Management of Radiological Safety - Lessons Learnt and Issues Arising from the Decommissioning of Berkeley Power Station.

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Abstract

Berkeley Power Station was a world leader when in June 1962 it became the UK's first commercial nuclear power station to produce electricity for the national grid. Berkeley then stood at the leading edge of nuclear technology. After 27 years of successful operation and the supply of nearly 40 billion units of electricity, Berkeley ceased generation in March 1989.

Just as it was at start up, Berkeley is continuing to lead the way as the UK's first commercial nuclear power station to be decommissioned. A three stage decommissioning process is under way to safely dismantle the plant and eventually return the site to its original 'green field' state. Stage 1 of this process is well advanced.

To set the scene and for general interest, this paper first provides some background to the development of the decommissioning strategy and a brief summary of the progress to date. Recognising the specific interest of the reader, the paper then focuses on the radiological aspects of the work carried out, specifically the hazards, the risk assessment process and the ALARP performance. Finally, and in some detail, the paper reports on the important lessons learnt and discusses one of the issues arising.

Note: The views expressed in this paper are those of the author and do not necessarily represent those of Magnox BNFL.

1 Background

At the time of the closure, the CEGB's decommissioning strategy involved three stages. The first stage focused almost solely on the removal of the nuclear fuel from the two reactors. This was expected to take five years. The second stage involved the dismantling of the majority of the plant and buildings external to the reactor biological shields and this was expected to take a further seven years. On completion of this second stage, the remaining plant would be left for a period of approximately one hundred years before the third stage of decommissioning, when the reactor cores would be dismantled. This strategy, known as the *Reference Case Strategy*, was thus targeted on the creation of a green field site in something over a hundred years after closure. It was within the framework of this strategy, that Berkeley began Stage 1 decommissioning in April 1989 following cessation of generation (1).

This first stage of decommissioning was divided into five phases for regulatory purposes. The first four of these phases covered the progressive removal of the fuel. The fifth phase was the final removal from service and tidying up of the fuelling machinery.

Defuelling was started in July 1989 and was carried out with the reactors in air at atmospheric pressure with all control rods inserted and immobilised. Defuelling operations were undertaken on one reactor at a time, alternating between reactors approximately every eight weeks, to progressively and equally reduce the fuel loading of each reactor and hence reduce the reactivity. The overall rate of defuelling was actually determined by the availability of the irradiated fuel transport flasks for shipping the fuel to Sellafield. The fuel was removed using the existing refuelling equipment and the fuel route which had served to exchange fuel during operation of the station. These five phases were completed by March 1992, having dispatched some 84,877 fuel elements to Sellafield for reprocessing.

During the period that this defuelling was taking place, Nuclear Electric plc which had became the owner of the nuclear stations following the split of the CEGB, was reviewing its strategy for decommissioning. From a study which was carried out, a revised strategy, to become known as the *Safestore Strategy* (2), was identified as the Best practicable Environmental Option (BPEO).

Following completion of defuelling, the Safestore Strategy required preparations to be made for a care and maintenance phase which would last for some thirty years, at which time the reactors would be enclosed as necessary by high integrity structures (safestores). These structures could then be left with the minimum of maintenance for a further hundred years to allow the residual radioactivity to decay prior to the dismantling of the reactors and return of the site to a green field state. This approach minimises the exposures of workers, the technical complexity of the task and the cost. Safestore was identified by Nuclear Electric plc as the Company's preferred decommissioning strategy and formal agreement for the change in strategy was sought with the Department of Energy in May 1991.

At the time of completion of defuelling at Berkeley in March 1992, however, the Department of Energy had not responded and thus Nuclear Electric plc and Berkeley were faced with something of a dilemma.

Against that background, Stage 1 Phase 6 was conceived. This involved the dismantling of some items of plant whilst securing the long term integrity of others. A programme of work, which was intended to minimise the extent to which work done was prejudicial to either the continuation of the reference strategy or the adoption of the proposed safestore strategy, was identified and agreed with the Nuclear Installations Inspectorate. Work commenced in April 1993 and by March 1996, the original programme had largely been completed. Since then the scope of the work has been extended. Beyond 2004/5, no further decommissioning activities are envisaged until it becomes necessary to consider the longer term integrity of the reactors (safestore construction). The objective of the current work is to reduce the Care and Maintenance 1 costs (which precede safestore) to a level similar to those costs projected for the Care and Maintenance 2 period (which follow safestore).

Note: Safestore has since become recognised by the UK Government. One of the conclusions reached in the Government's review of waste management policy (3) carried out in 1995 was 'that there were a number of potentially feasible decommissioning strategies for nuclear power stations, including safestore'. Safestore is Magnox Electric's preferred decommissioning strategy.

A brief summary of the progress to date in the major plant areas and future intentions is described in what follows.

i) The **primary gas circuits** have been reduced to practicable minimums. The upper and lower **gas ducts** have been removed and the heat exchangers laid down. All of the top gas ducts and some of the lower gas duct sections have been decontaminated and made available for recycling. As a trial, one **heat exchanger** has been dismantled and largely decontaminated (~ 85%).

ii) All of the **fuelling machinery** has been dismantled and most of the component parts have been decontaminated and made available for recycling. The fuel magazines have been disposed of as active material.

iii) The **reactor building structures** have been completely deplanted, reduced in height and prepared for longer term storage (replacement of glazing with cladding, etc.). The **reactor vessels** now breathe openly to atmosphere via engineered vents. Continuous monitoring of the main parameters (temperature, moisture, etc) remains in place.

iv) The **cooling pond tanks** have been drained, desludged and had gross contamination removed. The building has been largely deplanted. Decontamination (Phase 2) work continues with the aim of reaching a point at which the building can be collapsed and the area levelled.

v) Available processing/disposal/discharge routes continue to be used to deal with **low level wastes (LLW)**. Solid waste arisings are consigned for disposal to the national repository at Drigg. The **active effluent treatment plant** has remained in service throughout for the treatment of liquid waste arisings. The number of fixed gaseous waste outlets has reduced as the decommissioning work has progressed although this has been off-set in part as the use of mobile ventilation plant has increased requiring some temporary outlets.

   Overall solid waste disposals have been higher than during operation (as would be expected). Liquid effluent discharges which continued at the about the same levels until the ponds were drained have now significantly reduced. Gaseous discharges reduced from cessation of generation and have remained very low.

vi) **Conventional plant** has been dismantled and materials have been reused or recycled where possible. Buildings have been demolished and cleared areas have been landscaped.

vii) Preparatory work has begun with respect to the recovery of the operational solid **intermediate level wastes (ILW)** from underground vaults. These wastes (largely fuel element debris) are to be conditioned, packaged and stored above ground in a purpose built shielded store adjacent to one of the reactor buildings, pending the availability of a national ILW repository. Consideration is also being given to the conditioning and packaging of mobile ILW (sludges and resins) arising from the treatment of pond water and currently stored in the **Caesium Removal Plant**.

For more details of the work carried out to date in Phase 6 and future intentions, the reader is referred to Berkeley Power Station, Magnox BNFL.

2 Hazards and risk assessment

2.1 Hazards

Some 99.9% of the radioactivity inventory is removed during defuelling (2). The remaining radioactivity is largely associated with the reactor vessels and their internals and the operational wastes (magnox debris, redundant chutes and control rods, spent resins, etc). Thereafter radioactivity exists as residual contamination in certain plant areas (the cooling ponds in particular), as stored contaminated primary circuit components and as low level waste arising from the decommissioning activities and to a lesser extent from the operation of remaining essential plant.

The reactor vessels remain in place within their concrete biological shields. Very close approach has not been necessary. However, during the dismantling of the primary circuit duct work, careful control of doses was required for the separation of the top and bottom ducts from the vessels, an activity which had to be repeated 16 times (remembering that there were 8 cooling circuits per reactor). Gamma doserates within the secondary shield vary but close to the primary shield (the concrete bioshield), where some aspects of the dismantling work had to be carried out, doserates have measured up to a few tens of mSv/hr.

Since defuelling, the operational wastes have laid largely undisturbed in below ground shielded storage vaults. Gamma doserates above the unshielded wastes have been measured in the range of a few mSv/hr to a few tens of Sv/hr. Whilst this data has been required by the designers of the retrieval and processing facilities, it is otherwise of academic interest as direct exposure to even the lowest doserates is not envisaged during these operations since these activities will be carried out by remote means.

The highest levels of residual contamination in other plant areas were, and still are, associated with the Cooling Ponds. Although the ponds were well maintained during the operational years (note: both main tanks had been refurbished during their operational lifetimes), the legacy of leaking fuel had left the tanks and pond plant items grossly contaminated. Contamination of the building had became widespread as a result of the many movements of the various flasks from the ponds, the occasional transfer of skips from pond to pond and the removal of underwater plant from the ponds for maintenance as necessary.

During the first phase of the decommissioning of the ponds, both the external and internal exposure hazards were significant, increasing as the ponds were drained. Before decontamination of the tanks began, gamma doserates of up to a few tens of Sv/hr could be measured over residual sludge, although these doserates were exceptional. Surface doserates above sludge level were of the order of a few mSv/hr. Beta/gamma doserates were a factor of 10 higher than gamma doserates on those surfaces which had been continually or frequently exposed to pond water (pond walls and furniture).

The presence of actinide activity has and continues to dominate the internal exposure hazard. Alpha to beta activity ratios have varied across surfaces throughout the ponds building. The ratios have been highest in the main pond tanks typically 1:10 on wall surfaces and have been measured as high as 1:1 within sludge residues. Resuspension of activity has been unavoidable, requiring careful control of internal exposure. Whilst levels are now much reduced, there is no complacency allowed.

Elsewhere the contamination levels have not been high. The primary circuits are however of interest with respect to dose control. Exposure to reactor gas had left them only lightly contaminated with doserates on external surfaces typically a few uSv/hr. Low levels of fixed and some loose activity were measurable on internal surfaces requiring only basic controls during dismantling and subsequent size reduction. Significant doses were however attributable to delagging which required close and prolonged approach. Here though the asbestos risks were the principal concern.

2.2 Risk assessment

Risk assessment is a three part process within Magnox Generation and ALARP considerations are at the core of this process. It is aligned with regulatory requirements and is largely consistent with practices in other parts of the Industry.

The first part of the process considers the nuclear safety issues only and is concerned with safety principles (4). Decommissioning activities are modifications to plant and each modification is assessed for its potential effect on nuclear safety. The initial assessment identifies those changes which could, if inadequately conceived or executed, lead to an increase in the risk of radiological hazard and thereby defines the level of approval necessary before the change can be implemented. For those changes which might lead to a very significant increase in the risk of radiological hazard, regulatory approval is required. For changes of lesser significance, internal approval can be given.

As part of this first stage, an ALARP study may be required. This is determined by the projected collective dose and, if called for, will be submitted for assessment in support of the proposed modification. In practice this is an iterative process, during which the proposal is refined to ensure that doses are both justified and ALARP before final submission.

The second part follows from approval and considers both the radiological and conventional safety issues and is concerned with safety from the system. A detailed work specification is developed and assessed by site safety specialists. In considering the radiological issues, the Radiation Protection Adviser (RPA) will advise on any further control measures necessary.

Thereafter the work is subject to periodic reassessment. As the work progresses, a better appreciation of the hazards and the risks develops. The risks are re-assessed and where necessary additional control measures are introduced. It should be noted that in some cases re-assessment shows the risk to be reduced and control measures are relaxed accordingly.

3 ALARP Performance

In comparison with dose accrued during the operational years, the decommissioning to date has been achieved at very low dose. The total collective dose to 1997 attributable to Stage 1 is 1.9 man.Sv. The annual collective dose for 1998 is expected to outturn at about the 1997 level. The projected total collective dose for the completion of all the preparatory work in advance of care and maintenance (i.e. completion of Phases 1 to 6) is 2.5 man.Sv.

The dose attributable to decommissioning (to 1997) is broken down by work activity. Three activities are notable in this respect.

i. Defuelling (1989-1992) during which a significant component of the collective dose was accrued in the cooling ponds where the irradiated fuel was received from the reactors, processed and packaged for dispatch from site. Operators were exposed to low doserates for long periods and to higher doserates for shorter periods as and when necessary.

ii. Primary gas circuit delagging and dismantling (1993-1995) and to a lesser extent decontamination undertaken more recently. In all cases close approach to the circuit components has been necessary. Contractors were exposed to low doserates for long periods and when working within the secondary shield areas were exposed to higher doserates for short periods.

iii. Decommissioning of the Cooling Ponds (Phase 1) since late 1994 which has involved working for prolonged periods working in variable doserates whilst in respiratory protection. The highest exposures to date have been attributable to the decontamination and size reduction of skips and crane masts, manual Ultra High Pressure (UHP) water blasting of pond wall and floor surfaces (where remote blasting has not been practicable) and the removal of fuel element debris and associated sludges.

Of all these activities, the decommissioning of the Cooling Ponds (iii.) is likely to be of most interest to the radiological safety practitioner. Management of the ALARP aspects of the Phase 1 work was particularly challenging and it is from this experience that most of the lessons reported here were learnt.

Higher than expected internal exposures (1st Quarter - 1995) to front line and support workers required investigation and were assessed respectively as being directly and indirectly attributable to the decontamination of element skips. These skips were grossly contaminated and required considerable decontamination to reduce levels such that they could be disposed of as LLW. As a result of the investigation and subsequent re-assessment of risk, a number of improvements to control measures were made. As the work has progressed these measures have been frequently reviewed.

In summary the overall ALARP performance is considered by the Company to be good. More work has been carried out in Stage 1 than was originally envisaged. However, the increase in the scope of the work and in particular the advancement of some of the activities has not led to a significant increase in dose above that which would otherwise have been accrued had the buildings and plant been left as they were. For dose would have had to have been spent in maintenance.

4 Lessons learnt

The good practices and lessons learnt from the Berkeley experience are set out below. Best endeavours have been made to report these in an objective way. In many areas they have a wider applicability than radiological safety. Some operators will be wise to these lessons, others may wish to refer to this section as guidance to risk management when planning decommissioning activities, in particular the decommissioning of cooling ponds.

4.1 Operational Management

This point is directed to current operators, for all the bad operational practices come home to roost at decommissioning.

The greater the levels of residual contamination at cessation of generation, the greater the radiological risk at the onset of decommissioning. Whilst the magnitude and extent of the contamination will be related in part to plant design, it will also be related to how well the plant has been managed during its operational lifetime. The better plant is managed, the lower the radiological risks will be to those involved in decommissioning. Good records are also essential.

With respect to controlling cooling pond contamination levels, a good management programme will recognise the need to minimise fuel residency time, to periodically treat pond water to reduce activity levels and maintain clarity and to promptly remove debris and sludge arisings. General cleaning should be a routine activity.

4.2 Objectives and Targets

In addition to other business objectives and targets that may be set for the decommissioning work (e.g. time, cost, etc.), it is important that health, safety and environment objectives and targets are also set. These should be established at overall programme and project specific levels.

In determining which aspects of performance to measure, accident frequency rates and collective dose will typically come to mind. Whilst this data is important, these are measures of output. It is equally important to measure inputs, for example, the training provided, the number of tool box talks given, the number of safety awareness workshops attended, the number of safety improvement suggestions made. Performance can then be judged accordingly. One very useful performance measure is the ratio of the number of accidents to unsafe concerns.

4.3 Risk Assessment

A total risk approach should be adopted. The need to consider the relative significance of all risks and how they relate to one another is very important. Careful consideration should be given to the introduction of control measures to reduce radiological risk for these controls may elevate other risks.

It is noteworthy that when a total risk approach is taken in assessing risks associated with work activities of this nature, it is not always the case that the radiological risks are the highest (5). However it is often the case that the perception of radiological risk is such that, when considering control measures, this risk is elevated above all others. By comparison the need to put the radiological risk into context and consider the relative significance of other risks is probably less well appreciated.

The decommissioning experience to date supports the UK regulatory view that risk assessment should not be a once-and-for-all activity (6). The management system should provide for and ensure that periodic reviews are carried out.

4.4 Resources, training and supervision

The need to ensure all doses are ALARP, requires (amongst other things) optimisation of the use of resources. The experience at Berkeley has shown that collective dose is kept lower when small teams are used for they are more easily managed and controlled and generally train and work better together. The constraints on individual dose will require some dose sharing but this is usually permissible amongst suitably skilled persons. Prudent planning should ensure the timely availability of other suitably trained persons as necessary, rotating duties with those team members approaching dose constraints. Where dose constraints allow, every effort should be made to keep experienced teams together.

Unless comprehensive and readily accessible records exist, the selective retention of persons with operational experience is advised. An awareness of the lessons learnt during operation of plant will prove helpful when considering decommissioning activities.

Project specific ALARP training should be given in addition to that provided as part of general site induction training. It is important that persons entering plant areas have a clear understanding of the local hazards and risks. Thereafter, as refresher training, 'toolbox' talks are recommended.

The appointment of suitably experienced supervisors is essential. Close supervision should be a requirement of all high risk work. This should not be taken to imply close approach which can be avoided (see later sub-sections).

4.5 Attitude, behaviour and safety awareness

Whilst knowledge and skills are very important, other attributes are of equal if not greater importance.

The right attitude and behaviour are essential. Employees with bad attitudes or employees who are unreceptive to instructions or reminders can jeopardise their own safety and that of others. A questioning attitude on matters of safety is considered to be an essential attribute which workers should be encouraged to adopt.

Safety awareness is not common sense, it is a skill which needs development and should be included in all safety training programmes.

4.6 Access to, and designation of, work areas

Early consideration should be given to how best to access plant areas for the various work activities to be carried out. Access should be relatively simple, keeping distances short and avoiding hazards on route. In respect of distances, account should be taken of the possible use of airline suit RPE that may be required to be worn by persons entering the area.

When considering access, the designation or classification of the area should also be considered. Simple strategies work best in practice for control of access and egress to and from areas, and within areas, will become increasingly more complicated and prove difficult to manage. It is suggested that plant areas are simply divided into low and higher risk areas with periodic review of the positioning and adequacy of dividing boundaries.

4.7 Change facilities

Consideration of change facilities follows from 4.6 above.

Facilities established for operational use are likely to prove inadequate for decommissioning work for the numbers of persons entering plant areas and the frequency of entries may be considerably higher. In addition to the throughput of persons, consideration should also be given to the variety of tools and equipment that may be needed and in particular to the PPE support requirements. Running hoses or airlines through door ways, obstructing the closing of doors and possibly adversely interfering with air flows, is not good practice. Change facilities should be made fit for purpose and in this respect the best option may be to establish new arrangements.

Where change facilities cannot accommodate separated entry and exit, coincident entry and exit should be avoided.

4.8 Personal protective equipment (PPE)

The types of PPE made available should always be of an approved type and clear instructions given to entrants and dressers on what PPE is required for what areas and work tasks. The range of PPE available for use should be rationalised. Use and maintenance of many types may cause confusion and lead to a reduction in control.

All PPE should be serviced and maintained, in particular PPE used in contamination controlled areas. In addition to laundering and monitoring, contamination clothing should be inspected before being returned into service. Higher quality clothing often proves to be the most cost effective. RPE requires special attention. Monitoring checks should include internal surfaces (see also control of internal exposure 4.13). Airline hose and suit connections should also not be overlooked. The use of RPE requiring any connection to be made by the wearer inside a contamination area should be avoided.

Whilst it is well understood that use of RPE almost always requires an ALARP judgement to be made, it is less well understood that the wearing of RPE (and some other PPE) can increase total risk. In particular the wearing of RPE impairs vision. If the task involves working at height or near operating plant (e.g. cranes), careful consideration should be given to the use of RPE. Wearing RPE to avoid marginal risk may elevate the risk of a fall or collision either of which is likely to have far more serious consequences.

For rescue situations, the wearing of PPE should not be a rigid requirement. Specific advice should be given in contingency plans on when the casualties needs override the need for rescuers to wear PPE. In such cases, the justification for not wearing RPE should always be made clear to those who may be called upon to assist (preferably before an incident occurs).

4.9 Ventilation and containment

Most decontamination processes have the potential to generate airborne particulate and/or fumes. Control measures will usually include some means of removing and treated the gaseous waste produced. Installed or temporary systems may be used.

Where installed systems remain and are intended for on-going use in support of decommissioning work, their operating specifications should be re-examined. Systems are usually specified and configured for static plant conditions. Significant changes to these conditions as a result of decommissioning activities may adversely affect the efficiency of the system. For example, falling pond water levels will increase building air volumes, so reducing the number of air changes per hour for the same fan and damper configuration. In this case however whatever the specification and possible configuration, it is unlikely that installed systems will be very effective in moving air at the bottom of a pond tank or other low lying void. In these and similar circumstances, alternative arrangements will be necessary (e.g. modifications to installed systems, use of temporary systems, etc.)

Use of temporary systems requires careful consideration if they are to be used effectively and if their operation is not to be counter productive. When used within buildings where installed systems exist and are in service, their operation may reduce the effectiveness of both systems and may even elevate the hazard. Connection of extract outlets to installed system extracts in an ad-hoc manner (i.e. taped to grills) is not advised, for operation of the temporary system may introduce more air than the installed system can remove at that point, resulting in flows back into the work place. An engineered solution is advised. Extract outlets should always be positioned to minimise disturbance of any adjacent surface activity.

All ventilation systems should be tested prior to decontamination work commencing for the demands on the system, in terms of the clearance of gaseous waste, may be great. Systems should then be subject to frequent airflow checks and regularly maintenance.

Where buildings has been partitioned into low and higher risk areas, systems may need to be re-configured to obtain correct air flows across boundaries. Routine checks should be made to ensure that higher risk areas are always maintained at lower differential pressures than lower risk areas. When checking airflows, it is essential that checks are made at entry and exit points to the hazard areas to determine airflow characteristics across partially and fully open door ways.

The use of local containment in conjunction with temporary systems to contain and control the spread of loose contamination also needs careful consideration. In particular when considering work activities with the potential to produce large volumes of gaseous waste. The effectiveness of the set up must be proven before work commences. A larger rather than smaller enclosure is usually a better arrangement for under conditions where the generation rate of gaseous waste may exceed the clearance rate, higher concentrations of activity will arise in the smaller enclosure.

4.10 Inspection and communication

Entries into hazard areas for the purposes of viewing or inspecting work or to communicate only should be minimised. In this respect, early consideration should be given to the use of viewing windows, cameras and radio communications.

Where installed at strategic positions, viewing windows and/or remote controlled cameras should give reasonable coverage of most activities. For controlled areas clearly this is best done before work commences. Used in conjunction with good communication systems, inspection and communication need then not involve any exposure.

The use of videos to record work practices can have ALARP benefits. Operator working techniques can be reviewed and changes then made where it can be seen that different techniques might bring about safer or more efficient working. All this without unnecessary exposure. Furthermore video (and tape) recordings can be useful in event investigations.

With respect to communications, radio systems are advised for they are proven not only to be highly effective but also to be very reliable. Hard wired arrangements are less so, in particular systems using air hoses as the means of running communication wires. Failures can be costly in time and dose.

4.11 Remote control of work

Remote control of work follows from 4.10 above. Viewing windows and remote controlled cameras provide opportunities for certain work activities to be controlled remotely. Remote use of UHP water is a proven example in the Berkeley case.

Remote control completely eliminates operator risk, with entries into the hazard area only then being necessary for equipment alignment and maintenance.

An example of this at Berkeley was the development of a wet waste 'freezer' to recover fuel element debris from a pond sump. The 'freezer' avoided the need for persons to approach the waste and attempt a recovery in some other way. The 'freezer' unit was lowered by a hoist into the pond sump where the debris had been remotely collected and was lying under water. It formed a block of ice of the sump contents there by trapping the debris. The unit was then lifted and suspended over a waste skip placed in a tank of water, where the block of ice was released by reversing the freezing cycle and allowed to thaw. It was then possible to remotely transfer the debris to the active waste flask for subsequent transfer to the ILW vaults.

4.12 Dose management - general

Effective dose management requires access to up to date dose information. Where passive dosemeters have to be used (as the 'legal' dosemeter), electronic dosemeters should be used in conjunction to provide 'day to day' control. Assessment of doses measured by films and TLDs may lag the progress of work by several weeks, certainly where assessments are made by a third party.

For projects involving work subject to bio-assay as part of the process of dose assessment and control, estimates of possible internal exposure should always be included in running dose totals (see 4.14) until assessments have been made.

Dose planning and review should be a formalised process. Regular meetings involving the respective RPAs and RPSs (operator and contractor) should be established to review exposures to date (known dose attributable to work already carried out) and consider and plan future exposures (expected dose for work yet to be carried out). ALARP performance should be measured against pro-rata dose projections and (any) targets set.

As a tool for dose review it is suggested that, from the commencement of decommissioning, existing or new dose management systems are structured such that doses attributable to individual projects can be separately identified and reported. These reports should than be made readily available to the respective RPA(s) and RPS(s) as part of the review process.

Specific aspects of the control of external and internal exposure are considered separately below.

4.13 Control of external exposure

Whilst decommissioning strategies can take advantage of radioactive decay to avoid or reduce dose, once actual work is under way the other principles of radiological protection become important. In this respect particular emphasis should be placed on the importance of the use of time and distance to reduce dose when giving ALARP training for shielding may reduce as work progresses. Examples of this at Berkeley have been the draining of the cooling ponds and the dismantling of the chargeface machinery.

Hazard identification is essential. Surveys should identify points of elevated doserate within areas and this information should be made known to persons working within or close to these areas and clearly understood.

The generation of radioactive wastes in decommissioning can be very high at times and temporary storage areas and disposal routes should be identified before work begins. Accumulations of wastes within the working areas should be avoided for obvious ALARP reasons.

Relatively high doses can be accrued when handling and packaging wastes. However here a compromise is necessary for inefficient packaging of wastes can be very costly. A balance is required which satisfies the ALARP requirement and keeps costs down.

4.14 Control of internal exposure

RPE is not 100% efficient. Where work involves prolonged and frequent working in radiological conditions where high levels of airborne activity exist, some internal exposure albeit at very low levels should be expected and planned for. RPE types are typically quoted as being better than 99% but in practice the efficiency will vary, reducing with time particularly when being used in hot and stressful working conditions.

As an aid to dose planning, the Berkeley Cooling Pond decommissioning experience has shown that an internal dose (committed effective dose equivalent) of 1 mSv per quarter is a reasonable upper estimate for a person working full time in areas where the airborne alpha levels vary between 0.1 and 0.5 Bq/m3. This can be supported by calculation. Activity characterisation is essential if underestimates of internal exposure risk are to be avoided.

Avoidance of the transfer of gross contamination from the work area to the change facility requires a high level of training and an even higher level of awareness at all times. Support personnel are particularly vulnerable in this respect and their protection should not be overlooked when assessing risk. Change procedures should be subject to periodic review.

For projects requiring prolonged use of RPE, early arrangements should be made with an Approved Dosimetry Service (Internal Assessment) for bio-assay and internal dose assessment. The ADS should advise on the sampling required and should be provided with best information on excretion rates, work patterns and, where acute internal exposures are suspected, of likely exposure dates when samples are sent for assessment. Support personnel should always be included in monitoring programmes.

The monitoring of air activity levels will be a necessary requirement to determine the designation of the area and to provide advice on the PPE to be worn. This information will also be very useful should acute internal exposures be suspected. If graphically displayed, likely exposure dates should then be relatively easy to identify.

RPE servicing will require the availability of a suitable facility and adequate resourcing. Particular attention should be given to the cleaning and monitoring of internal surfaces of RPE for it should be recognised that it is not only the external surfaces that may become contaminated. It is possible and probably quite likely that contamination will be transferred to internal surfaces during the undressing process.

4.15 Contingency arrangements

By comparison with operation of plant, dismantling and demolition activities can expose workers to higher (conventional) risks. Should a serious accident occur, the recovery of a casualty is likely to require a coordinated effort on the part of fellow workers, site emergency teams and the rescue services. Recovery from controlled areas and in particular from contamination areas requiring the wearing of PPE will be more complicated.

In this respect each decommissioning project will be different. The development of project specific contingency plans for worst case rescue events is therefore essential. Workers should be familiar with plans, which should be periodically practised. Specialist rescue equipment should be readily available, as should sufficient quantities of PPE for all those who may attend to assist with recoveries from contamination areas.

A safety person should always be present when higher risk work activities are undertaken. This person need not be very close and exposed to the same risks as the worker but able to see what is going on and respond as necessary. In radiological areas, the ALARP aspects will require consideration but an ALARP case can generally be made for such exposure.

In this respect, the manual use of UHP water equipment for decontamination purposes is a notable high risk work activity. Operatives should carry cards to inform others of the nature of their work in the event that they are injured whilst using such equipment, for injuries which appear only to be superficial in nature can prove to be very serious. Injection of water at very high pressures can cause serious damage to internal tissues requiring urgent medical attention. Where injuries occur in contamination controlled areas, there is always the possibility that activity may be injected into the body and prompt liaison with medical staff is essential if biological samples (e.g. foreign matter, tissue, urine) are to be retained/obtained for exposure assessment purposes.

4.16 Contractual issues

Where fixed price contracts have been established and time penalties are applicable, the pressures will increase as projects run late. Keeping dose and other risks ALARP may then become of secondary importance. In such circumstances managers and safety practitioners need to be more vigilant in their inspections of working practices. Whatever arrangements are in place, there should always be a degree of flexibility built into the contract to ensure that safety is remains and remains the No 1 priority. It is better to finish late and safe.

5 Summary and Issues arising

As the UK's first commercial nuclear power station to be decommissioned, Berkeley Power Station has (on this scale) led the way into decommissioning. All parties have learnt from the experience. The Company, the contractors and the industry. Indeed, in the author's view, even the regulators.

To have achieved what Berkeley has achieved, a questioning and challenging approach has been necessary. The progress of the work has not been without its difficulties but these have largely all been overcome. Some issues have also arisen. Clearance of materials for recycling is one issue which merits some discussion. During the progress of the Phase 6 work to date, over 25,000 tonnes of material (largely steel) have been released form site for recycling. Achievement of this has not however been without its challenges.

A significant proportion of the steel had been exposed to radioactivity and as a consequence was contaminated. Whilst the contamination was typically bound to internal surfaces, in the case of primary circuit material tritium had diffused into the steel matrix, albeit to very low levels (< 100 Bq/g). This added a new dimension to the decontamination process.

As a means of demonstrating that the primary circuit material could be successfully decontaminated and therefore any surface contaminated steel item, an extensive trial was conducted. A number of duct component parts were decontaminated by grinding and later by UHP water. The diffused tritium was released in a controlled manner by heating. The clearance criteria was (and remains) rigidly aligned with the current UK's exemption limit of 0.4 Bq/g for solid material. A degree of averaging has been allowed by the regulator.

The trial was successful and a programme of further decontamination of primary circuit duct work followed. Since then a trial dismantling and decontamination of a heat exchanger has been carried out.

Decontamination of this material is however far from cost effective, for the return is small compared with the large investment. For this reason decontamination has only been undertaken either for the 'learning experience' or where there has been a need to use the storage space for other purposes. Of greatest contention (for the considerable cost and additional risk involved) is having to heat the steel on site to release the very low levels of tritium when it is known that the process of smelting soon after will achieve satisfactory dispersion. A more isotopic specific risk based approach to the setting of exemption/clearance levels is needed if operators are to be expected to do more decontamination, certainly as far as tritium is concerned.

To consign large volume wastes of this nature to Drigg (the UK's national LLW repository) is not the answer for it would be an inappropriate use of a valuable national asset which incurs high costs to the operator and ultimately the taxpayer.

In summary there is a strong case for safe storage at site to take advantage of decay and then to decontaminate when reasonably practicable in the context of the overall decommissioning strategy. This is the current approach being taken at Berkeley with the remaining primary circuit material.

6 References

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