RADIOLOGICAL PROBLEMS ON MAGNOX REACTORS WITH INTEGRAL BOILERS, WITH PARTICULAR REFERENCE TO PERSONNEL ENTRY INTO THE PRESSURE VESSEL

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Abstract

Radiological data is presented for the first 4 years of operation of Oldbury Nuclear Power Station. Radiation doses to personnel on site are very low; the average whole-body dose is about 0.2 rems annually and the highest cumulative dose in 4 years is 2.6 rems. The total annual dose-commitment for operating, refuelling and maintaining the two-reactor power station is below 100 man-rems.

During periodic entries into the pressure vessel, the main problem is heat. Protective clothing to enable men to work for extended periods at temperatures up to 60°C is described. The special medical requirements and the method of selecting personnel to work under these conditions are indicated.

Following an inspection period, sulphur 35 is released in gaseous form during the dry-out of a reactor core. A monitoring technique is described and surveys confirm that locally produced milk is not affected.

1. Introduction

At Oldbury-on-Severn Nuclear Power Station each reactor core and the boilers are contained within a single pressure vessel constructed of pre-stressed concrete with a minimum thickness of 5 metres and lined with a gas-tight membrane. This "integral" design has been adopted for all the power reactors currently under construction in Great Britain. The dose-rate at Oldbury in most operational areas is about 0.03 mrads/hour including the natural background level of 0.01 mrads/hour. Where the coolant gas is extracted from the pressure vessel to be passed through ancillary equipment, the controls are located in areas where the dose-rates do not exceed 0.5 mrads/hour.

Each power station operates as a self-contained unit with the man-power and equipment available on site for normal operation, maintenance and services such as health physics. At present, there is no reserve pool of trained labour available at a central base. The annual statistics of the radiation doses received by personnel at Oldbury-on-Severn Nuclear Power Station have been analysed for the last 4 calendar years and section 2 of this paper summarises this information.

The construction of Oldbury-on-Severn Nuclear Power Station was begun in March 1962 and the first of the two units was commissioned in November 1967. With the current operating temperatures the output sent out from Oldbury is 415 MW.

2. Oldbury Personnel Radiation Dose Statistics

All personnel at a nuclear power station working in areas of significant radiation dose-rates or where any loose contamination may occur wear a film badge. These films are processed monthly unless the information is required more rapidly. Thermo-luminescent sachets containing lithium fluoride powder are used for extremity dosemeters. All measurements of dose are added into the personnel dose record maintained by computer for each person. There are about 350 people employed at Oldbury and a considerable number of other personnel visit the site regularly and need a film badge on arrival, so over 500 are issued each month. Table 1 shows the number of film badges and replacements issued during the period 1969 to 1972. Damage to films is due mainly to the paper wrapping absorbing water or oil.

Table 1

Annual Totals		Year			
		1969	1970	1971	1972
Film badges issued		7265	7455	6681	6652
Film badges issued to contractors		856	850	604	874
Replacement films issued		136	110	69	69
Films damaged		38	22	16	5
Films lost and not recovered		66	35	19	23
TLD sachets issued		-	-	1241	779
Man-rems	(CEGB employees	95.3	78.2	79.3	75.3
per year	(Contractors	25.0	15.1	8.0	10.8

Doses below 0.01 rad per month would not produce detectable darkening of the film compared with controls kept in an area where the natural radiation causes an annual dose of 0.10 rems. Anyone employed at Oldbury for a complete year would be issued with 12 film badges and credited with a minimum dose of 0.12 rems. 65 man-rems of the annual total dose to personnel at Oldbury is due to the natural background.

In Table 2, the average and the highest individual radiation dose received by personnel at Oldbury are summarised. Table 2 is for C.E.G.B. personnel employed full-time at Oldbury whereas Table 1 includes regular visitors to the site, such as apprentices and inspectors.

Table 2

Group of Personnel	Number in Group				Individual Dose in Millirems							
					Average				Maximum			
	69	70	71	72	69	70	71	72	69	70	71	72
Engineers etc.	117	93	93	94	152	162	152	151	540	750	790	470
Admin. Dept.	41	34	34	32	123	121	121	124	160	160	170	160
Operations Dept.	127	117	97	84	207	211	218	300	570	550	660	970
Maintenance Dept.	137	127	119	113	221	151	217	194	1150	760	890	630
Health Physics Dept.	38	40	37	26	173	172	163	187	320	440	340	370
Total	460	411	362	349	187	170	198	201	1150	760	890	970

These figures show the small total dose involved in operating and maintaining a nuclear power station which has achieved load factors of 84% and 73% during 1971 and 1972. The number of personnel is high compared with the staffing at stations in other countries but almost all the work involving radiological exposure is carried out by station personnel. The average monthly dose recorded on the film badges issued to contractors was $18\frac{1}{2}$ millirems, including the natural background level.

Table 3 shows the number of persons in various ranges of whole-body and extremity radiation dose for the last four years. On average only 15 persons have exceeded 0.5 rems whole-body annual dose. No-one has exceeded a whole-body dose of 1.2 rems or an extremity dose of 5.5 rems in a year. The 58 doses exceeding 0.5 rems in the last 4 years were received by 51 different persons and the largest whole-body exposure integrated over the last 4 years by anyone at Oldbury is 2.6 rems, while the largest extremity total is 6.7 rems. No-one has had to be restricted from working due to an overdose of radiation, even though most of the personnel are not classed as occupationally exposed.

Table 3

Range of Dose		Number in dose bracket in year			
		1969	1970	1971	1972
Whole Body Dose	Not more than 0.5 rems	560	535	472	425
	Between 0.5 and 1.5 rems	15	6	21	16
	Above 1.5 rems	0	0	0	0
Extremity Dose	Not more than 1.5 rems	574	540	491	437
	Between 1.5 and 3 rems	1	0	2	2
	Between 3 and 7.5 rems	0	1	0	2
	Over 7.5 rems	0	0	0	0

3. Problems During Refuelling Operations

All C.E.G.B. reactors are designed for "on-load" refuelling and the parts which enter the neutron flux of an operating core are activated. Dose-rates up to 1000 rads/hour may be encountered during subsequent maintenance work.

After removal from the reactor, the irradiated elements are lowered into a storage area under 6 meters of water which has been treated to minimise corrosion of the Magnox fuel can. The used fuel remains in the Cooling Pond for about 100 days so that the inventory of short-lived fission products is reduced. During this period, some of the outer components of the fuel element are removed but the Magnox can around the uranium remains intact. This "desplittering" process improves the packing fraction of the fuel in the steel flask which transports the used elements for reprocessing. The desplittering machine becomes contaminated and dose-rates of 100 rads/hour are measured under water when the equipment is raised for maintenance.

Problems due to the isotope caesium 137 in the treated water of the Cooling Pond have been minimised by:-

1) Close control of the chemical composition of the water.
2) Retaining irradiated fuel under water for 100 days only.
3) Paying particular attention to any fuel used for experimental purposes.

The average concentration of caesium 137 in the Cooling Pond water at Oldbury is about 10 μCi per litre and the total quantity of caesium 137 present is 25 curies. About 15 curies of tritium and 5 curies of all other isotopes are discharged as liquids annually from Oldbury. The dose-rate to personnel engaged in fuel-handling operations above the Pond water is about 5 mrem/hour. The total dose due to this work is 1.8 man-rems per year distributed among the 15 men engaged in fuel handling operations.

To maintain the equilibrium fuel cycle for the two-reactor station, the annual refuelling rates quoted in Table 4 are needed. The actual rates of fuel movement achieved over the last 4 years are shown. There is no large refuelling backlog and the last two years should be typical of future operational conditions at Oldbury.

Table 4

Fuelling Operation	Required Annual Rate	Actual Rate Achieved			
		1969	1970	1971	1972
Channels refuelled	1820	1475	1149	1249	1441
Elements desplittered	12740	4278	8696	12492	10342
Flasks dispatched	64	34	52	63	56

4. Problems During Routine Inspection and Maintenance

At Oldbury one reactor is shut down each summer and the interior of the pressure circuit is entered for a statutory inspection.

The four boilers within each pressure vessel are separated from the reactor core by the boiler shield wall, consisting of 75 cm of graphite and 28 cm of steel, to attenuate the direct gamma radiation from the shut-down core and to reduce the activation of materials during power operation. The steel components contain 0.02% cobalt impurity but measurements indicate that impacted dust particles are responsible for most of the dose rate at present.

Man-access to the pressure vessel is required as soon as possible after the reactor overhaul has begun, so cold water is fed through the boiler tubes while the carbon dioxide coolant is being released. The circuit is then purged with air before man-access is permitted. Inflatable seals are guided into position and prefabricated screens are installed to isolate the particular boiler from the coolant gas flow which must be maintained to remove the reactor after-heat.

The level of loose contamination within the boiler is low but there may be residual pockets of carbon dioxide coolant gas initially and tritium may also be present. The space available does not allow men to wear self-contained breathing apparatus, so full protective suits supplied with air through a trailing hose are used for the first entries. After a period, dust respirators and "coveralls" woven from a mixture of cotton and a polyester thread are adequate.

During boiler entries the metabolic heat rate of a man may be 400 kilo-calories per hour. With an average body weight of 70 kg, this would be enough to raise the temperature of the entire body by 5.7 degrees Celsius per hour unless heat can be lost be sweating. About 0.5 kg of body fluid may evaporate per hour and most people experience discomfort if the total loss of fluid from the body exceeds $1\frac{1}{2}$ litres. The full protective suits restrict the evaporation of perspiration from the skin so the man is supplied with cooled air by the use of a Ranque-Hilsch "vortex" tube[1] which separates incoming compressed air at about 4 kg/cm^2 into a hot and a cold fraction. The cooled air is circulated through perforated pipes inside a foam plastic suit which acts as a thermal barrier against the surrounding temperatures. Men wearing these suits have performed arduous work under test conditions for one hour in temperatures of 80°C. Personnel have not yet entered the boiler spaces at temperatures above 60°C because of the difficulty of removing anyone who might be injured. Rescue equipment is installed at the top of each boiler by the first team to enter but fortunately it has not yet been needed.

Nuclear power station personnel do not work in hot environments and confined spaces sufficiently often to develop acclimatisation. Experienced medical observers select prospective workers and check for evidence of general physical disabilities, particularly of the locomotor system, poor vision and auditory defects, psychological disturbances such as a history of claustrophobia, and skin sensitivity to rubber or plastic materials. Specific factors which would influence selection are (a) age, (b) physique, (c) hypertension or hypotension, (d) infective foci, (e) anaemia and (f) skin disease. There is also an "exercise tolerance test" when the resting pulse rate is measured before the subject steps up on to a platform 45 cm above the ground and down again 30 times in 1 minute. The pulse rate is then taken and checked again after 2 minutes rest, to make sure that it has returned to its normal value.

During a typical inspection programme, the gas circuit is open to air for a period of 4 weeks during which 250 entries by two or more men are made into the pressure vessel, each lasting for about 2 hours. In addition, about 2000 items are individually logged in and out of the area. Personnel emerging from the boilers may have 100 c.p.s. on the outside of their protective clothing, measured by a scintillation counter probe sensitive to beta and gamma radiation.

The radiation doses incurred during these overhaul periods are no greater than those received during normal station operation. The dose rates measured within the boiler annuli are now about 8 mrads/hour due to beta-gamma radiation of which about 6 mrads/hour is due to the gamma component. Smear samples taken from the gas-side surfaces of the boilers show levels of loose contamination below 10^{-3} $\mu Ci/cm^2$ beta-gamma. Small piles of debris are encountered in the bottom of the boilers, usually in corners where there is little flow of gas, and dose-rates may be about 50 mrads/hour, mainly due to beta emitters. Small pieces of stainless steel foil which have become detached from the internal thermal insulation of the pressure vessel liner are occasionally found with surface dose-rates up to 100 rads/hour, mainly due to cobalt 60.

5. Reactor Core Dry-Out Following Periods of Overhaul

During the period when man-access is taking place, dried air is supplied to the vessel which is closed temporarily whenever men are not inside, but in 4 weeks 400 kg of water vapour may enter and 300 kg of perspiration may be given off by personnel working in the gas spaces. The graphite moderator absorbs part of this moisture which then must be removed before the reactor can be operated at significant power. At the conclusion of an overhaul, boiler access equipment is removed, the reactor closed and the vessel is filled with carbon dioxide gas. The reactor core temperature is then raised gradually, ensuring that the dew point is not reached.

The moisture-laden gas is discharged to atmosphere through the installed blowdown filtration system. During this process, the majority of the radioactivity found is a gaseous form of sulphur 35, a low-energy beta emitter with a half-life of 87 days. The rate of blowdown of the gas has been limited in the last 3 years by considerations of the permissible discharge of this isotope into a milk-producing area. This topic is also discussed in the paper by F.H. Passant to this conference, reference U-0078-R-5.

Considerable work has been carried out at the C.E.G.B. Berkeley Nuclear Laboratories by I.R. Brookes and his co-workers on the mechanism of production and release of sulphur 35[2]. The isotope is produced by neutron irradiation both of the stable sulphur impurity in the graphite moderator and the chlorine impurity in the carbon dioxide coolant gas. During power operation in a carbon dioxide atmosphere, sulphur 35 is circulated as carbonyl sulphide gas and is then deposited on the Magnox cladding of the fuel elements as magnesium sulphide. Hydrogen sulphide is released by the action of moisture when the temperature is raised during the dry-out of the reactor core.

Brookes has also devised a method of measuring gaseous compounds of sulphur 35 rapidly which does not need to be carried out by highly-trained staff[3]. The gas is drawn through 250 ml of neutral potassium permanganate solution at a rate of 2 litres per minute and the sulphur is oxidised to sulphate ion. At the end of the sampling period, clean carbon dioxide gas is passed through to saturate the solution. Hydrogen peroxide is then added to reduce the permanganate to manganous ion. Following this, the solution is electrolysed between a copper cathode and a porous paper anode coated on the under side with zinc powder. A thin layer of zinc sulphate is deposited on this lower surface behind a 1 mg per cm^2 "Melinex" window. This membrane is mounted directly above an end-window Geiger counter and the sulphur 35 activity can be counted without disturbing the deposited thin source. These novel anodes are prepared in a laboratory but only a few papers in each batch need be calibrated.

The work of P.M. Bryant of Harwell[4] was used to calculate the quantity of sulphur 35 which could be released into a milk-producing area. In 1970, 1971 and 1972, milk samples were collected from farms at distances up to 7 kilometres downwind from the reactors during and after the period of core dry-out. In 1972 air samplers were run at distances of 200 and 500 meters downwind in case the maximum deposition occurred close to the point of release due to entrainment in the lee of the building. The maximum airborne concentration found was 8×10^{-11} µCi per cm^3 of air, which is orders of magnitude below the M.P.C. Samples of milk and of grass herbage were analysed for sulphur 35 by radiochemical means and the situations during the last 4 years are summarised in Table 5. The last line of the table shows that the measured concentrations of sulphur 35 in milk were far below the derived working level of 5×10^{-2} µCi per litre in milk, although the rate of blowdown had been increased by 4 times the previous value in each of the last two years.

Table 5

	1969	1970	1971	1972
Total moisture evolved (kg)	640	530	340	140
Duration of moisture release (days)	9	8	6	7
Total CO_2 blowdown (tonnes)	250	370	390	350
Total S 35 evolved (curies)	0.5*	2.0	0.9	0.3
Duration of S 35 release (days)	18	10	20	10
Av. conc. of S 35 in CO_2(mCi/tonne)	2.0	5.0	2.5	1.0
Max.conc. of S 35 in milk (µCi/litre)	-	$<15 \times 10^{-6}$	120×10^{-6}	60×10^{-6}

*This figure is likely to be an under-estimate because measuring techniques had not been standardised in 1969.

6. Conclusions

The radiological data presented, particularly for the last two years, ought to be typical of normal power operation at a two-reactor station with integral boilers inside a prestressed concrete pressure vessel containing the Magnox reactor.

The low radiation dose commitment in operating, refuelling and maintaining this type of station is often not emphasised when discussing the relative merits of different reactor systems. If the recommended annual radiation dose received by occupationally exposed workers were to be reduced by an order of magnitude, it would cause little embarrassment at a station such as Oldbury.

References

1. U.S. Patent Number 1952281 (1934).
2. I.R. Brookes and S.F. Jones. C.E.G.B. Report RD/B/N1937 (June 1971).
3. I.R. Brookes, S.F. Jones and H.F. MacDonald. To be published.
4. P.M. Bryant. U.K.A.E.A. Memorandum AHSB (RP) M31 (1963).