A REVIEW OF THE FIRST SEVEN YEARS OF OPERATIONAL HEALTH PHYSICS AT DUNGENESS 'A' (MAGNOX)NUCLEAR POWER STATION

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Introduction

Dungeness 'A' Nuclear Power Station comprises two identical reactors each of the magnox type of nominal thermal power 725 MW(th), nominal electric power 205 MW(e). The first reactor achieved commercial full power in October 1965 and the second in December 1965. The reactors have been in operation with a lifetime load factor of 77.1% up to March 31st, 1973, and total electrical production 24.5 x 109 KWH (exported). Refuelling on magnox reactors is continuous with the reactor at full power. This paper reviews the Health Physics aspects of operation over the past seven years.

Early Commissioning Radiation Surveys

On completion of reactor construction, commissioning was undertaken in three stages. Firstly general plant commissioning tests and performance studies, secondly fuel loading and reactivity experiments, and thirdly stage by stage power raising including reactivity experiments and establishment of dose rate contours, shielding integrity studies and dose rate measurements for interpolation to higher powers in areas where the dose rate would be too high for actual measurements.

The whole site was divided into 76 areas and within each area designated survey positions were marked both in situ and on drawings. All survey positions were identified by unique code number related to the reactor number, area type, area identity and survey position number. These enabled rapid comparisons to be made between results in similar geometrical positions. In all some 1500 positions were nominated.

Surveys were undertaken at nominally 2%, 20% and 100% full power, including gamma radiation, thermal neutron and fast neutron measurements. Because of limited resources, it was not expected that every planned measurements could necessarily be made at each power level. Priorities were allocated to ensure that adequate information was gained, especially for extrapolation to higher reactor powers.

The surveys showed that

i) In general gamma radiation levels were lower than predicted.
ii) Neutron levels were higher than predicted especially in boiler cells and on the reactor roof.
iii) The integrity of shielding construction was confirmed.
iv) Dose rates on shutdown boilers were higher than expected, due to a higher than expected contribution through the reactor primary shield.

Studies on fuelling machines over the first few months operation were carried out and showed that

i) The general shielding design was satisfactory both for neutron and gamma radiation.
ii) Access to the charge face need not be restricted during fuel discharge, provided that only the shielding slab immediately beneath the refuelling machine is removed. However, access to the interspace between the primary biological shield and the charge face, must be strictly prevented.

Site Environmental Neutron Dose Rates

Neutron dose rates were found to be higher than expected both in boiler cell areas and in some working areas. Additional shielding was installed and this reduced dose rates to acceptable levels. However, in some working areas the neutron dose rate is still approximately equal to the gamma dose rate even though both are low and in some infrequently visited access areas neutron dose rates and gamma dose rates are of the order of 1 rem/hr. It thus became necessary at a very early stage in commissioning to consider the possibility of some form of personal neutron dosimetry. Crude neutron spectral measurements were made in the hope that there may be a fixed ratio between total neutron dose rate and thermal neutron dose rate. It would then be possible to infer total neutron dose to personnel from measured thermal neutron dose on personnel film badges. The results of the experiments undertaken in 1966 showed that the ratio total neutron dose to thermal neutron dose varied between 3.5:1 and 10.5:1. A weighted value of 5:1 was accepted as an interim value taking into account the likely occupancy factors. Thus all personnel dose records included a neutron contribution equal to five times the measured thermal neutron dose.

The minimum detectable dose on a film badge became of great importance, both for gamma dose and thermal neutron dose. The film badge used at Dungeness is that described by Heard and Jones [2]. Assessment of neutron dose is by comparison of film density under a cadmium filter against density under a tin filter of equal mass thickness. Statistical variation in density between areas of the same piece of film can lead to an apparent thermal neutron dose. Series of film badges were therefore exposed to low nominal thermal neutron doses of 1 m rem, 2 m rem, 3 m rem, and 14 m rem, concurrently with nominally 0 m rem, 5 m rem, 11 m rem and 80 m rem of gamma radiation. Standard deviations of the results were determined yielding minimum detectable levels (85% confidence) of 2σ i.e. 1.3 m rems for thermal neutrons and 3.5 m rems for gamma doses. These values were rounded to 1.5 m rem and 5 m rems. It is not surprising that a lower value is obtained from thermal neutrons than gamma radiation because variations in density are between areas of the same piece of film as opposed to variations between separate films. The minimum detectable level of total neutrons was taken as 5 X that for thermal neutrons i.e. 8 m rems (rounded). Sophisticated neutron spectrum measurements made more recently at Dungeness by Harvey [4] have shown that a revised neutron factor of 4:1 for film badges should be used.

The Berkeley Nuclear Laboratories of the Central Electricity Generating Board were asked to develop a suitable personnel neutron dosimeter. This has recently been described in a paper by Harvey, Hudd and Townsend [3] at a Symposium organised by the IAEA in Vienna, December 1972. This dosimeter (The Albedo Dosimeter) is now used on occasions when a known neutron exposure is to be incurred but a monthly assessment of neutron dose to all station personnel is assessed from the film badges.

Off Site Environmental Monitoring

An environmental monitoring programme was started around Dungeness in May 1963. The first phase, a pre-operational survey, was to establish levels of radiation and radioactivity in the area around the power station before commissioning of the reactors. The later phase, the continuing operational survey, is to assess any changes in the levels that may occur after commissioning, due either to operational discharges or following an accident.

The pre operational survey included gross α and gross β measurements on herbage, root mat and soil, gross β measurements on sea silt, sea water, shore silt, drinking water and I^{131} and milk, together with gamma dose rate measurements at a series of shore sites and on agricultural sites.

Gamma survey sites are selected in three rings between one half and one mile, between one and five miles and control sites at between fifteen and twenty miles. Measurement frequencies were initially set at monthly intervals for operator training and familiarity and later generally reduced to quarterly. Fig. 1 shows the mean value of herbage results resulting from the background fallout.

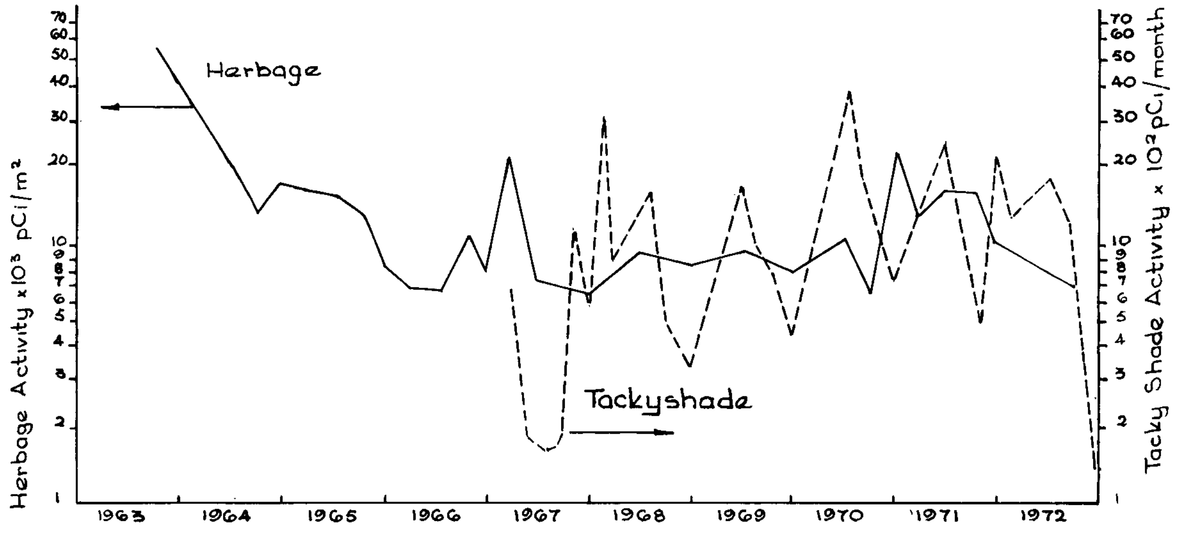

Fig. 1 Herbage & Tacky Shade Results 1963-72 (mean of all sites)

In early operation of the station, the environmental monitoring programme remained unaltered but subsequently a number of alterations to the programme have been incorporated. For example sea silt measurements are now annual instead of quarterly and control sites milk samples would now only be assessed for I^{131} if I^{131} was found in local farm sites. A major change is that a more sensitive indicator than herbage has been devised to act as an indicator for station emission, namely the tacky shade [5]. Herbage samples are now only collected once per year from individual sites but tacky shades are exposed over two month periods at seven sites near the power station, and at five control sites. In addition shades are exposed along the station fence and within it. By measurement of the total activity or specific isotopic activity on an exposed shade, a measure of the integrated airborne activity is obtained. A deposition velocity for the collectors of about 1.5 cm/sec has been determined [6]. At sites with high wind runs, higher apparent integrated airborne activity levels are found, and it has been shown that normalising factors for individual sites around a power station can be determined by analysis of site results over a long period [6]. These factors vary between 0.77 and 1.5 for the Dungeness sites. Experience to date shows that no measurements of radioactivity outside the station perimeter can be attributed to station emission. Mean values of tacky shade activities are included on Fig. 1.

In 1967, following a series of weapon tests, routine sampling showed a significant increase in I^{131} content of local milk production, at a time when most cattle were mainly under cover. Fig. 2 shows values of I^{131} in milk obtained at a typical site together with I^{131} activity on herbage. The occasion was used to mount a large programme of measurements to determine the practical limitation of local resources and valuable experience was gained.

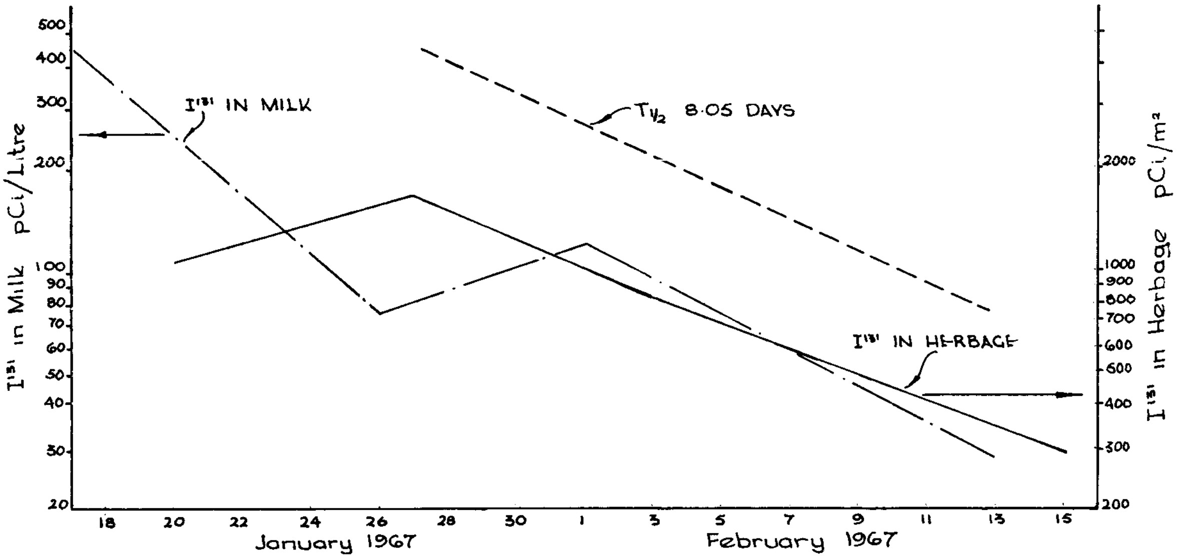

Fig 2 ~ I^{131} in Milk & Herbage ~ District Survey Exercise

Radiation Dosimetry

Whole Body Dose

Shielding design at Dungeness was on the basis of a maximum individual annual dose of 2.5 rem. The dose committment to maintenance staff depends not only on plant conditions but on Health Physics techniques and awareness. Dose committments to operators depend more on plant area dose rates and cannot be reduced significantly without major plant modifications.

In the very early years of operating with low integrated reactor fluxes, in pile activation levels were relatively low. Maintenance on reactor components did not therefore produce high dose committments. Progressively dose rates due to activated components will increase while at the same time component modification and development may still be necessary. It may be expected that dose committments would rise. A period of lower dose committments should follow when "teething" problems have been solved.

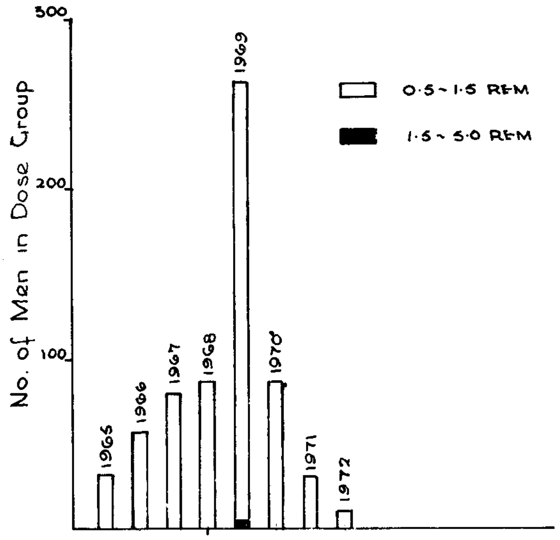

Fig 3. No. of Employees in Annual Dose Groups

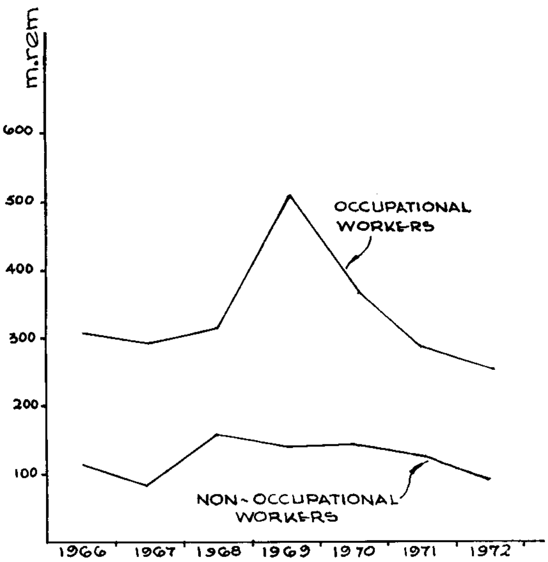

Fig. 4 Mean Employee Annual Dose.

Fig. 3 shows the number of men who have received between 0.5 and 1.5 rem and between 1.5 and 5 rem whole body dose in any year between 1965 and 1972 inclusive. Fig. 4 shows the average whole body dose per year for all occupational workers at Dungeness. In 7 years there have only been 10 occasions when 1.5 rem has been exceeded in one year.

Gaseous Effluents

Gaseous and airborne particulate effluents arise from three sources namely carbon dioxide leakage and primary circuit purging, biological shield cooling air and active area ventilation systems.

Argon 41 is emitted at the rate of about 20 curies per hour for each reactor from the shield cooling systems, and in small additional quantities from carbon dioxide (about 10 Ci per day).

Gasborne particulate activities are measured by sampling through charcoal impregnated filter papers. Experience has shown since 1965 that particulate activities in carbon dioxide discharges include about 0.2 m Ci per day total beta activity assessed against a Cl^{36} standard and alpha activities always below a minimum detectable value of about $2(10)^{-5}$ mCi per day. A further 0.1 mCi/day total beta and negligible alpha activity are discharged with shield cooling air. The contribution from ventilation systems is negligible in comparison with shield cooling and carbon dioxide discharges. No significant trends in activity discharges have been observed since 1965 except at a point when sampling techniques changed to incorporate a charcoal impregnated filter paper with a much higher collection efficiency to As^{76} than the earlier papers used.

Carbon dioxide discharges include S^{35}, As^{76}, Ag^{110m}, Co^{60}, Zn^{65}, Fe^{59} and Cr^{51}, Fe^{55} with Ag^{110m} as the greatest individual contributor. Shield cooling discharges include As^{76}, Br^{82}, Cr^{57}, Ag^{110m}, Co^{60} and Fe^{59} with As^{76} as the greatest individual contributor.

Quantitative returns are made to the Department of the Environment based upon activity levels after 72 hours decay as a condition of the Authorisation to Discharge. No quantitative maximum permitted discharge has been set. The Authorisation required that discharges must be kept to the lowest practicable level.

Liquid Effluents

The terms of the Authorisation to discharge liquid radioactive waste, administered by the Ministry of Agriculture Fisheries and Food permit discharges up to 200 curies of total activity other than tritium per twelve consecutive months, together with 2,000 curies of tritium. Discharges are made from the active effluent treatment plant on a batch basis to the English Channel mixed with 20 million gallons per hour of cooling water. Waste passes through a sand pressure filter and sintered stainless steel filter before discharge. Samples from each 20,000 gallon batch are assessed for total beta and alpha activity and separately for tritium using liquid scintillation techniques. Principle activities are Cs^{137} and S^{35} and tritium.

Fig. 5 shows the discharges since 1965. Tritium produced as a result of the reaction $Li^{6} + n \rightarrow H^{3} + \alpha$ on the lithium impurity in graphite, is removed from the reactors in the gas drying system. A peak value was expected about 2 years after start up followed by a continuous reduction due to burn up of the lithium. The figure shows this peak and shows that current discharges of tritium are about 1.5% of the authorised maximum. The figure also shows a peak in activity discharges other than tritium caused by a temporary period of release of Cs^{137} & Cs^{134} to the fuel element cooling ponds. Discharges of activity are currently about 15% of the permitted maximum.

Fig. 6 shows the variation in isotopic composition of the main contributers. In addition Cr^{51}, Fe^{55}, Nb^{95}, C^{14}, Sr^{90}/Y^{90}, Sr^{89}, Ca^{45}, Ag^{110m} and Ru^{106} have appeared at concentrations greater than 1% at various times.

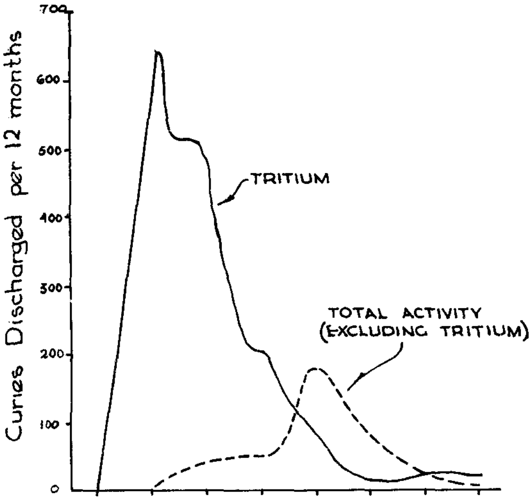

Fig. 5 ~ Liquid Effluent Discharges
(Curies per Running 12 months)

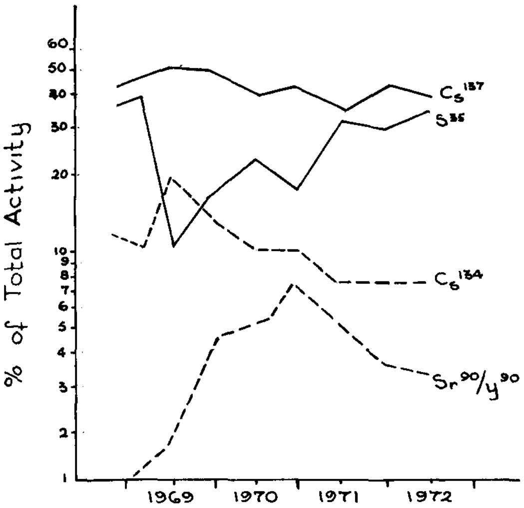

Fig. 6 ~ Liquid Effluent Isotope Composition.

Radiological Control

The system of radiation and contamination zone control used within the CEGB[7] is used at Dungeness. A permit control system is used for all significant radiological work covering specific precautions and dosimetry requirements. Permits are issued by authorised senior Operation Engineers with the backing of accredited Health Physicists. Health Physics advice in the form of a written certificate is issued to the permit Engineer for work of significant potential radiation dose or for work on plant normally sealed but which may contain loose contamination. Permits or the equivalent are required even for entry into zones of highest radiological classification. Health Physics surveys may be undertaken prior to the issue of either Permits or Health Physics Certificates and Permits may require continuous Health Physics surveillance during work. These surveys would be undertaken by industrial staff Health Physics Monitors and in many instances include the measurement of airborne radioactive contamination during work progress.

Routine radiation surveys and routine surface contamination surveys are undertaken in all areas, the frequency being dependent on the likelyhood of a hazard existing. Airborne radioactivity is assessed as an average over a two month period in areas where a low level hazard may exist intermittently or where no hazard should exist, by exposing indoor tacky cloth collectors in the form of a 1 square metre frame doubly covered with tack mat cloth.[8] Such collectors would be exposed in areas such as active laundry rooms, decontamination areas, active workshops, active effluent plant, active waste sorting rooms, fuel cooling pond buildings etc. Assessment of radioactivity by standard ashing and counting techniques has shown that averaged airborne radioactivity concentrations as low as 10^{-6} pCi/cm^3 above background may readily be measured.

Operational Health Physics Problems

Radiation Accident

Early in 1966, when contractors responsibilities had not been completed, a contractor was investigating a fault on fuel pond machinery and moved what appeared to be a loose washer. The item was subsequently shown to be a stainless steel end cap from a fuel element with a contact dose rate of approximately 500 R/hr ($\beta + \gamma$) and a gamma dose rate of about 1 R/hr at one foot distance. Reconstruction of the events subsequently demonstrated that a maximum hand exposure of 18.75 rem could have been received accompanied by a whole body dose of less than 100 m rem. As a result of the incident additional fixed gamma alarms were installed.

Predominant Contaminant

In the main, loose radioactive contamination found at Dungeness is Ag^{110m}. Its source is still unknown but whilst in general it is associated with smaller quantities of other isotopes such as Co^{60}, Fe^{59}, Cr^{51} and S^{35}, occasions have occurred when pure Ag^{110m} has been identified. Microscopic examination [9] has shown that metalic silver exists sometimes associated with iron and copper. Construction records indicate that no silver, silver plating or silver bearing alloys were used in construction.

Fuel Pond Bacterial Growth

Early in 1969 it became apparent that the walls and floor of the fuel element cooling ponds were becoming covered in a green slime even though conditions are maintained at pH 11.5. As the thickness increased, large pieces would break away leading to many problems such as blocking of filters. The slime appeared to have the characteristic that it absorbed radioactive contamination particularly insoluble Ag^{110m}. Any pond equipment taken from the ponds became coated with slime and if allowed to dry would then cause spread of contamination. The slime turned out to result from non pathogenic bacteria. For operational reasons it was necessary to eliminate the cause. All known bacteriacides would have caused corrosion of the magnox canning material of stored irradiated fuel elements, releasing fission products to the water. It was not possible to remove all the fuel from the ponds without holding up the reactor refuelling cycle for at least three months. The course of action finally adopted was to place all fuel in one isolated bay of the pond complex and to empty and mechanically clean all the other bays. The water temperature in the bay with fuel in was then allowed to rise to 50°C by decay heating to kill the bacterial growth there. The resulting dead slime was cleared by recycling the water through a large muslin filter and finally by continuous dilution and purging. There was later an increase in the amount of Cs^{137} and Cs^{134} leached to the pond water by the fuel, ultimately causing the rise in liquid radioactive waste discharges shown in Fig. 5. Further formation of the bacterial growth is now prevented by keeping water temperatures below 20°C and by maintaining water movement.

Shielding for Major Maintenance

It has been necessary on two occasions to construct major shielding assemblies for work on active components. Firstly it became necessary to modify 240 in pile steel mechanisms approximately 20 metres long with dose rates of some tens of rad/hr existed over about 5 metres. A cylindrical lead shielding assembly some 4 metres high and of diameter 2 metres with 15 cm wall thickness, lead glass viewing windows and remote tool access parts was constructed. The dose rate in the working position was about 5 mR/hr. The modification work without shielding would have taken about 15 minutes. With the shielding the work took approximately one hour for 2 men. Thus a potential radiation committment of several hundred man rads was reduced to less than 2 man rads to complete all assemblies. Ultimately these same assemblies had to be replaced and the original ones were cut into pieces and disposed to a waste void within the biological shield of the reactor. A second lead shielded cell was constructed over the disposal hole and the assemblies lowered in steps as pieces were cut off and allowed to drop into the void below.

Statutory Boiler Overhauls

It is a statutory requirement that the gas side of two boilers, and associated gas ducts are inspected every two years. This requires that the reactor is shutdown, cooled and depressurised and the sections to be inspected are isolated from the reactor CO_2 atmosphere and purged with air. Once an air atmosphere is established, a comprehensive Health Physics radiological survey is undertaken in all horizontal sections where small irradiated objects could ledge. The gas ducts are some 2 metres in diameter and the boilers some 20 metres high. Comprehensive surveys are therefore time consuming. They are undertaken by staff with full air line respiratory protection. On receipt of written clearance, inspection teams enter and later teams to undertake minor repairs such as to thermocouple pockets. Full telephonic contact is maintained by staff at the entry control point with teams inside the primary circuit. Surveys, inspections and minor repairs are usually completed within 1 week but other maintenance work is undertaken whilst the reactor is shut down. It has been found at Dungeness that general dose rates inside gas ducts and boilers due to loose and fixed radioactive contamination are only a few m rem/hr and reducing as years pass. Occasional small pieces of radioactive debris are found during surveys.

Routine Health Physics Programme

A nuclear site such as Dungeness requires a fairly comprehensive Health Physics service ranging from dosimetry, effluent control, environmental monitoring, decontamination laundries, etc. Associated with this there is a great deal of routine work either of a statutory nature or of a support nature. This work continues on a 24 hour basis. Many statutory requirements require sampling, measurement etc. and a wide range of instruments are used. These instruments require regular calibration. All breathing apparatus, air lines, suits and communications equipment need regular testing and inspection. A range of routines has been established divided into the following groups: Radiation Surveys, Surface Contamination Surveys, Gas Borne Particulate Activity Surveys (including primary coolant) District Survey, Breathing Equipment, Isotopic Analysis (including effluent analysis) Instrument Calibrations and Emergency Equipment checks. In all over 170 different routines are completed at frequencies varying from once per shift to once per year. Control of such a programme is complex and is fulfilled by dividing routines into two groups - those of frequency 1 week or less and those of frequency greater than one week. The former group are listed on either daily or weekly log sheets and the later are catalogued in a computor programme which gives a printout each 12 weeks of routine work due and date due. It is therefore relatively straight forward to satisfy inspecting authorities that statutory work is adequately completed.

Conclusions

Seven years experience of operating two magnox reactors at Dungeness have shown that personnel doses can be kept very low, currently at an average of 300 m rem per year for occupational workers. Off site measurements of radioactivity in the environment have shown that there is no measurable activity attributable to the operation of the station, even though the extremely sensitive tacky shade collectors are used for sampling. For the past three years liquid effluents have been below 15% of the permitted discharges. A programme of routine work controlled by computer ensures that statutory requirements are met.

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