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PWR DESIGN FOR LOW DOSES IN THE UNITED KINGDOM: THE PRESENT AND THE FUTURE*

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ABSTRACT

The Pressuriser Water Reactor (PWR) design chosen for adoption by Nuclear Electric plc was based on the Westinghouse Standard Nuclear Unit Power Plant System (SNUPPS). This design was developed to meet the United Kingdom (UK) requirements and those improvements are embodied in the Sizewell B plant.

Nuclear Electric plc is now looking to the design of the future PWRs to be built in the UK. These PWRs will be based as replicas of the Sizewell B design, but attention will be given to reducing operator doses further.

This paper details the approach in operator protection improvements incorporated at Sizewell B, presents the estimated annual collective dose, and identifies the approach being adopted to reduce further operator doses in future plants.

INTRODUCTION

Nuclear Electric is a Government-owned utility which owns and operates all the commercial nuclear power stations in England and Wales. The bulk of these stations are gas cooled reactors but Nuclear Electric is currently building its first commercial PWR station, Sizewell 'B', in Suffolk, England. The station is now under commissioning and it is intended to be in full commercial operation in the second half of 1994.

Sizewell 'B' is based upon the SNUPPS design and there are two such plants already operating in the USA at Callaway and Wolf Creek. The Sizewell 'B' design has been developed to include additional safety features required to address UK licensing requirements. This includes additional fault mitigation equipment to address potential public release concerns and design improvements to reduce operator dose uptake.

With Sizewell 'B' nearing completion, Nuclear Electric is already looking to the design of any future station to be built in the UK. These future plants would be built as replicas of the Sizewell 'B' design, but attention would still be given to reducing operator doses further. This has the dual benefit of providing the maximum operational flexibility to the station in achieving the very low operator dose targets and also ensuring operator doses are As Low As Reasonably Practicable (ALARP). This paper outlines the approach in operator protection improvements incorporated at Sizewell B, presents the estimated annual collective dose and identifies the approach being adopted to reduce further operator doses in future plant.

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OPERATOR DOSE TARGETS

The whole body dose targets which have been adopted by Nuclear Electric for their PWRs have been derived from consideration of operator doses at their gas cooled reactors, from the requirements of the U.K. Nuclear Installations Inspectorate (NII) and the Public Enquiry for planning consent for Sizewell 'B'. The most important targets are the individual annual target of 10 mSv (1 Rem) and the station annual collective dose target of 2.4 man-Sv (240 man-Rem)

These targets were set when average PWR collective doses were about twice this value and hence were extremely demanding targets for a PWR at the time.

OPERATOR PROTECTION IMPROVEMENTS IN SIZEWELL B[1]

A number of changes from the SNUPPS design have been incorporated in the Sizewell B design to reduce operator doses. The approach adopted in identifying the improvements was to reduce the radiation sources and source strengths, improve systems and layout to reduce the impact of the radiation sources on operator doses, and introduce remote equipment.

Examples of the improvements are:

(a) minimisation of radiation sources and source strength:

- reduction of Ni and Co impurities in materials; e.g.
  - replacement of stellite in the Chemical and Volume Control System (CVCS) control valves
  - use of Inconel 690 in Steam Generator (SG) tubing
- control chemistry at all stages
- remove crud traps
- etc.

(b) system and layout improvements:

- introduction of a permanent Reactor Pressure Vessel (RPV) cavity seal
- introduction of shielding in the Reactor Coolant Pump (RCP) seal change platform
- location of major items in individual shielded cells
- replace the wet Resistance Temperature Detection (RTD) system with alternative N-16 based measurements
- introduce platforms to improve access for maintenance
- carry out system and layout ALARP reviews to identify further improvements
- etc.

(c) use of remote equipment:

- Multi Stud Tensioner for the RPV stud removal/installation
- RPV flange and stud hole cleaning equipment
- all RPV and nozzle volumetric In Service Inspection (ISI) will be carried out by a submersible robot
- all volumetric ISI of welds in high dose rate systems will be carried out by automated equipment
- SG inspections eliminate the need for SG bowl man-entry
- etc.

The attention paid to operator protection improvements benefitted significantly from international operational experience and helps in ensuring that operator doses will be ALARP.

SIZEWELL 'B' OPERATOR DOSES

The Pre-Operational Safety Report (POSR) for Sizewell 'B' was submitted to the licensing authority in November of 1992, and it included an assessment of the operator doses for the station. The assessment was based on dose-rate data from the two SNUPPS plants Wolf Creek and Callaway and similar plants operated by Electricite de France (EdF). It then utilized the expected operator residence times to compute the operator doses for all the well defined tasks on the station. For the other tasks like Health Physics work and unplanned maintenance, overall reported dose information from relevant plants was used.

The assessment which was based on dose rate data for the coordinated 6.9 pH chemistry, concluded that for the planned 12 month fuel cycle the annual collective dose would be 1.97 man-Sv (197 man-Rem). The maximum individual annual dose was calculated to be 8.5 mSv (0.85 Rem).

The collective dose assessment was recognized as a conservative estimate because whilst the most applicable operational dose-rate information had been used it did not reflect all the source reduction steps taken for Sizewell 'B'. In particular, the benefits from the selection of Inconel-690 material for the SGs and the removal of stellite from CVCS valves were not included.

It was estimated that these improvements could reduce the annual collective dose to as low as 1.32 man-Sv (132 man-Rem) for the planned 12 month fuel cycle operation. Consideration of the dose savings from design and equipment improvements on Sizewell 'B' and from the adoption of higher pH chemistry would further reduce this value.

Following the dose assessment it was decided to implement the modified chemistry (2.2 ppm Li; $7.4pH_{300}$) to benefit from the operator dose savings associated with this chemistry regime. The dose saving is estimated to be about 23% (see later sections).

FUTURE PLANT OPERATOR DOSES

The Sizewell 'B' design was effectively frozen in the mid to late 1980s when the majority of components were ordered. However, since then there have been significant steps forwards in both the operation of PWRs and in the reduction of the radioactive source terms. The following are considered to be the most important features for consideration for future plant:

Adoption of an 18 month fuel cycle

Adoption of Zircaloy fuel grids

Adoption of higher pH chemistry

Stellite removal

All of these are being considered for any future plant in the UK, as they can provide both significant financial advantages and greater operational flexibility in achieving lower dose targets.

An assessment of the operator doses has been carried out for the above changes to detail the potential dose savings. The assessment is again based upon operational data from the SNUPPS plants and has used the collective dose data for the periods of 18 month operation at Wolf Creek and Callaway. It then removed any dose not applicable to a Sizewell 'B' replica design due to design and equipment improvements. The benefit from the source term improvements on Sizewell 'B' in terms of material selection have also been recognized. The assessment then went on to recognize the benefit from the improvements beyond those already included in the Sizewell 'B' design.

Adoption of 18 Month Fuel Cycles

Wolf Creek and Callaway both started life with 12 month fuel cycles but Callaway changed to 18 month cycles from cycle 3 and Wolf Creek followed in cycle 4. The outage and operational doses for these plants have been averaged over a 3 year period which includes two refuelling outages, to provide an estimate of the operator doses. The annual average collective doses are 2.5 man-Sv (250 man-Rem) for Callaway and 1.8 man-Sv (180 man-Rem) for Wolf Creek.

These values are higher than would normally be expected, because they include one-time-only design changes to improve operation and operator doses. In particular both plants have replaced the Resistance Temperature Detection (RTD) System with an improved system. These replacements incurred doses of 1.5 man-Sv (150 man-Rem) at Callaway and 1.0 man-Sv (100 man-Rem) at Wolf Creek.

Design and Equipment Improvements

The SNUPPS dose records have been assessed to identify any dose incurred which is not applicable to a Sizewell 'B' type of design due to design and equipment improvements. The dose was reassessed where Sizewell 'B' did not have that type of equipment or when the task was carried out differently. Due to the way plants collect their dose information, it was not possible to identify all the dose for work not applicable to Sizewell 'B'. Therefore, operator dose was only removed in those cases where the dose was clearly identifiable and an exact comparison could be made.

The most notable saving is the deletion of the RTD system which was mentioned above and was replaced on Sizewell 'B'at the design stage.

The derived average annual collective doses for a Sizewell 'B' type plant recognizing the design and equipment improvements and operating an 18 month fuel cycle are 1.71 man-Sv (171 man-Rem) based on Callaway and 1.43 man-Sv (143 man-Rem) based on Wolf Creek. These are considered to be similar values and reflect the normal variability of operator doses and hence the two have been averaged to provide a representative value of 1.57 man-Sv (157 man-Rem). It is considered that this value will still be conservative as it has not been possible to identify all the dose savings for the Sizewell 'B' improvements.

Sizewell 'B' Material Improvements

The SG tube material for Sizewell 'B' (Inconel-690) is an improvement over the Inconel-600 used in the SNUPPS plants. The Inconel-690 has a reduced Nickel content and a very low Cobalt impurity specification (0.015 against 0.1 wt%). In addition, Sizewell 'B' has had the Stellite removed from 14 CVCS valves.

The impact of the SG material change was extensively reviewed by Westinghouse and it was concluded there will be a 35% improvement in dose-rate and hence operator doses. This results in a reduction of 0.55 man-Sv/yr (55 man-Rem/yr). Similarly the impact of Stellite removal in the CVCS valves has been assessed to be a 5% reduction in operator doses. This reduces the average doses by 0.05 man-Sv/yr (5 man-Rem/yr).

The two savings together give a reduction of 0.6 man-Sv/yr (60 man-Rem/yr) and would result in an average annual collective dose of 0.97 man-Sv (97 man-Rem). This applies for a Sizewell 'B' type plant operating an 18 month fuel cycle and recognizing all design, equipment and material improvements that can be readily and reliably identified.

Adoption of Zircaloy Fuel Grids

Historically, fuel grids have been made from Inconel which has a significant Nickel content and Cobalt as an impurity. However, more recently plants have been using Zircaloy fuel grids that have negligible Nickel and Cobalt content. At the time of ordering the first charge fuel for Sizewell 'B' it was considered that the Zircaloy grids were not a proven design and hence Inconel grids were selected. It is now considered that Zircaloy grids are a proven design and hence they will be adopted in any future design.

The improvement in operator doses from using Zircaloy has been estimated by Westinghouse and it was shown that plants with Inconel grids have dose-rates and hence doses which are typically 24% higher. This improvement relates to plants with dose values equal to or greater than the SNUPPS plants. Hence using the minimum value for a SNUPPS Plant in Section 4.2 above (1.43 man-Sv/yr) results in a saving of 0.27 man-Sv (27 man-Rem) each year. An independent assessment by Nuclear Electric assessed the saving to be 0.22 man-Sv/yr (22 man-Rem/yr). In order to be conservative a value of 0.22 man-Sv/yr has been used and this reduces the annual average collective dose to 0.75 man-Sv (75 man-Rem).

Adoption of Higher pH Chemistry

The main options for operating a primary circuit chemistry above the standard Coordinated 6.9 pH regime is either a Modified or an Elevated regime.

For the 12 month cycle the Modified regime is where the initial Lithium level is 2.2 ppm and it is held constant until a pH_{300} of 7.4 is achieved. The Lithium levels are then reduced in line with the Boron reductions to maintain a constant pH_{300} of 7.4. The Elevated regime is similar but the initial Lithium level is 3.35ppm and again this is held constant until a pH_{300} of 7.4 is achieved and then the Lithium is reduced to maintain a constant pH_{300} of 7.4.

For an 18 month cycle and depending on the initial Boron concentration, the Lithium level at the beginning of the cycle may need to be increased beyond the values above in order to keep the pH_{300} above 6.9. The choice of the precise chemistry regime for 18 month cycles is kept under review as operating experience becomes available.

The Modified regime has been successfully implemented at many plants and has shown dose improvements with no adverse effects on the plant. The Elevated regime is known to have been implemented at 13 plants. While these plants have shown higher dose savings, in the majority of cases, the plants have reverted to either a Modified or standard Coordinated regime. At this stage it is therefore considered that the Elevated regime is not a proven option and hence the Modified regime has been selected.

There have been independent assessments of the benefits of adopting a Modified regime by Westinghouse and Nuclear Electric. In both cases, operating plant data was used to estimate the benefit in dose-rate and hence operator doses. The Westinghouse assessment indicates an improvement of 25% and the Nuclear Electric assessment indicates an improvement of 23%.Based on this data, it is concluded that the adoption of modified chemistry regime will reduce the annual average collective dose from 0.75 man-Sv (75 man-rem) to 0.57 man-Sv (57 man-Rem).

Stellite Removal

Stellite is a major contributor to operator doses and substantial savings in dose can be made by removing the Stellite hard facings. This is strongly supported by the German Konvoi plant experience where the significant Stellite sources have been removed with no adverse impact on operation. The significant sources of Stellite are considered to be:

Stellite inside the RPV including the Control Rod Drive Mechanisms (CRDMs)

Stellite on all valves in circuits which can return water to the Reactor Coolant System (RCS). Exceptions are those valves with high stress loads such as the containment isolation valves

Stellite from Reactor Coolant Pump (RCP) bearings

The assessment of the impact of Stellite removal on operator doses indicates a saving of 0.22 man-Sv/yr (22 man-Rem/yr) further reducing the annual average collective dose to 0.35 man-Sv (35 man-Rem).

CONCLUSIONS

The design of the Sizewell 'B' plant has benefitted greatly from operational experience. Its anticipated annual average collective dose will be well below the POSR value of 1.97 man-Sv (197 man-Rem) when the benefit is recognized from the design, equipment and material improvements and from the adoption of the modified chemistry. It will then have one of the lowest operator doses of those plants with Stellite and operating 12 month fuel cycles.

However, there are still improvements to be considered in any new plant that is being designed. The above assessment shows that on a conservative basis it is possible to achieve annual average collective doses of 0.35 man-Sv (35 man-Rem) within the current understanding and technology.

The potential to achieve these low operator doses is supported by the German Konvoi Plant experience where there has been a progressive improvement in operating pH, incorporation of Zircaloy fuel grids and Stellite removal. There are similar improvements in operator doses as those described above and the Konvoi plants have an annual average collective dose of 0.18 man-Sv (18 man-Rem). These plants have not removed the Stellite from the CRDMs and they only operate a 12 month fuel cycle. This implies that the operator dose assessment above is conservative.

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REFERENCES

1. Willcock A., and Zodiates A. M., "Designing in Radiation Protection to Sizewell B", *Nuclear Engineering International, April 1992*, pg. 44-46, 1992.

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