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Optimization and Decommissioning: Challenge and limits

V.Massaut, P.Deboodt , F.Vermeersch, M.Klein
SCK•CEN, Mol, Belgium

A. Lefèbvre
BELGATOM, Brussels, Belgium

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Abstract

The BR3 Pressurized Water Reactor, shutdown in 1987 after 25 years of operation, was selected by the European Commission as one of the four dismantling projects of its Research Programme. Since the start of the project in 1989, the radioprotection has been extensively analysed and applied. An extensive ALARA programme was implemented in collaboration with CEPN during the first phase of the project. This comprised the traditional aspects of prediction, performance follow-up and feedback analysis. This phase comprised mainly the Full System Decontamination of the primary circuit and the segmentation of the high active thermal shield with different techniques. The ALARA programme has further been applied for the successive dismantling phases comprising mainly the dismantling of two sets of high active internals with different cooling times and the dismantling of contaminated circuits. An ALARA "culture" has so been progressively introduced and is now daily applied. The main lessons from the practical application of an ALARA programme for a rather "non-repetitive system" such as the dismantling of a reactor will be covered by this paper.

1. Introduction

The BR3 reactor was the first PWR (Pressurized Water Reactor) installed in Western Europe. Put into operation in 1962, it was definitely shut down in 1987. It was a low rated plant with an electrical net power output of 10.5 MWe. In 1989, BR3 was selected by the European Commission as one of the four pilot dismantling projects, in the scope of the third EU five year research programme on decommissioning of nuclear installations.

This project involved three main operations : the chemical decontamination of the plant primary loop, the selection and testing of techniques and tools for the remote dismantling of the highly radioactive reactor internals and then the dismantling of all the internals (Stainless Steel AISI 304).

The comparison of the techniques used (Electric Discharge Machining or EDM, plasma arc torch and mechanical) for dismantling a first internal, the thermal shield, led to a preference for mechanical segmentation techniques, which are well known in the industry and require only adaptation for working under water and in a nuclear environment. One of their advantages is the secondary waste generated. The chips just fall down and can be easily sucked off afterwards. This without impeding on the total operating time. Two main mechanical cutting techniques were then tested, used and compared : underwater circular sawing and band sawing. Comparison on the generated secondary waste, the manpower needed, the cost and the operators dose uptake was also performed and will be highlighted.

Even if BR3 was a low rated plant, the results and lessons learned can be used to derive data for commercial plant dismantling: indeed the geometrical scale is only a few times smaller than commercial plants and the radiological and waste problems are similar.

In parallel with these activities, a hard decontamination workshop is set up for decontaminating metallic pieces coming from the dismantling of equipments and loops, with the free release of the material as main objective. Two main methods were first tested on labscale and then used on large scale: the wet sand blasting technique and the $Cerium^{4+}$ method with regeneration of the Cerium. The melting of slightly contaminated material seems also promising.

Concrete dismantling is also an important part of the decommissioning of reactors and nuclear plants. Test on full scale mock-ups of dismantling and decommissioning techniques for activated or contaminated concrete were carried out in association with specialised institutions.

The BR3 project is a pilot for the decommissioning, but has also been extensively used as a pilot project for implementing operational dosimetry (see also ref.[4]) and radioprotection optimization throughout the whole project. Moreover, as the regulation about decommissioning and decontamination (D&D) was not yet complete at the project start up, this project has been seen by the authorities as a test case for different approaches of the problem, and therefore followed in detail by an extensive exchange of information.

Thanks to its European pilot project character, the BR3 has also been regarded as a knowledge and expertise source and the personnel acting in the project is involved in different expert groups from the IAEA, the OECD and the EC. It must also be noted that the gained expertise is presently valorized in different external decommissioning projects.

2. Practical cases of implementation

The implementation of the ALARA principle on the decommissioning operation was decided at the beginning of the project. Therefore, some help in analysing the operation (dose commitment estimate and modelling) was requested from external partners during the design and study phases of the first operations to be carried out: the pre-dismantling decontamination and the dismantling of the reactor thermal shield.

For the primary loop decontamination, the implementation of the radioprotection optimization exercise was launched when the operation was already started.

In fact, for this operation, the major dose uptake was due to the old design of the plant where the closure of the reactor head has to be done "hands on", in a radiation field coming from the pressure vessel itself as well as from the contamination of the reactor pool. Most of the optimisation was then concentrated on this task, and resulted in a decrease of the estimated dose commitment of about 30%, or about 60 man-mSv, by taking appropriate actions [1]. The main influencing action decided was the reduction by a factor of two of the number of studs to be fastened, the reactor operating during the decontamination at a much lower pressure than during normal operation (about 20 bar instead of 150 bar).

The foreseen dose uptake for the whole preparation tasks amounted finally to 139 man-mSv (starting from 200 man-mSv first prevision), and the actual preparation tasks gave rise to about 135 man-mSv. The rest of the decontamination operation was less important for the dose commitment, and the total collective dose uptake for the whole operation, including the evacuation of solid and liquid waste amounted to 159 man-mSv.

The preparation and the performance of the dismantling of the reactor thermal shield was also analysed on the radioprotection optimization point of view. A complete detailed analysis of the operation was carried out and the whole operation was divided into jobs, tasks and subtasks with attached manpower and ambient dose rate. This analysis did not directly influence the work and way of operation but was a very efficient help in analysing afterwards the complete job and determining the important parameters for the dose reduction or for subsequent estimation of dose commitment. This analysis showed, for instance, the importance of the "learning effect" (see fig.1 and ref. [3])

3. Impact of the radioprotection optimization

The application of the ALARA principle and the optimisation of the radioprotection has got different impact on the operations, the strategies and the organization of the works.
This will be explained a bit hereafter.

3.1. Impact on the operations

The main operations involved in the decommissioning of the BR3 reactors were analysed following different points of view: on the cost minimization, the technological feasibility, the waste minimization and the reduction of the occupational exposure and dose uptake.

This last one is presently an *obliged* way to initiate any operation. The dose estimate and the means used to reduce the total dose commitment is part of the operation file to be submitted before the activity starts.

The impact was first psychologic for the responsibles of the individual operations: indeed the obligation to estimate the dose commitment and to reduce it as far as possible induced progressively an ALARA reflex in the technological approach of any operation. Moreover, the application of the radioprotection optimisation led to analyse the different tasks and operations, even the simplest, on a detailed manner leading often to simplification or to dose reduction by application of simple systems. For low complexity operation, the total collective dose estimate is calculated using simple assumptions on the manpower, the dose rate (supposed to be uniform in the different working areas) and the duration. Nevertheless, the experience gained has shown that the dose calculated in this way is approximately 1.5 to 2 times overestimated (mostly due to the uniform rate assumption, i.e. the local esposition factor, and to the actual dose exposure time of the operators: they are not 100% of the time in the radiation field). Therefore, presently, the results of these simple estimates are arbitrarily divided by a factor 2, also to keep the pressure on dose reduction.

On the other hand, better dose uptake evaluation is needed to better estimate the actual dose commitment, and a new tool is in development (see § 4. under).

3.2. Impact on the strategies

The optimisation of the radioprotection can have important influence on the strategies applied in the D&D operations. One typical example was the choice of carrying out a pre-dismantling decontamination of the primary loop, in order to reduce the dose uptake during subsequent dismantling of the loop. This was in fact the actual incentive to carry out this operation before beginning any dismantling task. According to rough pre-estimate, the dose savings should at least be of a few man-Sv, regarding the immediate dismantling strategy involved.

After the operation, which led to a mean decontamination factor of 10, the estimate of dose savings vary between 4.25 and 9 man-Sv depending on the assumptions taken for the dismantling of the primary and auxiliary loops.

Other applications and impact can be exemplified by selecting different strategies for specific tasks. As example, the dismantling of some upper internals of the reactor (see also fig.2.) could be done either with a reduced water height in the pool , i.e. about 1.5 m. above the flange, and a dedicated footbridge placed just above the water level, or using the usual water level, i.e. about 8 m. above the reactor flange, with operators working from the usual platform. A global cost/benefit analysis, taking into account the dose commitment of both options led finally to select the first option, as it allowed to work easier, in a shorter time and with simpler tools; the dose commitment estimate being similar in both cases.

3.3. Impact on the work organisation

Taking into account the lessons learned and the experience gained by the different phases of the project, the organisation of the different operations have evolved. The cold testing of the principal operation on actual size mock-ups (see fig.3), applied since the beginning of the project, has proved to be worthwile as well economically as for training and radioprotection purposes. This principle of cold testing and training of operators was applied for all the tasks of dismantling of the reactor internals, but also for other auxiliary tasks, like for instance, the transfer of highly radioactive pieces from the reactor pool to the deactivation pool of the plant using a home designed shielded container.

4. Tools and development

Different tools were used to improve the optimisation of the radioprotection. The first one, which had probably the most important influence on the individual dose uptake, was the introduction of electronic dosimeters with alarm level. Indeed, the presence of a sound alarm when the dose rate trespass a certain level indicates directly to the operators that he is coming into a higher level dose rate ambience and even unconsciously, the individual tends to escape from the field.

For dose prevision and alternative simulation, the computer code "Dosi-ana" from CEPN was used during the implementation of the Radioprotection optimisation analysis of the first operations of the decommissioning. This code allowed to analyse into details the different tasks and subtasks and also to simulate different alternatives for carrying out an operation; and then to select the "best one" regarding the foreseen dose uptake.

Nevertheless, the ALARA-planning is a difficult task especially when multiple radiative sources are present in the work environment. This task becomes even more difficult when the environment has a complex geometry. Therefore a new calculational tool is under development at the SCK•CEN, called **VISIPLAN.** This tool makes it possible to plan the work in a 3D virtual environment, based on information about the geometry, the materials and the radiation field.

The **VISIPLAN** methodology is characterised by three different stages:

- The information gathering and model building stage
- The general analysis stage
- The detailed analysis stage and the work planning
- The follow-up stage

In the first stage the computer model of the environment is built based on the known geometry, the materials information and information about the radiation sources of the site. When the sources are known a calculation of the field can be performed immediately. When no information about the source intensities are present, a source inference algorithm provides the possibility to determine source strengths from a semi-detailed dose mapping of the working area. The mapping together with the information about the history of the site results in pinpointing the position of the main sources which contribute to the field.

The end of this stage results in the basic geometry from which other geometries, mostly with supplementary shielding, are derived.

In the general analysis stage the calculated field is studied and suggestions about shielding techniques are tested and analysed using calculated dose maps for each of the suggested shielding geometries.

Once a shielding geometry is chosen, a detailed dose calculation can be performed along a trajectory which is constituted of a series of tasks each characterised by a position, a task description and a work duration. Several trajectories can be calculated in different shielding geometries.

A set of scenarios can then be build from a selection of trajectories in the different geometries.The intercomparison of these scenarios then leads to an optimisation of the work to be performed.

In the follow-up stage the dose accounts of the workers are compared with the predictions from the model. When large deviations occur a reassessment of the work can be performed by adapting the model to the new information. This makes it possible to adjust, and thus to further optimise the work during its progress.

5. Conclusions: challenge and limits

"The BR3 reactor dismantling at Mol appears to be a "first" as far as PWR dismantlings are concerned. It provides a good opportunity for testing different techniques (...)" [1]. So began the conclusions of a first radioprotection analysis report given by the CEPN after completion of the first phase of the pilot decommissioning project.

The pilot aspect of the BR3 project made it a challenge for the different aspects of the operation, and in particular for the optimisation of the radioprotection. Moreover, the implementation of a systematic ALARA approach within the CEN•SCK was just started at the same time, and BR3 was regarded as a judicious test case for this implementation. The challenge was then double: the decommissioning was a quite "new" operation for the nuclear industry, and the ALARA approach was also quite "new" for the operators and contractors innvolved in the activities.

Nevertheless, this "innovative" character was also an advantage to implement the radioprotection optimisation, as almost no "bad habits" were already existing in this domain.

This challenge was taken by the CEN•SCK and sucessfully applied to the different main operations carried out so far. Dose reductions and improvements in the dose estimates were reached. Moreover, the operational dosimetry was also implemented sucessfully, and helped to optimise further the radioprotection approach.

But some limits were already touched, and developments appeared necessary to be able to apply this optimisation systematically, and in an economical way. The first difficulty encountered is the very heavy work involved by the dose estimate evaluation and the very long work needed for introducing the necessary data (up to subtask level) to carry out the detailed estimate of the dose commitments. If this can be easily justified for jobs implying high dose commitment, it is much more difficult to justify for rather simple operations or operations carried out only once.

The dose distribution estimate in complex installations appeared rapidly also to be a challenge, and the assumptions made to simplify the calculation were often too rough to give really useful results. Therefore, developments in radiation field modelling and dose uptake estimation were started to help the ALARA coordinator to better evaluate the actual dose uptake of operators working in complex environment and in different locations. This resulted in the development of the VISIPLAN code.

Dose mapping, which is also one of the input of the dose uptake modelling programme, remains a development area, where different institutions are busy to develop efficient tools and processes. And this is particularly true in low radiation field area, where the sources are distributed and where hot spots or main sources are absent or difficult to track.

Finally, the "spirit of good practice" remains also a very important way to reduce the dose commitment and this must be helped by dedicated tools allowing to assess the assumptions made in the engineering feeling of the designers and conceptors.

The decommissioning is surely a task where the optimisation of the radioprotection has to be applied, and where dose reductions can be gained by appropriate actions and analyses. Some developments are still to be made, and the approach of the internal contamination should also be considered in such operations. The decommissioning project also has lead to the development of a new safety culture which can be considered as the ultimate goal.

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