CONTROL OF OCCUPATIONAL EXPOSURE WHEN WORKING WITHIN A REACTOR CONTAINMENT BUILDING AT POWER

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Introduction

Sizewell B is a 1200 MW, 4 Loop Westinghouse-designed Pressurised Water Reactor, owned and operated by the private utility, British Energy. In the extremely competitive UK electricity market, where wholesale electricity prices have fallen as low as €11 per MWh, generators are under intense pressure to reduce their costs. Sizewell B has attempted to reduce costs by achieving shorter refuelling outage durations. One technique has been to maximise the scope of work performed whilst at power, including work inside the reactor containment building. This paper describes the radiological challenges presented by a routine containment entry programme and the techniques used to manage doses.

Radiological hazards at power

The information on the radiological conditions come primarily from surveys conducted during station commissioning and on subsequent containment entries, and also from Monte Carlo radiation transport calculations prepared for the pre-commissioning Station Safety Report.

External radiations

In most areas of containment, the external radiation field is dominated by intermediate & fast fission neutrons and by high-energy gamma rays from the decay of water activation products (e.g. ^{16}N; gamma ray emissions at 6.4 & 7.1 MeV). However, the presence of activation and fission products, deposited as crud on the internal surfaces of pipes and vessels or present as solutes & colloids in the process fluids, still dominate the radiation fields around certain plant components.

Figure 1 shows the variation in doserates and the variation in neutron radiation quality throughout the reactor building annulus whilst at 100% power. The highest doserates are found on the upper levels of the building, especially in areas with line-of-sight to the Refuelling Cavity and RPV Head. Neutron quality is given by the k-factor (a higher k-factor indicating a harder neutron spectrum).

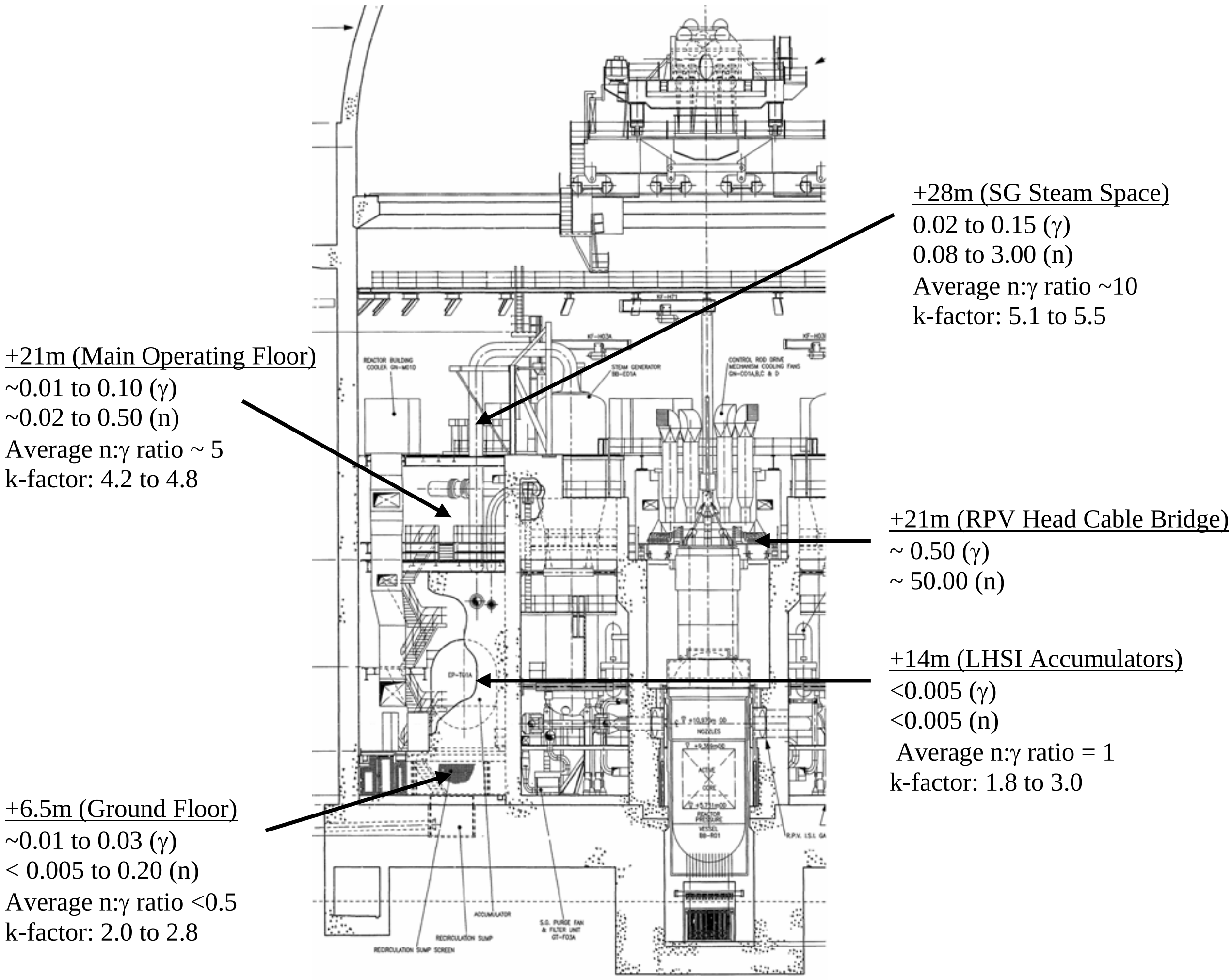
A negligible contribution to the external radiation field also comes from noble gases in the containment atmosphere (typically <100 Bq/m^3).

Internal radiations

Low levels of activation & fission products (4 to 40 Bq/cm^2) are present as both fixed & non-fixed surface contamination inside containment.

Airborne radioactivity levels are usually low (<0.001 Bq/m^3 alpha, < 0.1 Bq/m^3 particulate beta and radioiodine). However, elevated levels of tritiated water (HTO) vapour, between 10 to 60 kBq/m^3, are found inside containment, giving an effective doserate of approximately 0.2 to 1μSv/h. It is postulated that the source of this HTO vapour is gradual desorption of tritium from concrete & metalwork contaminated by a primary coolant leak during Cycle 5.

Figure 1: Variation in radiation doserates (in mSv/h) inside the Containment Building, whilst at 100% power.



Justification of work at power

Establishing a routine containment entry programme presents the opportunity for cost savings by reducing the scope of the Refuelling Outage. However, due to operational & nuclear safety restrictions on plant isolations at power, the tasks that can be performed are unlikely to be “critical path” activities; therefore one cannot make a robust justification argument based solely on critical path reduction. Other factors need to be considered, and a variety of arguments were used, either individually or in conjunction, to justify the decision to work at power. The principal arguments were:-

Trivality of dose - Although the whole of containment is designated as a High Radiation Area; many places in the annulus have doserates sufficiently low to make the conditions similar to rooms within the Auxiliary, Fuel & Radwaste Buildings, where no special access arrangements are necessary. As such, short duration jobs would accrue minimal dose, and a collective dose of less than 0.05 man.mSv was deemed to be trivial, requiring no further justification or optimisation.

Lower doserates - Some areas of containment have lower doserates at full power than when the unit is shutdown. This is principally due to different plant configurations, especially around the Residual Heat Removal System. In many other areas, doserates at power are not significantly higher than at shutdown.

Improved industrial safety – Some tasks (especially scaffold construction) in areas that would be highly populated during the outage, could be performed at power, without risk to persons that would otherwise be in that area at shutdown.

Resource minimisation – The draft outage plans had a number of resource peaks where demand for manpower and service equipment (e.g. scaffolds) was greater than supply. Working at power would enable these resource peaks to be flattened.

Improved outage mobilisation – Pre-staging & installation of radiological protection equipment (such as temporary shielding), would enable faster access to plant areas and improved radiological control during the first few days of the outage.

Prevents a reactor trip – Work to prevent an imminent reactor trip, was justified as it would keep the unit on-load, thus avoiding the dose associated with a forced outage maintenance plan and the subsequent plant operations required to return the reactor to power.

Optimisation of doses

Engineered controls

Airborne radioactivity levels were minimised by running the Mini-purge extract system for 2 to 3 days prior to each containment entry, which enabled the containment atmosphere to be cleaned at a rate of 7200 m^3/h. Access to very high doserate areas inside the Bioshield was restricted by simply locking doors. As the radiological conditions in the annular areas are relatively stable whilst at power; signs and barriers were used to identify low doserate areas, hotspots and radiation beams in order to prevent inadvertent access to other areas that could not be locked off.

Pre-job briefings & setting to work

All staff entering containment received a detailed brief. Where available, Health Physics Information Sheets were given to each work party. These showed a photograph of the item to be worked, a map of its location and details of the expected radiological conditions in the immediate area.

Radiological measurements at the workplace

RP Technicians ran air samples and conducted detailed surveys during the planning stages of tasks, to determine whether the proposed work area was tenable. They only accompanied work groups when personnel were accessing areas where steep doserate gradients existed or where significant intrusive work on active systems was being performed (e.g. valve replacements).

Where work was determined to be of low radiological risk and experience showed that radiological conditions were stable, maintenance teams were able to rely on their own specially trained staff, that were able to perform simple self-monitoring for gamma radiation & surface contamination (known as Radworkers). This allowed the work party to confirm the validity of the measurements made some weeks previously by the RP Technician. Use of Radworkers also enabled us to minimise the collective dose by reducing the RP dose burden.

Assessment of doses

External radiations

The main dosimetric problems associated with containment entries at power are the assessment of neutron dose and the presence of high doserate radiation beams that may not interact with personal dosimeters.

All staff entering containment wore a passive neutron dosimeter. Sizewell B uses the CEGB Albedo, which uses two lithium fluoride TLDs to measure thermal & intermediate neutrons below 25 keV. To account for neutron energies greater than 25 keV, Albedos are assigned a correction (or “k” factor). Detailed neutron spectra surveys had been performed throughout containment at various reactor power levels. These surveys had identified a range of k-factors between 1.8 and 5.5, as shown in Figure 1. All neutron dosimeters were assessed using the maximum k-factor of 5.5.

Sizewell B’s legal beta/gamma dosimeter is the Siemens Mk1 EPD. Staff entering the reactor building at power had EPD alarms set at 500μSv/h and 100μSv. The dose alarm is 50% lower than that normally used in other controlled areas on-site; this was done in order to compensate for the neutron component not measured by the Mk1 EPD. As a practical indication of total dose (in the absence of a direct reading electronic neutron/gamma dosimeter), staff were instructed to assume that their total dose was in fact *10 times* the EPD reading when working on the 21m level and above, and *twice* the EPD reading when working on the 14m level and below.

Where highly localised beams were present, access to these areas was simply prohibited, rather than attempting to multi-badge individual workers.

Internal radiations

Under the Ionising Radiations Regulations 1999 [1], components of dose less than 1mSv are deemed to be non-significant and as such, no formal assessment is required (provided that the sum of unassessed doses remains less than 1 mSv). Using air sample data and airlock entry records to measure area occupancy, estimates of dose were made and tracked on a spreadsheet to ensure that no individual received a significant internal dose; therefore no personal air sampling, *in vivo* or *ex vivo* bioassay programmes were required.

Results of dose assessment

The dosimetric results of the Cycle 5 and Cycle 6 containment entry programme are shown in Tables 1 & 2. Between 2001 and 2003, the total station collective dose received during normal power operation has remained constant at approximately 54 man.mSv. In 2001, the proportion of this dose received performing containment entries at power was 44%. In 2002, this proportion fell to 36%, but had risen again in 2003 to 51%.

Table 1: Estimated doses for containment work activities, excluding radiological protection, by year.

Calendar Year	2001	2002	2003
Neutron Collective Dose (man.mSv)	15.120	7.590	16.800
Gamma Collective Dose (man.mSv)	2.775	4.232	4.991
Collective Dose (man.mSv)	17.895	11.822	21.791
Number of people	43	129	119
Average Individual Dose (mSv)	0.416	0.091	0.183
Maximum Individual Dose (mSv)	1.595	0.803	1.052

Table 1 shows that over the period 2001 to 2003, collective doses have increased, although average and maximum individual doses have fallen. Also, it is interesting note that the contribution of the neutron component to collective dose is between 2 and 5 times the gamma component.

The data for radiological protection staff (shown in Table 2) is not as complete as the data for bulk work activities, as RP staff were instructed to use the standard EPD task code, which has made the subsequent differentiation of gamma dose received in containment at power from other RP activities difficult.

Table 2: Estimated doses for radiological protection activities inside containment, by year.

Calendar Year	2001	2002	2003
Neutron Collective Dose (man.mSv)	5.610	2.600	3.800
Gamma Collective Dose (man.mSv)	~ 2.000	~ 2.000	1.608
Collective Dose (man.mSv)	~ 7.610	~ 4.600	5.408
Number of people	8	22	22
Average Individual Dose (mSv)	~ 0.951	~ 0.209	0.246
Maximum Individual Dose (mSv)	1.590	0.430	0.781

However, this data shows that as the amount of work performed in containment grew, the numbers of RP staff required to manage these activities also increased. Twenty-two RP technicians and engineers were involved in 2002 and 2003 compared to just 8 in 2001. Over this period, the RP collective dose and the maximum individual dose fell, although the average individual dose rose to just under 0.25 mSv. Unlike the bulk of the containment work, the difference between the contributions of neutron and gamma radiations is less than a factor of 2.

The impact of using Radworkers is clearly demonstrated by comparing the 2001 and 2003 collective doses. RP dose contributed approximately 30% to the overall collective dose received in containment at power in 2001, when use of Radworkers was minimal. In 2003, the scope of work enabled much greater utilisation of Radworkers and as a result, the RP contribution to containment collective dose fell to 20%.

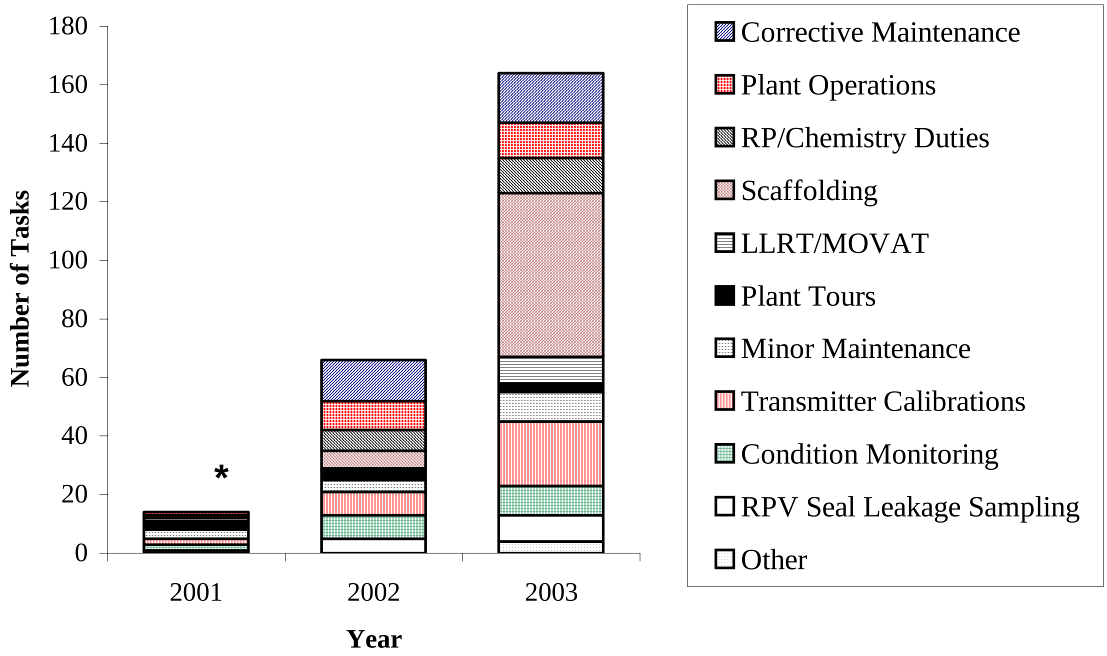
Scope of work performed

The definition of “task” used in Figure 2 is simply a single Work Order. A better measure would be number of man-hours in each task category. Unfortunately, it was very difficult to obtain an accurate estimate of this parameter from our work management computer system, and information for 2001 is extremely unreliable.

Despite these limitations, a clear trend shown in Figure 2 has been the increase in the amount of work performed in containment at power since 2001. This has increased from approximately 30 tasks in 2001 to over 160 in 2003. In addition, the data is sufficiently robust to show that the relative contribution of each type of task has varied considerably over the period shown. Most tasks performed in 2001 were plant tours required to identify the location of a primary coolant leak (which caused a forced outage in March 2001) and the intensive leak searches & corrosion monitoring surveys subsequently required as part of the return to power safety case.

In 2002 & 2003, regular entries were made for 1 to 2 days per month, increasing to 6 days per week in the month prior to the refuelling outages (RF05, May 2002 & RF06, October 2003). Mandatory leak searches and corrosion surveys were still being performed every 6 to 8 weeks, but additional tasks were incorporated to maximise the cost-effectiveness of the containment entry. Tasks included scaffolding, transmitter calibrations and plant operations. Corrective maintenance was also performed, mainly to keep a defective Emergency Boration System valve actuator operable. Significant modifications to the Steam Generator ventilation ductwork were also performed during the pre-RF06 period.

Figure 2: Number & type of tasks performed during containment entries, by year. * denotes data for this period is significantly underestimated (see text for further detail).



Discussion

International experience with containment entries at power varies considerably. Most European utilities only undertake containment entries to rectify faults that threaten an imminent reactor trip, where as some North American utilities have established a routine containment entry programme. For example, Three Mile Island performs entries every 6 to 8 weeks to execute a similar range of tasks as Sizewell B. The programme at TMI accrued 12 man.mSv, equivalent to 20% of their normal operation dose in 2002 [2].

Whilst planning these entries, there was little published data or operational experience available to identify a suitable dose constraint. The individual doses received during this programme were low compared to national dose limits and a company dose constraint of 10mSv [3]. Collective doses were also low, although relative contribution to overall normal operation dose was approximately twice that at Three Mile Island. In terms of dose, the most significant tasks in 2001 and early 2002, were the primary coolant leak searches and subsequent corrosion monitoring inspections. By 2003, the most radiologically significant tasks were scaffold construction on the upper floors of containment. Doses to radiological protection staff were mostly received installing temporary shielding (on the lower floors) and accompanying System Engineers on leak searches etc. This difference in work area explains the variation in the neutron:gamma ratios between RP tasks and maintenance tasks highlighted in the results section.

The results show that the neutron component of dose dominates when working inside containment. This is partly due to the high neutron:gamma ratio found on the upper floors, the conservative choice of k-factor and also the wide variation in limits of detection for the albedo (~50μSv) and the EPD (<1μSv). Prior knowledge of the neutron spectra is essential to avoid significantly underestimating dose. For example, workers at another UK power station received approximately 11 man.mSv (3.7 mSv, maximum individual dose) when working close to a Bioshield penetration. Lack of knowledge of the neutron spectra had led RP engineers to underestimate neutron doserates. This lack of recognition persisted, even after having confiscated the workers' neutron-activated jewellery and clothing at the RCA exit monitor [4].

As part of the ALARA review, it is important to establish the "usefulness" of the work performed. A quantifiable benefit was a reduction of 3 days in the RF06 critical path, by modifying the Steam Generator ventilation ductwork whilst at power (for a collective dose of approximately 1.5 man.mSv). Less discernible benefits were derived from other tasks. Individually, small tasks such as transmitter calibrations have negligible impact on outage scope and dose. And when many tens are performed together, the contribution to outage workload reduction is still rather small, but the radiological impact with respect to normal operation dose can become significant.

Conclusions

This work has shown that a wide range of tasks can be performed inside a containment building at power, for comparatively low individual and collective doses (although these represent significant proportions of the normal operation dose). However, to achieve these outcomes, an extensive input from RP engineers and technicians was required. For certain tasks, such as scaffolding & lagging on the RHR system, doses are clearly optimised by working in containment at power. However, the doses received on some other tasks, may not have been ALARA, especially during 2003. This paper recommends that further refinement of the justification arguments is necessary and that annual dose constraints of 1.5mSv and 15 man.mSv are implemented for routine containment entry programmes at Sizewell B.

References

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