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Radiological Protection During a PWR Refuelling Outage

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Sizewell B and Refuelling Outage

The EDF Energy operated Pressurised Water Reactor (PWR) at Sizewell B (SZB) is the UK's only PWR. Located on the Suffolk coast; its reactor is based around the design of the Westinghouse '4-loop' PWR known as a SNUPPS (Standard Nuclear Unit Power Plant System). Generating approximately 1200 MWe it is currently the largest of the UK's nuclear power plant fleet and has been operational since 1996.

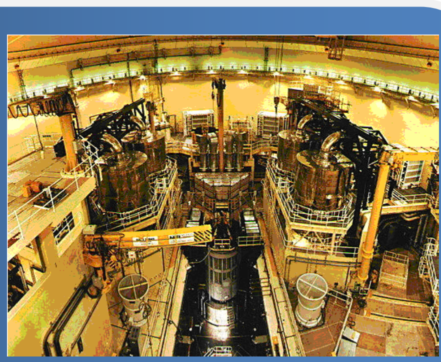

Figure 1 - View of reactor containment building from the polar crane gantry

The design of the plant means that it can operate at full capacity for around 18 months at the end of which the plant is shutdown for refuelling of the reactor core. During the shutdown period (outage) a large number of planned and emergent inspections and maintenance work takes place across the station. The refuelling period provides the radiological conditions and time necessary for routine inspections of the reactor. Typical outage maintenance inspections include:

- Checks of the plant safety and control systems;
- In service inspections of many of the plant welds;
- In service inspections of the reactor pressure vessel (RPV);
- In service inspections and maintenance of the Steam Generators (SGs);
- Inspections and maintenance of the plant auxiliary systems (known as Balance of Plant BOP);
- Inspections of reactor fuel and re-shuffling of fuel in the reactor core in order to optimise the fuel burn-up during operation.

Every third refuelling outage, the reactor coolant level is reduced to a lower 'mid-loop' level allowing for inspections of the primary circuit. In the early autumn of 2011, refuelling outage 11 (RO11) commenced at Sizewell B. This outage was a mid-loop outage with the addition of two large projects: the replacement of one of the reactor coolant pump impellors and all of the pressuriser heaters. These two projects were a first at Sizewell B.

The RP Team

A typical refuelling outage requires a large team of additional personnel - mechanical, electrical and instrument engineers, non-destructive test personnel, refuelling engineers and health physics staff. During the outage the station RP team are complemented with an additional 50 contractors from Nuvia consisting of health physicists, health physics (HP) supervisors, HP surveyors, decontamination supervisors and operators, and barrier monitors. The Nuvia supplied team merge with existing station personnel to form one large RP team which work together throughout the outage. Nuvia have supported Sizewell B in this way since the first outage, RFO1 in 1998.

The RP team is split into shifts and teams to cover BOP and the reactor containment building as well as specific high risk task teams. RP control desks are set up around the reactor containment building to support entry into R4 areas, issue teledosimetry, which provides the ability to monitor dose uptake in real-time, provide communications with the work parties (via headsets) and other areas via telephone, as well as allow space for survey reporting.

Planned Outage Tasks

During the first few days of a refuelling outage, after the reactor has been shutdown, activities are carried out to get the plant ready for the removal of fuel – forced oxygenation 'crud burst' is performed to the primary circuit to release corrosion products from the system surfaces, principally to control refuelling pool clarity, but it also has the additional benefit of reducing plant primary circuit dose rates. Pressure is released from the primary circuit, the reactor head vented and then finally disassembled. As the reactor pressure vessel head (RPVH) is removed, simultaneous water filling of the refuelling cavity occurs. The water provides shielding for the refuelling activities. The RP team provide constant support to this phase of the outage, setting up and monitoring no-go areas, using extendable radiation monitors to survey dose rates as the RPVH moves across to its storage stand and ensure the lifting crew adhere to good working practices.

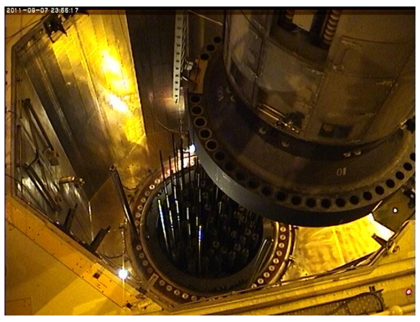

Figure 2 – RPVH removal view into reactor upper internals and cavity floor

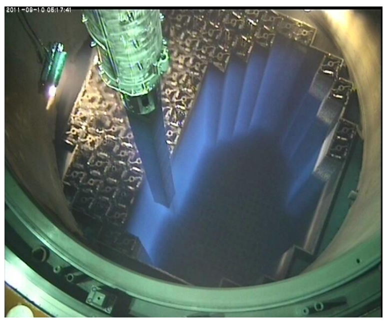

Figure 3 – Core offload

Further work allows for the reactor upper internals package to be removed (under water) to its storage stand and the reactor core is exposed for de-fuelling to commence. All 193 fuel assemblies are removed from the core individually and taken to the fuel storage pond in an adjacent building (under water).

During a PWR refuelling outage the water level, which remains within the reactors primary circuit, is crucial for keeping the radiological conditions optimised. A reduced water inventory means increased radiation dose rates and increased operator doses. However, during some maintenance aspects of the refuelling outage a reduced water inventory is unavoidable – Eddy Current inspection of SG 'U' tubes, various system valve maintenance and reactor coolant pump maintenance.

Mid-Loop Outage Activities

SG Primary Side EC Inspections

Work carried out on the primary coolant circuit requires a great deal of detailed planning and overview due to the significant radiological hazards associated with this system:

- High radiation dose rates; typically 15-20 mSvh^{-1} inside the channel head of an SG;
- High ambient dose rates on the SG maintenance platform; typically 0.1 – 10 mSvh^{-1};
- Very high loose contamination levels on the primary coolant circuit internal surfaces; typically 1 - 2 kBqcm^{-2} beta.

Figure 4 – SG primary side platform work area

Prior to breaking into the primary side of a Steam Generator, the maintenance platform is prepared with a series of removable layers of plastic sheeting to aid with decontamination during, and on completion of the maintenance activities and help prevent a spread of contamination. The team receive mock-up training and pre-job ALARP briefs. Blankets of lead shielding are also used to shield the work area from high dose rate pipework running around the platform.

On breaking the primary circuit boundary operators are required to wear appropriate PPE and RPE (for RO11 this consisted of scrubs, C2 coveralls with impervious over suit, cotton gloves plus double rubber gloves (one sacrificial), two pairs of rubber soled overshoes, a cape and a positive pressure air fed hood.

- A dedicated forced ventilation system is used to reduce the likelihood of dislodged surface contamination escaping from the SG;
- Specialist robotic equipment is used to install foreign material exclusion (FME) debris covers into the SG channel head legs. It is also used to install and manipulate the EC test equipment.
- Once installed the equipment is generally controlled from a remote trailer unit, located outside the reactor building. Occasional operator intervention is required but the remote operation keeps operator radiation dose uptake ALARP.

Pressuriser (PZR) Heater Replacement

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During RO11 all of the pressuriser heater elements were replaced. Dose rates at the worker platform were around 1 - 2 mSvh^{-1}. The project took 16 days with a collective dose of 98 man.mSv; involving around 100 staff. The maximum individual external dose was 4.2 mSv. Significant levels of contamination were generated (~ 4 kBqcm^{-2}) when each heater element was pulled from the bottom of the pressuriser. The works proved a significant challenge to the RP team in;

- preventing a spread of contamination from the immediate PZR work area;
- containing the contamination on the heater elements;
- completing regular decontamination of the area;
- ensuring good undress procedures of the team leaving the work area.

Two temporary undress areas with contamination control barriers were created at specific exits to the pressuriser cell. Static air samples with swan necks were set up in various locations around the work area to monitor airborne contamination levels.

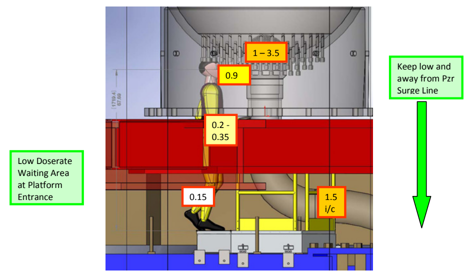

Figure 5 – Working platform doserates (mSvh^{-1}) underneath the Pressuriser

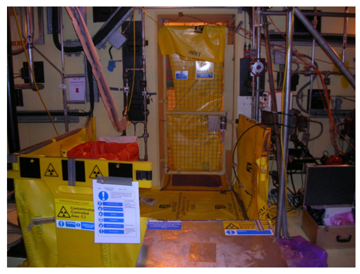

Figure 6 – Photograph of the entrance to the Pressuriser Cell showing barrier

Reactor Coolant Pump (RCP) Impellor Replacement

Historical information was used from other PWR impellor replacement projects. High radiation dose rates were expected on the impellor during the lift. A bespoke shielded transport box was constructed to transport the removed RCP impellor to France for inspection and maintenance. In order to remove the impellor, the complete reactor coolant pump was dismantled from the top down including removal of the motor, the seal package and housing, the motor stand, and pump cell. The RCP 'D' work platform is in close proximity to the pressuriser therefore care had to be taken to ensure the two work activities did not impact on each other radiologically -contamination from PZR reaching the RCP platform had to be eliminated and enhanced dose rates, when lifting the impellor out of its seat, had to be minimised.

- The area between the two work platforms was separated with plastic sheeting for containment and lead blankets for shielding.
- Static air samplers were placed in representative locations on the platform.
- Loose contamination levels were kept under control on the RPC platform during the entire mid-loop phase.
- Radiological conditions on the impellor were lower than expected (A-E refers top – bottom of impellor).
- Up to 10 microSvh^{-1} at 1m was measured on the external shielded transport box.

Table 1 – Impellor Radiological Conditions as Lifted

Position	Dose rate (mSv/h)		Contamination (Bqcm^{-2})	
	Contact	1m	α	βγ
A	7	2	<0.04	70 μSvh^{-1} by smear
B	7	2	<0.04	
C	7	2	<0.04	
D	8	3	<0.04	
E	12	4	<0.04	

Shielding was used around the RCP 'D' platform to lower ambient dose rates in the work area. During the impellor lift, the number of personnel in the area was kept to a minimum (lifting crew x 1, HP x 1 and project engineer x 1). All personnel involved in the lift donned RPE and PPE as worn by the SG EC crew. Individual external dose uptake during the lift was <1 mSv.

Returning to Power

After the mid-loop activities and fuel shuffle, the core is reloaded and the RPVH replaced. The HP and decontamination team carry out a thorough decontamination of the refuelling cavity using remote and manual techniques. Figure 7 shows the upper cavity during decontamination with a protective cover over the RPVH:

- Decontamination of the upper and lower cavity as well as the fuel upender pit usually takes around 20 hours.
- Methodology is important to prevent cross contamination.
- A temporary barrier is used at the top of the lower cavity ladder to ensure the upper cavity remains relatively clean (generally <250 cps by large area smear).
- The cavity walls are cleaned using a special wall cleaner (RM1) attached to the reactor building polar crane to ~100 cps.

Figure 7 – Upper Cavity Decontamination using RM1 Wall Cleaner suspended from the Polar Crane

Radiological Dose and Contamination Information

Dose estimates by major task area were principally derived from historical dose data.

- There was generally a good correlation between dose estimates and actual, with the majority showing low negative variance between the estimate and the final out-turn.
- It is estimated that around 40 man.mSv of radiation exposure was saved by the use of temporary radiation shielding at the station during outage. This equates to around 8% of the collective radiation exposure for the outage.
- The RP and decontamination doses were within 3% of predictions. Doses were controlled by use of remote monitoring systems and decontamination techniques that facilitated rapid decontamination (such as the use of floor scrubbers). The RP team's doses were about 10% of the overall outage dose. Although slightly higher than the previous outage the percentage is still well down on earlier outages and is close to the industry median value.

Compared to previous outages, RO11 recorded an increase in the Personal Contamination Event (PCE) rate. An increase in the PCE rate was anticipated as a result of the new Whole Body Contamination Monitors (WBCM) with gamma detection capability. In addition to this a more challenging source term, fairly small change rooms, several instances of poor practice and a large number of new contractors to SZB attributed to the rise in PCE's.

Conclusions

i) From a radiological protection perspective RO11 proved to be a very challenging outage. The large work scope combined with less comprehensive station preparations (due to the impact of a previous forced outage in the cycle) placed a significant challenge on the effectiveness of the RP function.

ii) Notwithstanding the challenges, radiation doses were generally well managed and targets for collective radiation dose and maximum individual dose were achieved.

iii) The new WBCMs have highlighted opportunities for improvement in the station's contamination control programme.

iv) The RP team worked well under pressure and have learnt some valuable lessons from the high risk projects (PZR, RCP, SG primary side).

v) The RP control desks and temporary barriers work well to control access, manage dose uptake, communications and prevent PCE's at the undress stage.

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