THE DECOMMISSIONING OF A PWR EXPERIMENTAL FACILITY DURING THE REFURBISHMENT OF THE BR2 RESEARCH REACTOR

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ABSTRACT

Research reactor BR2 has successfully restarted its activities – production of medical radio-isotopes and doped silicon, amongst others - after a 16-month refurbishment. In February 2015, BR2 was decommissioned for thorough maintenance and refurbishment, particularly the replacement of the beryllium matrix, the heart of the reactor. At the same time, a number of preventive maintenance and modernization activities have been carried out, including the dismantling of the CALLISTO PWR experimental facility for in-pile studies, which had been in operation into BR2 for more than 20 years.

The CALLISTO end of life decommissioning strategy aims for waste, cost and dose uptake minimization and includes:

- the unloading and removal of the in-pile sections,
- a closed-loop full system decontamination for dose reduction,
- the complete dismantling of the loop,
- the further sorting and segmentation in a dedicated workshop,
- a hard chemical batchwise decontamination for unconditional clearance.

The entire project is foreseen to end with the evacuation of all material from site in 2017. The paper will describe in detail these subsequent decommissioning steps, with a focus on decontamination, dismantling and waste management. Lessons learned and potential benefits towards the D&D of commercial PWR will be highlighted.

Introduction

BR2 is one of the world's principal high-flux materials testing reactors, with a number of unique features in terms of reactor geometry, performance, flexibility and experimental accessibility. The ageing of the core material under irradiation required the replacement of the beryllium blocks composing the reactor core matrix. In combination with the decennial safety reassessment with particular attention to the impact of ageing on safety, it was decided to subject the reactor to a third major refurbishment campaign (2015-2016). After this successful refurbishment BR2 continues to play a key role in the production of various radio-isotopes and neutron transmutation doped silicon, in combination with a full scope R&D capability on fuel and structure material research.

CALLISTO has been one of BR2's principal irradiation experiments since the early 1990s, used for PWR fuel and material studies. Three reactor channels have been used for this purpose, with a common pressurized loop installed principally in the sub-pile room (SPR) directly underneath the lower reactor vessel head. The ageing of the loop required its removal and replacement with new flexible devices for material and fuel testing during the reactor's fourth operational period (2016-2026). Due to difficult access conditions, elevated dose rates caused by deposition of activation products and potentially high waste costs, a dismantling strategy was developed for CALLISTO including decontamination steps aiming dose rate reduction and unconditional clearance.

CALLISTO decommissioning

CALLISTO PWR loop

The high pressure and high temperature experimental water loop CALLISTO in the BR2 reactor has been used extensively for various irradiation studies, making use of its three experimental rigs – called in-pile sections (IPS) – which were installed in three of the reactor channels. These IPS were connected to a common pressurized loop, which could deliver a wide range of pressure and temperature regimes. CALLISTO consisted of a main loop (high pressure and temperature) inside the SPR including pumps, heater, pressurizer and main cooler. The CALLISTO feed/bleed loop (low pressure and temperature) - both inside and outside the SPR - controlled the system volume/pressure and the water quality. It consisted of bleed coolers, purification system with resins and filters, pumps and some tanks. The total water volume of the loop in operation was in the order of 1 m^3, with a water chemistry representative of that of a PWR primary circuit and piping diameters in the range of 1/2" up to 3", mainly stainless steel.

CALLISTO decommissioning strategy

During the lifetime of CALLISTO, the three IPS have become highly radioactive by neutron activation, while the deposition of (mainly) activated corrosion products on the interior surfaces of the components of the CALLISTO system throughout the years has led to elevated dose rates in the vicinity of the loop, especially inside the narrow SPR. A partial chemical decontamination operation on CALLISTO's main loop highly irradiating components has already been performed in 2011. The evolution of dose rates inside the SPR is illustrated in Figure 1, plotting registered values on a number of fixed measuring points (MP) over time.

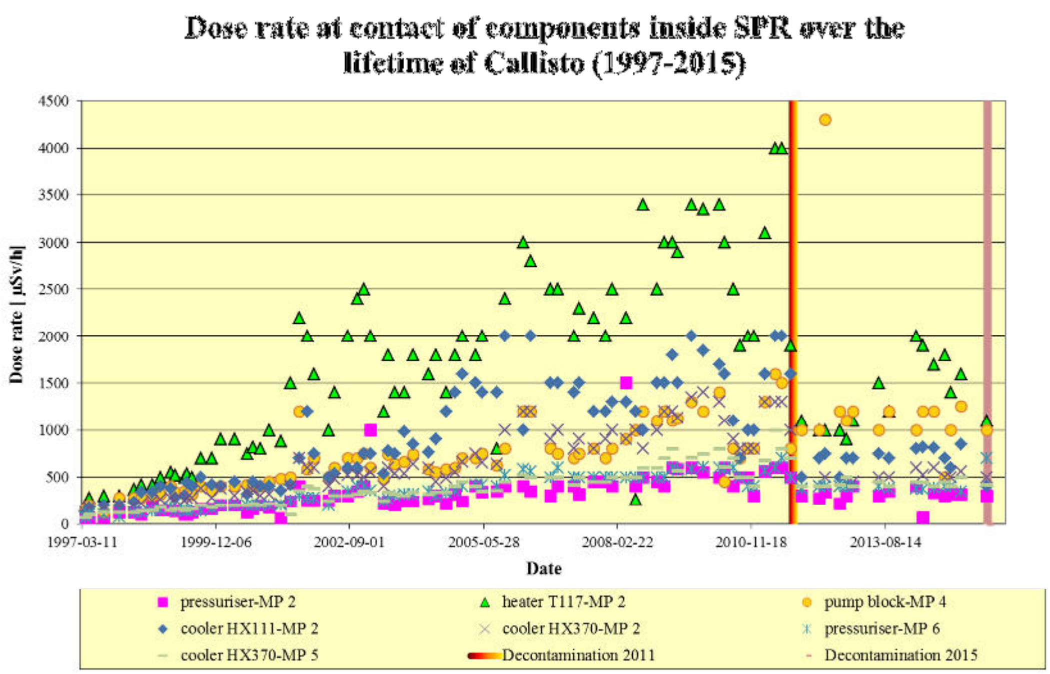

Figure 1: Evolution of dose rates in SPR during CALLISTO exploitation

Figure 1 shows the effect of the partial decontamination operation of 2011, but also reveals that the dose rates remained considerably high for a labor intensive hands-on dismantling in a room (SPR) of limited dimensions which is full of CALLISTO equipment. Ambient dose rates in the SPR were in the order of 300-400 µSv/h, with contact hotspots well over 1 mSv/h.

Figure 2: Impressions of CALLISTO main loop over the different levels of the SPR

The decommissioning strategy therefore involved:

- Unloading of the three IPS, transfer to BR2 hotcell for cutting-up and disposal as radioactive waste;
- Chemical decontamination of the water loop, with the focus on the components inside the SPR and the goal of maximal dose rate reduction;
- Conditioning of the ion exchange resins (exploitation + decontamination) for disposal as radioactive waste;
- Transfer of the two filters (exploitation) to BR2 hotcell for cutting-up and disposal as radioactive waste;
- Removal of all non-radioactive equipment for disposal as industrial waste;
- Removal of all radioactive equipment inside and outside the SPR for
  - Disposal as radioactive waste;
  - Further handling in the BR3[1] controlled area
    - Cutting-up;
    - Thorough chemical decontamination of the cut-up pieces, with the goal of release from regulatory control and recycling (direct clearance or through melting).

IPS removal

The three IPS have been neutron activated and highly contaminated over the years of exploitation. Their decommissioning involved the following steps:

- Unloading of the IPS;
- Separation of the IPS from the common pressurized loop in the SPR by cutting of all the connections;
- Removal of the IPS and temporary storage in BR2's storage channel;
- Transfer to BR2 hotcell for cutting-up and radioactive waste disposal;
- Reclosing of the pressurized loop by welding of pipe bends on the created openings (for future loop decontamination);
- Testing of the new connections on leak tightness and pressure resistance (for future loop decontamination).

Chemical decontamination

The performance of a closed-loop chemical decontamination operation demands the connection of a specific installation for decontamination to the loop. The decontamination installation was mounted on three skids for ease of manipulation and flexibility on the skids' mutual distance with the goal of limiting personnel exposure during execution.

[1] BR3: Reactor at SCK•CEN in dismantling, equipped with facilities for radioactive material (pre)treatment

Figure 3: Installation for decontamination in the BR2 containment building

The connections between the installation for decontamination and the CALLISTO loop were made outside the SPR for ease of access. The entire CALLISTO system inside the SPR was included in the decontamination loop, with its three main circulating pumps in use for high flow rates.

The decontamination protocol involved a number of repetitive cycles, each containing the following steps:

- Oxidation with $HNO_3/KMnO_4$ for chromium dissolution;
- Decontamination with $H_2C_2O_4$ for activity removal;
- Purification with ion exchange resins for solution clean-up.

The heating of the decontamination solution was delivered from the CALLISTO heater, with an adapted control in the nominal temperature range of the decontamination loop. The purification loop with the ion exchange resins was limited to a lower temperature of 40°C. All excess decontamination chemicals and dissolved corrosion products were to be captured by the cationic and anionic exchange resins, together with the dissolved activity.

The decontamination operation was done with teams of three persons in a 24h working regime. A total of six decontamination cycles have been executed, with a hold point and slight change in decontamination flow path after cycle 4.

The decontamination targets were to minimize the total activity inventory and lower ambient dose rates to values under 50 µSv/h to limit future personnel doses during decommissioning. Table 1 summarizes the main results. [4]

Process Parameters	
Decontamination Time	7 days
Main Loop Temperature	95°C
Main Loop Pressure	6 bar
Main Loop Flow Rate	8-10 kg/s
Corrosion Products (Fe, Cr, Ni)	600 g
Total Activity Removed (Co-60)	16E+09 Bq
Radiation	
Dose Reduction Factor Overall	10
Collective Radiation Exposure	4 man.mSv
Waste	
Ion Exchange Resins	250 kg
Filters (<2 mSv/h)	10

Table 1: Main decontamination parameters

Ambient dose rates over the different levels of the SPR have been reduced on average by a factor 10 to values in the magnitude of 30 µSv/h. Contact dose rates have also been significantly reduced, with over 95% of the measurement points lower than 100 µSv/h. Estimated gain on collective dose uptake for the cutting and removal of the loop from the SPR lies in the order of 100 man.mSv.

Waste evacuation

After discharge of the purified decontamination solution as low active waste water, the highly irradiating spent ion exchange resins have been transferred to waste drums for transfer, conditioning and storage at the national waste repository.

The ion exchange resins used for purification of the CALLISTO water during operation (~ 30 liters) have been removed from their column to a waste drum in the same manner as the ion exchange resins used for decontamination. Figure 4 shows the system configuration during this remotely operated transfer operation. These resins will be evacuated as medium active waste.

Figure 4: Resin transfer set-up with shielded containers

The two filter units used for purification of the CALLISTO water during operation are composed of a stainless steel filter (housing) surrounded by a lead castle. They contain high levels of deposited activity. They will be separated from the rest of the loop and transferred to BR2's hotcell for further handling and conditioning for evacuation as medium/high active waste.

System dismantling

The CALLISTO system consisted of a number of circuits with different levels of contamination, situated both inside and outside the SPR, such as:

- CALLISTO water loops (main loop, feed/bleed loop, make-up circuit, analysis circuits, waste circuit);
- Cooling water circuits;
- Gas and ventilation circuits;
- Electrical systems.

The construction of CALLISTO was such that a considerable amount of equipment had to be cut up or dismantled in situ using hands-on methods. As a result of the performed chemical decontamination, radiation levels around this equipment were low enough to make such work possible in a justified manner. The larger items (tanks, pressurizer, heater, coolers, pump block) were transported as a whole to a confined workshop at BR3 for hands-on cutting in a controlled environment.

The dismantling started outside the SPR, with non-radioactive components such as electrical cabinets, gas lines, cooling water piping, … All connections with the SPR were interrupted and shut off. The smaller radioactive equipment outside the SPR has been cut and assembled in drums for evacuation (Ø < 1/2") or further decontamination. Before cutting operations started inside the SPR, all loose parts and thermal insulation were removed for better accessibility to the actual CALLISTO loop(s).

A systematic approach was maintained inside the SPR, starting with the cutting of the piping, valves, instrumentation between the larger components (pressurizer, heater, coolers) using industrial equipment as grinders and reciprocating/band saws, always taking into account the origin, type and further destination of the material for sorting and traceability reasons. The larger components have then been removed from the SPR one at a time.

Figure 5: Dismantling of CALLISTO circuits and larger components

Since the delay tank – liquid waste tank outside SPR - was not part of the decontamination loop, high-pressure water cleaning was performed before transport as a whole to the BR3 cutting workshop to remove residual high active sludge from the bottom of the tank.

Further Treatment

Contaminated pipework (Ø ≥ 1/2") and all larger components were/are transferred from BR2 to BR3 for further treatment. The stainless steel material is eventually meant to be offered to the in-house hard chemical decontamination workshop, and therefore primarily had/has to be cut and sorted accordingly. The cutting and size reduction workshop at BR3 allows for a safe and controlled handling of contaminated material, both for the operators doing the hands-on cutting as for the environment to be kept free from contamination.

Figure 6: Material processing in the cutting and size reduction workshop at BR3

Aiming unconditional clearance of contaminated material originating from a PWR loop requires the thorough decontamination of the interior surfaces of the dismantled material. The dismantling of BR3 has led to the construction of an in-house decontamination workshop based on the MEDOC® process, which is appropriate for the treatment of stainless steel CALLISTO material. The MEDOC® (Metal Decontamination by Oxidation with Cerium) hard decontamination process is based on the use of cerium IV as a strong oxidant in sulfuric acid with continuous regeneration using ozone. [2] Single step dissolution of both the oxide layer (if present) and the base metal at high corrosion rates allows for the unconditional clearance of the treated material as schematically depicted in Figure 7.

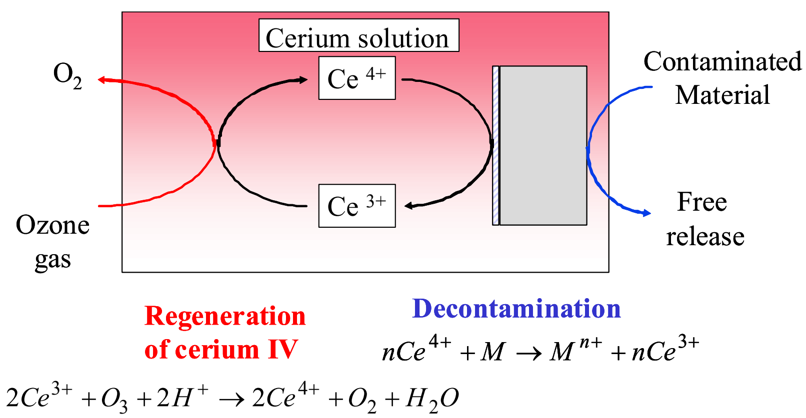

Figure 7: MEDOC® single step treatment with continuous regeneration of cerium

The batch treatment of dismantled contaminated pieces consists of the following steps [3]:

- Loading and sorting of the pieces via the basket into the decontamination reactor;
- Circulation of the decontamination solution;
- Rinsing of the decontaminated pieces in the rinsing reactor;
- Drying and characterization of the rinsed pieces.

Figure 8 shows the manual loading of contaminated CALLISTO piping, which was cut and sorted accordingly. The basket passes the decontamination process, and is afterwards left for characterization by well-defined measuring methodologies.

Figure 8: MEDOC® chemical decontamination workshop

The high corrosion rates necessary for efficient metal attack are established by heating the strongly oxidizing solution to 80°C and promoting the decontamination even more with ultrasonic resonators. The applied strategy aiming waste minimization as described allows an estimated 20 tons of material to be unconditionally cleared by the end of 2017 instead of deposited as radioactive waste.

Conclusions

CALLISTO has not only proven to be useful in simulating PWR conditions in exploitation, but can also be seen as representative for the coming major dismantling activities with regard to commercial power plants. The strategy applied at NPP's is of course country and site specific, but some of the experience from the decommissioning of CALLISTO can certainly be taken into account [4]:

- The successful chemical decontamination prior to dismantling has proven to be indispensable for a justified hands-on dismantling of the loop;
- A thorough sorting, conditioning and labeling of all dismantled material at the source is needed for a safe and traceable management;
- Temporary storage facilities for dismantled material in attendance of evacuation or further treatment are often limited and can as such be(come) a major factor in planning and logistics;
- An evacuation route for all material coming from the decommissioning of contaminated water loops should ideally already be defined before the start of the actual dismantling;
- Waste minimization by thorough decontamination can be an independent, economical and viable strategy for decommissioning of PWR's.

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