### 3rd European Forum of "Radioprotectique"
### Radioprotection and logic of dismantling

October 2 – 4, 2002
La Grande Motte, France

# Mise en oeuvre de la démarche ALARA dans un projet de démantèlement réel: le cas du BR3

# The radioprotection optimisation applied in an actual case: the BR3 decommissioning project

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## ABSTRACT

The BR3 (Belgian Reactor nr 3) plant is a small pilot PWR plant, with a net power output of 10.5 MWe. It was the first PWR built outside the USA and is the first to be dismantled in Western Europe. It was started in 1962 and definitely shut down in 1987. In 1989, the BR3 decommissioning was selected by the European Commission as Pilot project within the framework of the 3rd European Research and Technical Development programme.

The Radioprotection optimisation approach has been applied since the beginning of the project as this operation was conceived as pilot and demonstration project for future decommissioning activities in Europe. Various operations were carried out, like the decontamination of the reactor primary loop, the dismantling of all the reactor internals, the dismantling of the reactor pressure vessel, the dismantling of the primary and auxiliary loop, the asbestos removal in the primary loop area, etc... with applying the ALARA approach and comparing various alternatives for optimisation.
The SCK•CEN developed also a 3D ALARA planning tool, allowing easy calculation and fast answer to the operators request, and this tool was used extensively for the optimisation of complex operations.

The presentation will present the different phases of the project as well as the concrete application of the radioprotection optimisation in decommissioning.

## RÉSUMÉ

La centrale BR3 (Belgian Reactor n°3) est un petit réacteur REP pilote ayant une puissance électrique nette de 10.5 $MW_e$. Il a été le premier réacteur de ce type construit hors des Etats-Unis et est le premier à être démantelé en Europe de l'Ouest. Rendu critique en 1962, il a été mis à l'arrêt définitif en 1987. Deux ans après, la Commission Européenne l'a sélectionné comme projet-pilote de déclassement dans le cadre de son 3ème programme de recherches et développements technologiques.

L'approche d'optimisation de la radioprotection a été appliquée dès le début du projet, comme cette opération était conçue comme pilote et démonstration pour les déclassements à venir en Europe. Des opérations très variées ont été effectuées, telles que le démantèlement des pièces internes du réacteur, le démantèlement de la cuve, des circuits primaires et auxiliaires, le retrait d'amiante autour du primaire, etc… tout en appliquant l'approche ALARA et en comparant diverses alternatives pour l'optimisation.
Le CEN•SCK a également développé un outil 3D de planification ALARA, permettant d'effectuer aisément les calculs et de recevoir rapidement les réponses aux requêtes des opérateurs. Cet outil a été utilisé de manière extensive pour l'optimisation d'opérations complexes.

La présentation s'attachera aux différentes phases du projet ainsi qu'a des applications concrètes de l'optimisation de la radioprotection en démantèlement.

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## 1. INTRODUCTION

The BR3 reactor was the first PWR plant to be built in Western Europe. Started in 1962, it has been definitely shut down in 1987. It is a low rated plant with a net power output of 10.5 $MW_e$. Nevertheless it presents all the features of commercial light water reactors, has undergone the same type of life, water chemistry, irradiation etc.

At the end of 1989, the European Commission selected the BR3 as European pilot decommissioning project within the framework of its five year Research and Technological Development programme. The Commission selected four pilot projects, covering almost all kind of nuclear reactor types and facilities (PWR, BWR, AGR and reprocessing plant).

The BR3 project started with the chemical decontamination of the plant primary loop and auxiliary loops (full system decontamination). This operation was carried out using the CORD® process, in partnership with Siemens-KWU. Afterwards, one continued with the remote underwater dismantling of a first reactor internal: the thermal shield. Three techniques were used and compared for doing this job: mechanical cutting (using a circular milling cutter), plasma arc torch cutting and Electric Discharge Machining (or EDM). The comparison of these three techniques led to favour mechanical cutting for the further dismantling of the remaining internals and of the pressure vessel. Indeed, it produced almost five times less secondary waste than the two other ones, and the overall duration for the operation was comparable with the plasma cutting but much shorter than the EDM. The operator exposure was also similar, but smaller, to the plasma, as this parameter followed closely the overall operation duration.

The decommissioning continued with the dismantling of the remaining reactor internals and then of another set of irradiated internals, unloaded from the reactor in 1964, and stored since then in the refuelling pool of the plant. This last set of internals had thus a 30 years decay period since its unloading. Therefore it was also possible to compare here two dismantling strategies: either the immediate dismantling (applied on the second set of internals) or the deferred strategy (applied on the first set, with a safe store duration of about 30 years). The results showed that waiting for 30 years did not bring any significant gain in terms of reducing waste, dose and costs. After these operations, the reactor pressure vessel has been dismantled, and evacuated, as for the internals, in 400 litre drums for further conditioning by cement grouting and intermediate storage.

In parallel to these operations concerning the activated components of the plant, the team started in 1995 the dismantling of contaminated loops of the plant. This activity generated a huge amount of materials to be managed, and decontaminated. Therefore, a system of quality assurance was implemented to follow up the material flow in the plant. Decontamination processes were developed and installed to cope with the generated waste in order to decrease the final fraction of radioactive waste. This was achieved by decontaminating a group of materials, parts and equipments down to the free release level. The overall material flow system is summarised on figure 1.

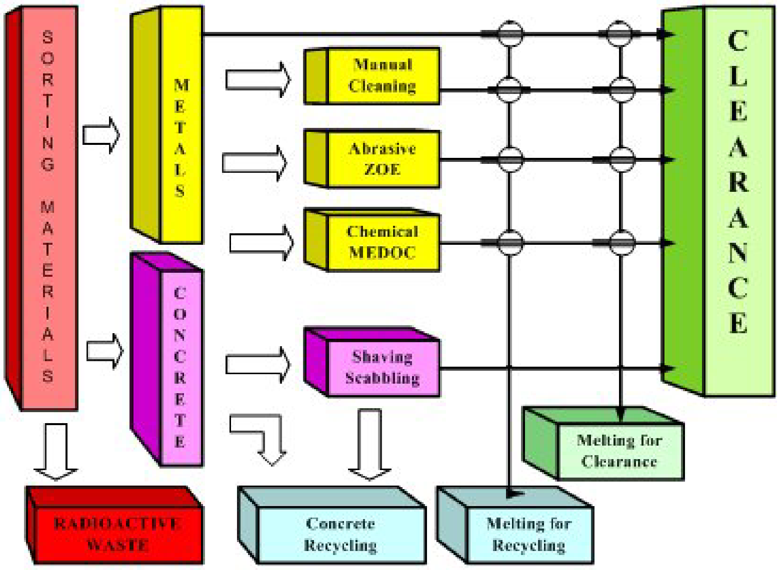


Fig.1. Material flow within the BR3 decommissioning

Dismantling and decontamination of concrete was carried out during the last 5 years, especially to create openings and new access paths into the plant or to evacuate concrete shielding slabs and blocks. Various techniques were also tested and compared and improvements were brought to enhance the efficiency and to minimise the waste production.

## 2. OPTIMISATION OF THE RADIOPROTECTION THROUGHOUT THE PROJECT

Since the very beginning of the project, the optimisation of the radioprotection and the application of the ALARA principle was one of the main concerns of SCK•CEN. The project was also selected as pilot project inside the SCK•CEN for applying the new ALARA procedure and for testing the functioning of the complete procedure involving the newly created ALARA committee. On the other side, the BR3 project was also considered as pilot project by the safety authorities, as it was one of the first to be applied in Belgium, and no regulation specific to the decommissioning was existing.

The first actual application was in the selection of the operation order. It was chosen to start with a full system decontamination in order to decrease the dose rate in the vicinity of the primary coolant loop. The operation, which implied a dose uptake by the operators of less than 200 man-mSv, lead to subsequent dose savings during the dismantling of the loop of about 4 to 8 man-Sv.

At the beginning of the dismantling of components, quite simple instruments were used allowing to apply the rules of good practice. Nevertheless it appeared rapidly that for complex operations a more powerful tool was needed. Some dose analysis tools were also tested but appeared to be too “heavy” for use in such one-shot operations.

Therefore, after different explained needs and requests, the SCK•CEN developed a computer code, called VISIPLAN, allowing to answer to all the questions raised by the operators and by the responsible of the preparation of dismantling operations. The application of this code and of this approach will be explained more in detail at the next paragraph.

Nevertheless, the introduction of this approach, after the early introduction of electronic dosimeter with alarm, in 1992, have led to minimising the dose uptake for the whole operation. For example, the complete dismantling of the two sets of reactor internals (i.e. representing the most radioactive pieces of the plant) has been carried out within about two years and involved a total dose uptake of less than 300 man-mSv.

The aspects of radioprotection optimisation concern as well the minimisation of doses as the reduction of internal contamination risks. Indeed, in a dismantling operation, the airborne, and thus internal, contamination is a real risk, probably greater than during the facility operation: dismantling opens (by cutting) loops which were not foreseen to be opened, produces aerosols and dust by the cutting and dismantling processes, and the demolition or even decontamination of concrete produces a huge quantity of dust which can be sometimes slightly contaminated.

Another aspect of the safety approach of decommissioning is the potential mutual influence of classical industrial safety and radiation protection features. A good example was the removal of asbestos from the primary loop piping, where the asbestos removal work had some specific requirements, while the optimisation of the protection requested for example to make the operation in a specific order which was not the one foreseen by the asbestos remover.
For taking into account the aspects of industrial safety, we introduced the concept of ASARA, or As **S**afe As Reasonably Achievable.

All these aspects were thus applied in this pilot project from its beginning. We will present more in detail the aspect of the ALARA approach for some specific operations in the following chapter.

## 3. TYPICAL APPLICATIONS

Different applications of the ALARA approach and of the optimization of the radioprotection have been carried out, not only within the decommissioning of the BR3 reactor but also in some other applications of nuclear research facilities.

The first real application concerned the sampling of the concrete walls at the Gelina accelerator at IRMM (JRC) in Geel. The approach using the Visiplan software was used to estimate the dose uptake for the operators performing the drilling in the concrete shielding.
The result was encouraging as the predicted dose amounted to 1.26 man-mSv and the measured actual dose uptake was 1.30 man-mSv. This result was really very close to the reality, but the geometry and the source problem were relatively simple.
A second application, a little bit more complicated concerned the dismantling of a hot cell in our laboratories for high and medium activity. The foreseen work included the dismantling of the walls and the decontamination and dismantling of the floor of the cell. Quite high dose rates were present due to the former use of the cell. The cell was formerly used, during years, for the post irradiation examination of irradiated components and fuel pins. The main emitters were Cs-134, Cs-137 and Co-60.
Here again, the final result of the estimate, after corrections for taking into account the changes in the operation framework, led to a quite satisfactory result. The predicted value amounted to 31 man-mSv, and the actual dose uptake was 37 man-mSv. This is one of the few cases where the predicted value was underestimated. This was probably due to the various difficulties encountered during the performance of the work, and the relative lack of knowledge of the whole history of the cell (quite common for old installations), and of the real source position and strength. Moreover there was also alpha contamination within the cell, which imposed to work in protective suit and which extended the time allocated for the operation.

For the third main application, one concern was really the estimate of the real time to be spent by the operators. Indeed, for complex dismantling activities, it is often difficult to estimate the actual time to be spent by the operators (including the time for displacement and for setting up). Therefore, one of the main error comes from this estimation (and thus the related dose uptake estimate follows the same error). Nevertheless, the tool used allowed to compare various scenarios, including the shielding of components, or no shielding, the early dismantling of hot spots or not and even the decontamination of some parts before the work or not. The analysis done allowed to see the benefits created by one or the other options. Moreover this analysis also allowed to estimate which were the most important sources of radiation, and which were the operations with the highest dose distribution.
Even if this concerned quite low dose rates (about a few µSv/h to some tens of µSv/h) the accumulation of the doses can lead to significant total dose distribution, and such an analysis is thus important. The first estimate was thus mostly qualificative, and allowed to help in the decision between different scenarios. The results reached shows that this approach was indeed fruitful.

The operation concerned the dismantling of loops and components situated in the vicinity of the primary coolant loop of the plant, and under the operating deck of the reactor building (see fig.2). The operation was divided in 3 main phases, which were analyzed in detail. Afterwards some complementary phases had to be added to allow for the preparation and some specific features and the work yard. But the analysis focused mostly on the three main phases.

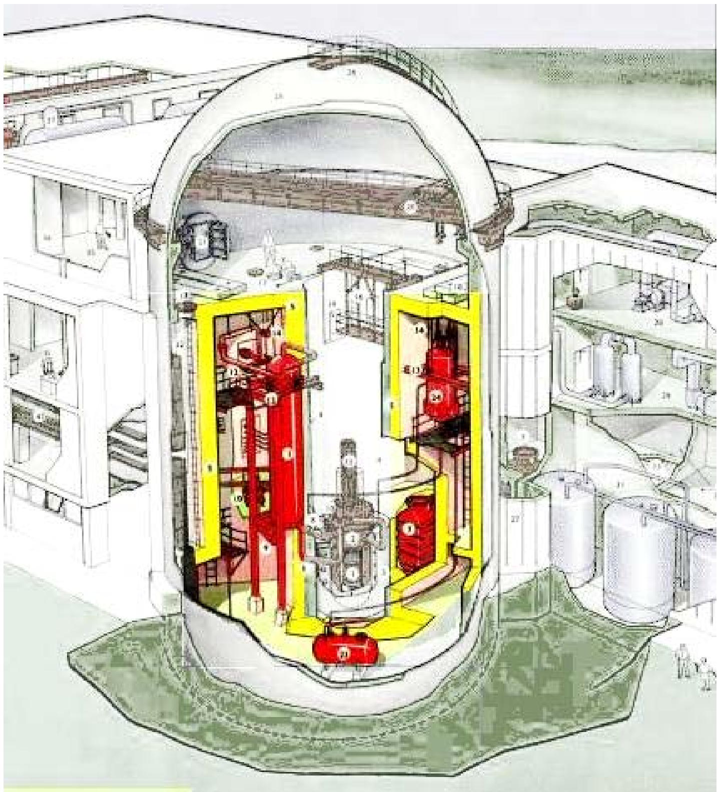


Fig.2. Area "under the operating deck" of the BR3

The analysis is built in three steps as follows:

- first a dose measurement on site followed by the calculation of the main radiating sources
- then the geometrical model of the working area is built (this model building was made using simple geometrical building blocks, like cylinders, sphere, cubes etc.)
- then, one build the scenarios, based on the operations to be carried out, and the potential alternatives to be analyzed
- the calculation is then performed, and allows to compare the various alternatives, and to refine some of the selected scenarios
- the analysis should then be completed by a follow up of the dose uptake and of the workload during and after the work has been carried out.

Some of these steps are explained a little bit hereafter, for a small part of the operation, to show how the approach is made and how the optimization is carried out.

### 3.1. Dose rate measurements on site

A set of dose rate measurements was performed in order to determine the position of the most important source. On the basis of these measurements the most important sources could be localised and could be attributed to the different structures like the steam generator, the primary pumps, the pressurizer tubes, some tanks, ...

### 3.2. Determination of the source strength and source geometry

The structures corresponding to the sources are mainly cylindrical. Therefore the following approach for the source term determination was taken; the source is considered as a line source located on the axis of the source structure. The source strength of each source is determined on the basis of a measurement in contact or in the neighbourhood of the structure taking into account the geometrical and material data of the structure. The source strength is wholly attributed to the isotope Co-60 (simplification based on spectral analysis of the radiation field). All source strength calculations were performed with the program MicroShield 4.

### 3.3. Model building

A simplified 3D-model of the site under the operating deck was developed (see fig.3) which includes the main structures of the site i.e.:

- steam generator
- primary pumps
- pressurizer
- hydrogen dump tank (HDT)
- pressurizer tubes
- spray tank
- deuterium dump tank (DDT)
- primary circuit

The geometrical and materials data were taken from technical drawings.
(Note that there was an earlier experiment from the 60's, with use of a mixture of heavy and light water, which led to the existence of specific loops and tanks like the "Deuterium Dump Tank", used at that time for collecting and recovering the heavy water from the mixture).

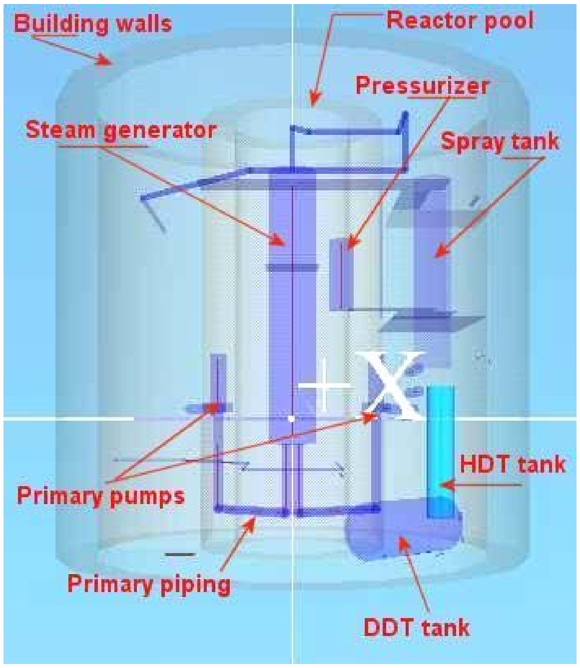


Fig.3. Simplified 3D model of the BR3-site under the operating deck

### 3.4. Actions to be studied

With the use of this geometrical model and information about the position and the activity of the sources we could determine the contribution of each source to the dose rate at a certain position. By changing the activity of a source we can investigate the influence of decontamination of a source on the radiation field. This helps us to assess the importance of some of the proposed cleaning actions.

The actions that were proposed are:

- Decontamination of the pressure tubes
- Decontamination of the deuterium discharge tank.

These actions were put forward after a first study which determined that the pressure tubes (PT) and the deuterium discharge tank (DDT) are the main contributors to the dose rate at different levels under the operating deck.

It is expected (based on earlier experiences) that cleaning the PT will reduce the activity by a factor 3. The cleaning of the DDT is expected to result in a decrease of its activity with a factor 10.

### 3.5 Calculation method

All calculations of the dose rates are based on the point kernel method. The build-up factor used in all calculations is the build-up factor in iron in an approximation called the infinite-media build-up technique.

The photons of 1.0 and 1.5 MeV of Co-60 are taken into account for the calculations.
The fluence to dose conversion factors are taken from the ICRP 51 for a rotational geometry.

### 3.6 Results

The results of this method will be exemplified by the results only at one level (the calculation being done at all working levels in the reactor building). This will show how an analyse with the contribution of the main sources and looking for alternative scenarios can really avoid doses and thus optimise the work for the radioprotection purposes.

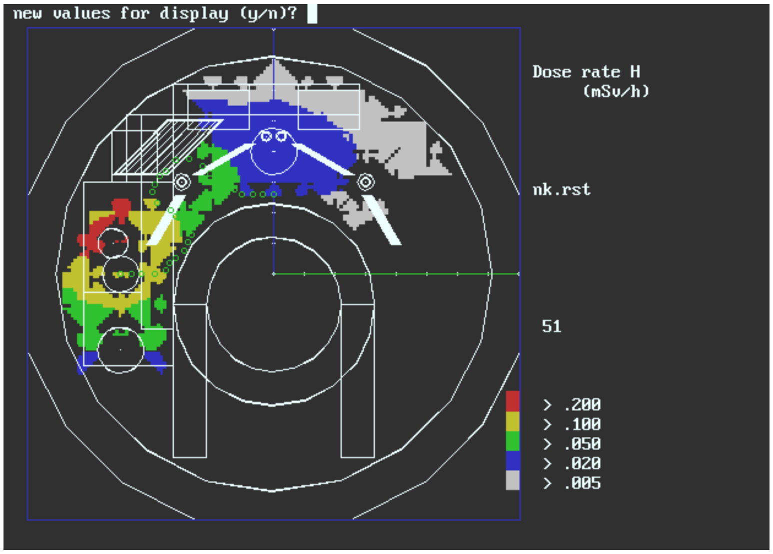
The predominant source contributing to the dose rates in this area is mainly the Deuterium Dump Tank (DDT), as can be seen from Table 1.

| Source\Position | m1 | m2 | m3 | m4 | mean |
|---|---|---|---|---|---|
| Steam Generator | 0.2 | 0.1 | 0.1 | 0.0 | 0.1 |
| Pressurizer | 3.5 | 0.7 | 3.9 | 3.1 | 2.8 |
| Pump1 | 0. | 0. | 0. | 0.1 | 0.7 |
| Pump2 | 0. | 0. | 0. | 0. | 0. |
| DDT | 89.9 | 95.3 | 85.0 | 70.5 | 85. |
| Spray Tank | 0.7 | 0.2 | 1.1 | 0.0 | 0.5 |
| Tubes Spray Tank | 0.3 | 0.1 | 0.0 | 0. | 0.1 |
| Cold leg | 1.3 | 1.2 | 3.3 | 16.5 | 5.6 |
| Pressurizer Tubes | 4.0 | 2.3 | 6.6 | 9.8 | 5.7 |
| ***TOTAL*** | ***100*** | ***100*** | ***100*** | ***100*** | ***100*** |

Table 1. Contribution in % of the different sources to the dose rate at the specified positions (m1, m2, m3, m4).

The original calculated dose rate distribution at this level is represented in fig. 4. The highest dose rates are found near the Deuterium Dump Tank.

The average dose rate at this level, determined by averaging over all calculated points is found to be 46 µSv/h, the maximum value of this set of points is 250 µSv/h.



new values for display (y/n)?

Fig.4. Estimated dose rate distribution; current original situation.

It is clear from this table 1 that actions undertaken to reduce the activity of the DDT will have a great influence on the average dose rate in this area.
The influence of cleaning the pressurizer tubes to 1/3 of its current value is small as can be seen on fig. 5.

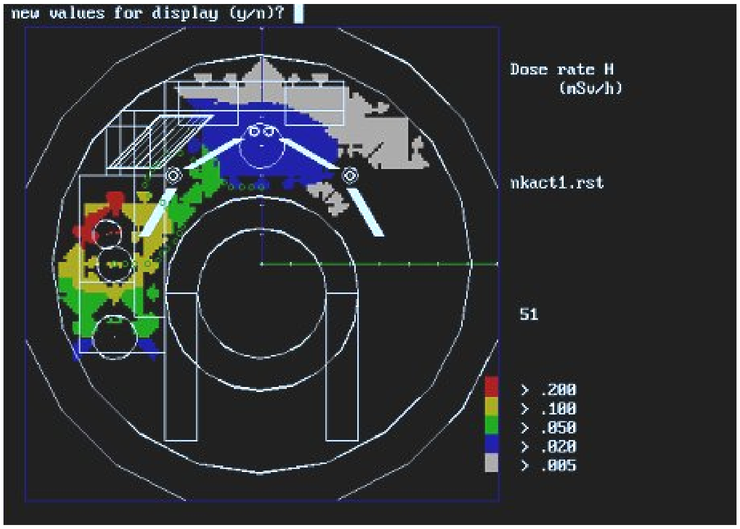


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Fig 5. Dose rate distribution with the Pressurizer Tubes cleaned.

The decontamination of the DDT to 1/10 of its current value will decrease the dose rate on level -4.805 m considerably (fig. 6).

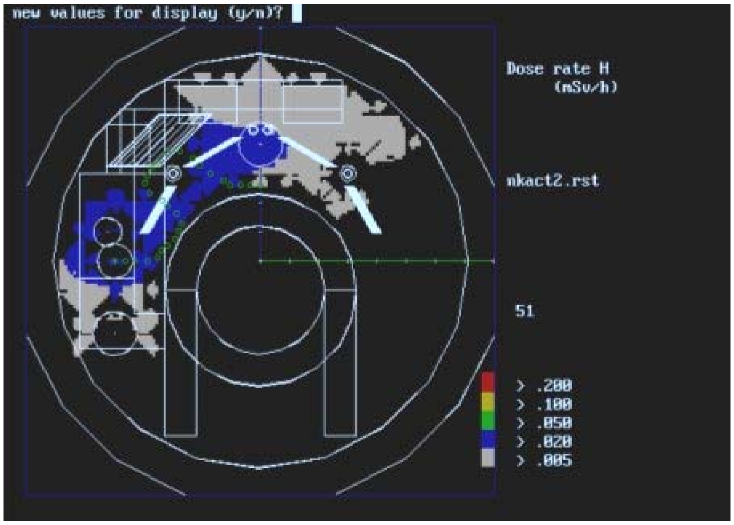

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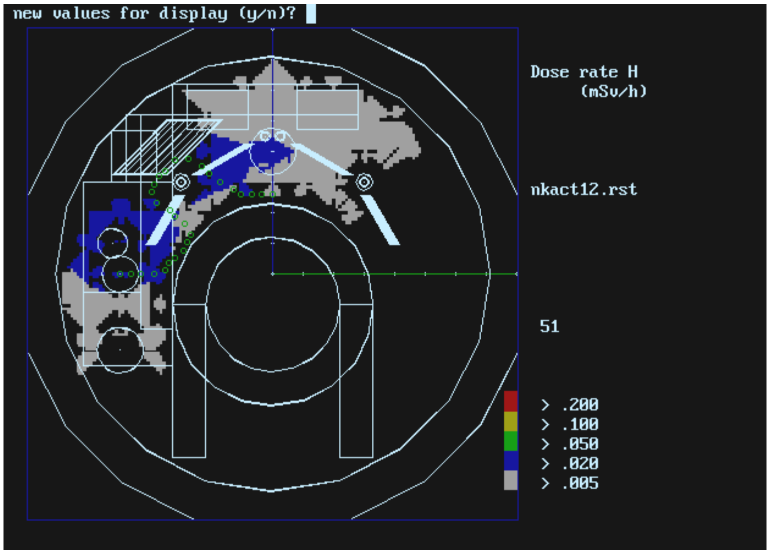
Fig.6. Dose distribution after reduction of the DDT activity with 1/10 (decontamination).

The combined effect, of cleaning both the pressurizer tubes and the DDT is represented in fig. 7.



new values for display (y/n)?

Fig.7. Dose distribution, following decontamination of PT and DDT.

The dose reduction, resulting from these actions, for a typical intervention in this area can be calculated using the VISIPLAN software by simulating a trajectory in this area (fig.8). The accumulated dose is calculated (fig.9) for the same trajectory in the different dose distribution frames. The intervention takes about 12 minutes in total. The trajectory consists of a path from the stairway to the DDT where a work of 10 minutes is performed.

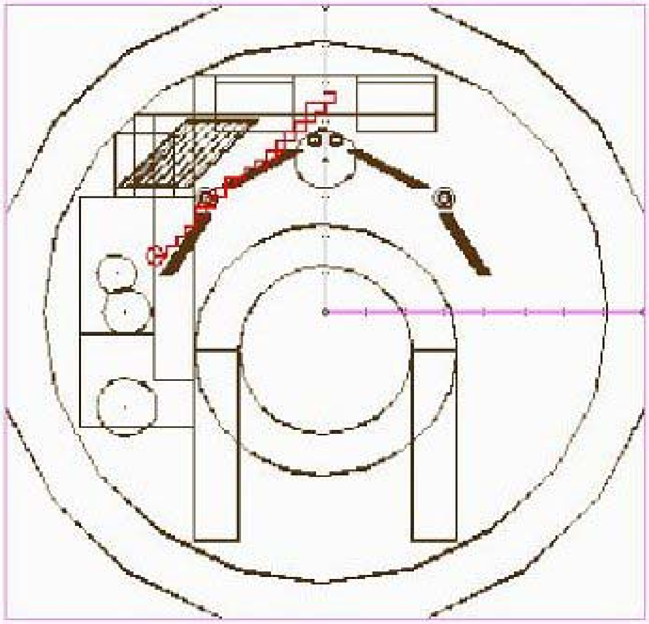


Fig. 8. Trajectory on level -4.508 m used for the calculation of the accumulated dose for an intervention.

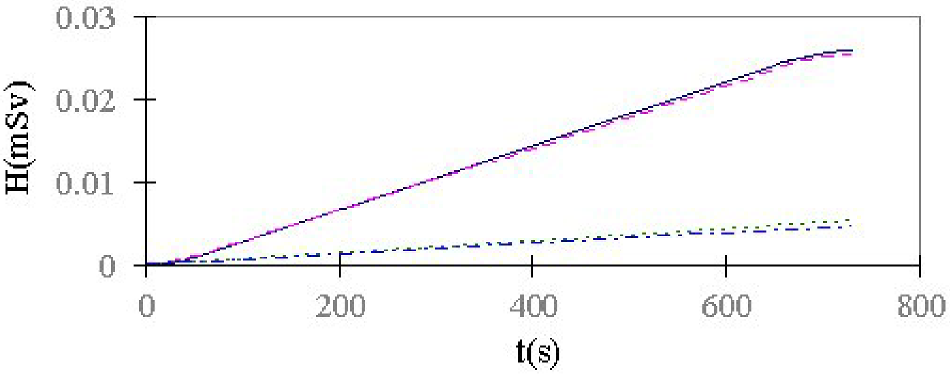


Fig. 9. Accumulated dose at level -4.805 m for the given trajectory and for different situations.

The accumulated dose uptake in the different radiation fields can be summarized as follows:

| Description | H(mSv) | H(mSv) avoided |
|---|---|---|
| Present situation | 0.026 | 0 |
| PT cleaned | 0.025 | 0.001 |
| DDT cleaned | 0.0051 | 0.021 |
| PT + DDT cleaned | 0.0044 | 0.022 |

It is clear that the cleaning of the pressurizer tubes will have a marginal effect for work done on level -4.508 m. The cleaning of the DDT results in a dose reduction of 22 µSv, an improvement of 80% with respect to the former situation.

In order to investigate the overall influence of the cleaning actions on the dose rates on the different levels, we calculated the average dose rate on each level before and after the suggested cleaning operations.

The dose rate averaged over all levels is calculated as 46 µSv/h in the present situation. This corresponds with the accumulated dose acquired by an intervention team of two people who spent 1 hour beneath the O.D. of the BR3-site.

The cleaning actions reduce the dose rate with 75% on level -4.805 m, on level 0 m a dose reduction of 50 % is expected. The overall dose reduction averaged for all levels is expected to be in the order of 48 %.

### 3.7 Conclusion from this simplified example

It can be seen, from this example, that by using tools, like the Visiplan Alara planning tool, various scenarios can be virtually tested and compared. If the complete calculation for a whole operation does not always give precise figures of the total dose uptake to be expected (depending on the amount of details input in the calculation and on the time spent to estimate the specific operations and tasks duration), a first qualitative approach of the optimisation can already be done quite simply, to select between various alternatives. Once the "optimum" alternative is chosen, one can then carry out more detailed calculation for the expected dose uptake. But it should always be reminded that for dismantling operations, it is often very difficult to go too much in detail because of:

- the common lack of precise knowledge of the actual detailed situation
- the continuous change in the environment due to the dismantling operations themselves (although this can be simulated)
- the movements of the source due to the dismantling and material collection
- the "one-shot" aspect of the operation, which leads to make a compromise between economical calculation, flexibility for the operator and precision in the estimation.

It is often more important to know where to make a decision and in which direction to improve the radiation protection than to make a precise estimate of the dose, which is often not followed, due to the work constraints and to the flexibility let to the operators for performing the job.

### 3.8 Overall calculation for the complete operation (whole dismantling of the loops)

The complete operation took into account the optimisation scenarios calculated with the same system as explained above. For instance, most of the hot spots were located and removed early in the dismantling tasks.

Moreover, the Visiplan tool was improved, in order to give almost virtual reality 3D screens to better visualize the work and results of the calculation (see fig.10).

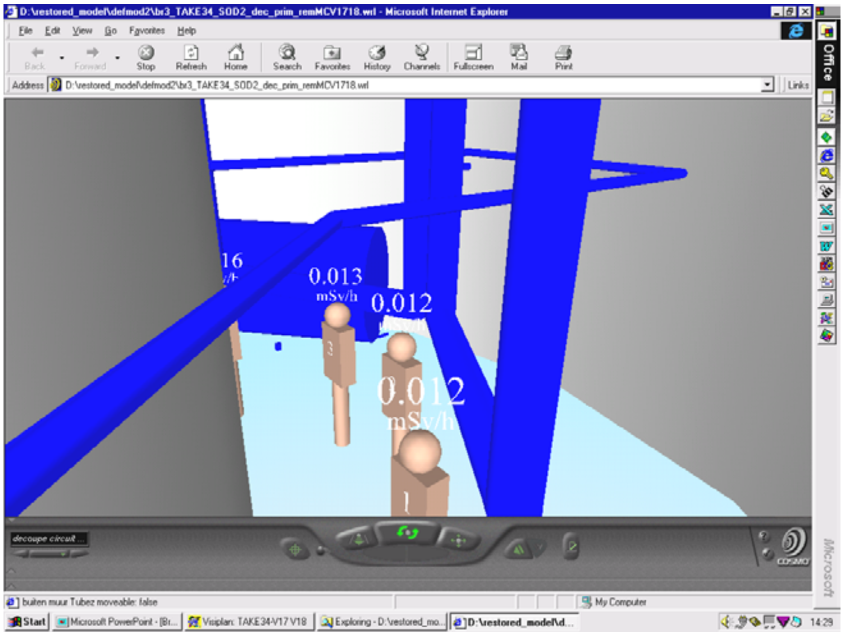


Figure 10: 3D visualisation of the work site, including indications of the local dose rate

The global estimate of the operation duration and of the dose uptake is given in table 2. It takes already into account the optimization recommended by the analysis done for each of the main phases. It should be noted that the estimated hours concerns only the operational hours and do not cover the mobilisation, entrance and exit time, which represents commonly almost 40 % of the actual spent time, but which does not contribute to the dose uptake.

| **Operation** | **Rough estimate** | | **Visiplan estimate** | | ***With occupational factor*** |
|---|---|---|---|---|---|
| | man*mSv | man*hours | man*mSv | man*hours | *man*mSv* |
| SOD1 | 5,90 | 498 | 5,00 | 400 | *3,33* |
| SOD2 | 7,90 | 500 | 8,00 | 900 | *5,33* |
| SOD3 | 3,62 | 422 | 1,50 | 250 | *1,00* |
| | | | | | |
| Total | 17,42 | 1420 | 14,50 | 1550 | *9,66* |

Table 2: Overall dose estimate for the whole operation (excluding preparation and post-operational phases)

Another aspect is the occupational factor. This factor is really difficult to estimate but is well known from radio protectionist. In fact when operators are busy in a certain area, they are not remaining all the time at the same place, and are often removed from the high radiation areas (this is still more the case since the use of portable electronic dosimeters with alarms). Currently, in the decommissioning project of BR3 we have deduced from former experience that the occupational factor is situated between 0.6 and 0.7 (i.e. the actual exposure to the radiation field amounts to 60 to 70% of the calculated exposure if the operator was still standing at the allocated position). This has been applied to the last column of table 2, to give a corrected estimate of the dose uptake.

Finally, table 3 gives the actual results of the dosimeters measurements, and a column taking into account the correction (on the operation duration) for the entrance and exit time periods.

| Operation | **Actual** | | **Actual (excluding entrance & exit time)** * | |
|---|---|---|---|---|
| | man*mSv | man*hours | man*mSv | man*hours |
| SOD1 | 3,74 | 959 | 3,74 | 575 |
| SOD2 | 1,77 | 784 | 1,77 | 470 |
| SOD3 | 3,05 | 1135 | 3,05 | 681 |
| **Total** | **8,57** | **2878** | **8,57** | **1726** |

Table 3: Overall dose uptake for the whole operation (excluding preparation and post-operational phases)

* *Note: those times are approximated to be 40 % of the total, which comes from the return of experience*

## 4. APPLICATION OF THE RADIOPROTECTION OPTIMISATION THROUGHOUT THE PROJECT

As could be seen the radioprotection optimisation has been applied throughout the dismantling project of the BR3 reactor. Some decision helping tools have been developed to help the dismantler in selecting between various options for performing an operation. This optimisation exercise can also be done for larger strategic alternatives in selecting the best way to follow. In this approach, not only the radioprotection has to be optimised, but also the classical industrial safety, the waste production and management, and the costs (which are in fact also part of an overall ALARA or ASARA approach).

For the specific operations, the preparation and execution is currently made as follows, to enhance the awareness of the importance of optimisation:

- Selection of the strategy
- Historical background of the parts and components to be dismantled
- Preparation of the operation (gross overall framework)
- Dose estimate
- Optimisation
- Writing of detailed procedure (including the dose estimate and the optimisation approach carried out)
- Approval by the Health Physics department
    - this approval can be submitted to a review by the internal ALARA committee set up at SCK•CEN level
    - potentially, and following the recommendation of the ALARA committee or of the HP specialists, request for further optimisation
- Performance of the work
- Follow up of the operation and analysis of the discrepancies between estimate and realised (return of experience).

This has led to improve the overall dose uptake and to keep the dose distribution quite low, while the number of operators was increasing.

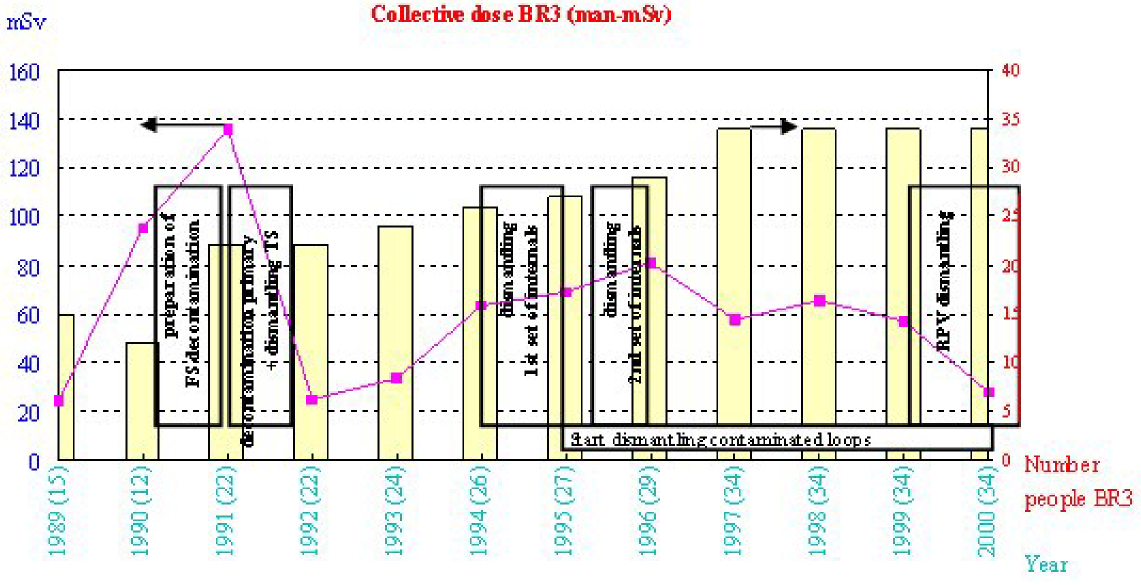


Figure11: overall collective dose uptake for the whole project

## 5. CONCLUSIONS

The BR3 dismantling project was selected by the European Commission as European pilot decommissioning project. But it was also selected, within the SCK•CEN as one of the pilot projects for applying, from the beginning of the project, the optimisation of the radioprotection.

This has be done by various means, but has led to an improved awareness of the potentialities of optimisation and has allowed to keep the dose uptake quite low throughout the project performance, even when working with highly radioactive pieces or in complex environment.

The mutual influence of radiological and industrial safety on decommissioning yards have also led to introduce the ASARA approach, for reducing and minimizing the total risk for the operators and the environment, but this is probably the subject of another debate.

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