than those seen in Figure 3. Furthermore, if regulations are stated in terms of an annual dose limit, dose rate measurements near the limiting value would have to be present for more than one quarter to result in a dose in excess of the limit. A dose large enough to exceed annual limits in one quarter would be well beyond the range of data variations for most of the limits now being considered. However, the Netherlands limit of 0.04 mSv would likely be within the natural variations and not detectable in the monthly averages. Real time PIC monitoring may be required in this case. Depending on how other regulations specify what fraction is allowed for internal and external components, the measurability could be difficult as well. It is clear that any monitoring program would have to establish natural levels for a specific site. Where possible, this would ideally be achieved through a few years of monitoring before the facility becomes operational. Where this is not possible, it may be necessary to establish background levels at some distance from a site. Alternatively, gamma spectrometry could be applied to determine if there is any facility contribution.

INTERNATIONAL INTERCOMPARISONS OF ENVIRONMENTAL MONITORING INSTRUMENTS

The European community has sponsored several international intercomparisons of environmental monitoring instruments beginning in 1984. The most recent intercomparison involved eight countries and was held at the PTB in Germany and Riso National Laboratory in Denmark in 1994 (25). In an earlier study, PIC, GM, proportional counter and TLDs were used to measure the routine discharges of a nuclear power plant over a 2-month period (26).



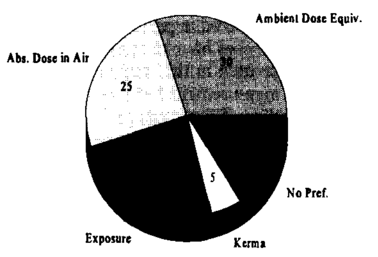


Figure 4. Relationship of dispersion of participants' results and the delivered dose from the International Intercomparisons of Environmental Dosimeters. Most of the participants used TLDs.

Figure 5. Results of survey of preferred quantity to use for environmental monitoring from 10th International Intercomparison of Environmental Dosimeters (28). Number of participants preferring each quantity is shown, out of 100.

While the active instruments provided an indication of the time of the releases and tracked the power level of the reactor, only the TLDs provided a good measure of the total dose without corrections that required independent knowledge of the energy spectrum of the radiation field (27). This is a result of the LiF TLDs' appropriate energy response for such monitoring. Because of the variations in their energy response, the PIC, GM and proportional counter overestimated the dose by 10%, 40%, and 50%, respectively.

This illustrates that passive integrating dosimeters can be particularly useful for assessing the external dose to the public to check compliance with annual dose limits. While they do not have the time resolution to identify transient dose increases, this information is not required for assessing compliance with annual dose limits. Also, because they are completely passive there is no associated "down" time that is inherent in any type of active instrument which may occasionally not be serviced on schedule because of such things as weather conditions. Active detectors like PICs and GM detectors are most useful to monitor in real time or for short-term studies or for model validation. TLDs are useful for widespread coverage off-site.

The U. S. Department of Energy (EML) has sponsored the "International Intercomparison of Environmental Dosimeters" since 1972. This program is open to any type of integrating dosimeter, and typically includes over 100 participants from 25-30 countries. It provides a measure of the state of the art in passive environmental dosimetry. For example, in the 10th International Intercomparison of Environmental Dosimeters (28) in 1993 it was found that 90% of the participants were within 30% of the delivered dose. Figure 4 shows the dispersion of participants' results plotted against delivered dose from all the intercomparisons. For lower doses, there is greater dispersion, but still most participants were within the performance criteria recommended by the American National Standards Institute (ANSI)(29). The 10th intercomparison included a survey where participants were asked to select their preference from a list of quantities. The results are shown in Figure 5. Thirty percent of the participants selected ambient dose equivalent, 54% selected one of the physical quantities of exposure, absorbed dose in air, or air kerma, and 16% indicated no preference.

NATIONAL AND INTERNATIONAL ENVIRONMENTAL DOSIMETRY STANDARDS

Despite their widespread application in measuring dose to the public, there are presently no testing or accreditation programs for environmental dosimetry providers. In contrast, several national programs exist for the testing of personnel dosimetry services. There may not be a need for such testing unless there are cases where public dose assessments are challenged. In such cases it may be difficult to defend doses derived completely from calculations. In anticipation of such a need the ANSI has developed a draft standard on performance testing of environmental dosimeters (30) that is analogous to the one currently used for the occupational dosimetry National Voluntary Laboratory Accreditation Program (NVLAP) in the U. S. (31). In addition to this, the current standard for environmental thermoluminescence dosimetry, ANSI-N545 is being revised as ANSI-N13.37. The Netherlands is in the process of establishing requirements for environmental dosimeters in its standard NVM5648 (32). There s a more general international standard already in place that covers this subject as well, IEC 1066. Particularly for environmental monitoring where the dose limits are much lower than for occupational settings, one of the most relevant issues to be covered in performance standards is requirements for the lower limit of detection for dosimetry systems. Many researches have analyzed the methods for defining this quantity, which is not straight forward (33).

Regulations are written in the interest of public health and they do not necessarily take into consideration the abilities of current measurement technologies. National and international standards, on the other hand, may focus on physical properties of detectors and are not necessarily linked to regulations. It would be most useful if both regulations and performance standards could converge on practical methods to meet the needs in dose assessment.

CONCLUSIONS

Many countries have regulations that limit the radiation dose to members of the general public. Most are consistent with the ICRP and are moving towards a 1 mSv annual dose limit, with some specifying additional lower limits to allow for exposure from multiple sources. Such limits currently being considered are in the range of 0.10 mSv to 0.30 mSv. Limits apply to all pathways, and, therefore, will require dose modeling. Measurements of the external dose could help to verify the assumptions made in dose modeling codes. Based on long-term measurements of the natural background radiation, assessing an additional external dose on the order of 0.15 mSv or more would be possible using currently available technology. However, interpretations of any environmental monitoring data require knowledge of the natural background radiation field and its variations. Results from international intercomparisons demonstrate that passive dosimeters, such as TLDs, are appropriate devices for measuring the external dose off-site. National standards being developed for such devices should address the needs of regulations on dose limits. Active instruments such as PICs and GM detectors are useful for real-time monitoring or spot measurements, and provide more information than may be needed to demonstrate compliance with public dose limits. Limits of 0.15 mSv or less may require more extensive measurements with spectrometers and calculations of derived limits for soil concentrations, similar to those being presently developed in the U. S. for decommissioned sites.

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