Chemical decontamination in nuclear systems – radiation protection issues during planning and realization

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ABSTRACT:

In nuclear power plants the dose rate from many systems and components rises with usage. In the last few years chemical decontamination has been increasingly applied to reduce operator dose uptake.

This paper gives an overview of the chemical decontamination process and a comparison with two other decontamination processes is made. The most commonly used (mobile) equipment and the interfaces to the nuclear power plant are outlined. In particular, the radiation protection issues during planning, installation and operation are identified. The assessment of the decontamination success is explained and examples of achieved decontamination factors and estimated dose reduction are given.

The main focus of this paper is on:

- Activity inventory, flow and containment during the decontamination;
- Optimizing installation areas for decontamination equipment for radiation protection;
- Limitation of impact of accidents (to environment and operators);
- Monitoring of the operation;
- Waste volume and waste handling.

1 INTRODUCTION

Chemical decontamination is one of the commonly used decontamination techniques in nuclear power plants worldwide. Like other decontamination techniques, it is used to remove activity from the nuclear systems. The activity can originate from activation/corrosion products, or from fission products, that managed to enter the primary coolant circuit. This activity can exist as soluble activity or insoluble activity. The insoluble contamination forms the commonly known CRUD. In both cases, the activity generates increased dose rates near those systems containing it.

In recent years an increasing demand for chemical decontamination of nuclear systems has been observed. This is due to the rise of dose rate from nuclear systems and components with the operation of the power plant. Fig. 1 shows that the dose rate near the primary circuit loop in a German pressurized water reactor (PWR). It can be clearly seen that the dose rate rises over the operating time (in this example, 10-years) of the nuclear power plant.

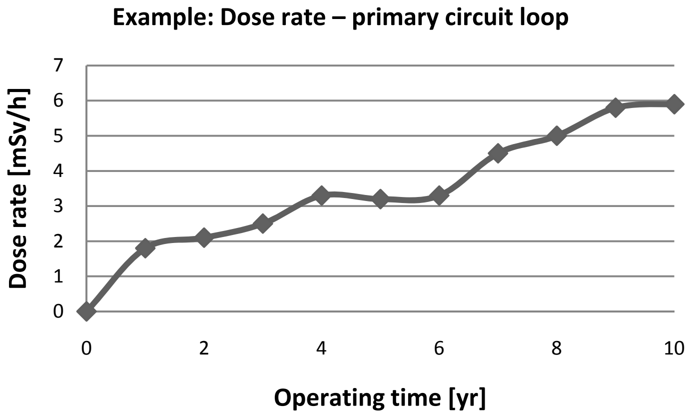

Fig. 1 - Dose rate near the primary circuit loop in a PWR

Rising dose rate causes rising collective doses for the plant operators. As one of the main objectives of radiation protection is the reduction of occupational exposure during maintenance and operation of the power plant, one way to satisfy this objective is to remove activity from the system. This can be accomplished by chemical decontamination.

2 COMPARISON WITH TWO OTHER DECONTAMINATION TECHNIQUES

As chemical decontamination is not the only decontamination technique available, a short comparison with two other common decontamination techniques (High pressure water jet cleaning and mechanical decontamination) is presented. It is not intended to provide a complete list of available decontamination techniques, but to demonstrate the differences in scope and complexity between three decontamination techniques.

High pressure water jet cleaning is a fast decontamination technique, which achieves good decontamination results in a wide range of applications. It involves inserting a blasting nozzle into the piping, or tanks, that are to be decontaminated and blasting the surfaces with high pressure water jets. The activity is washed out with the process water.

Another widely used method for decontamination is the use of mechanical force, which can be described as mechanical decontamination. The surface of the contaminated area is removed by blasting (with sand, metal, etc.), shaving, cutting or grinding.

These two decontamination methods are compared to the chemical decontamination. Chemical decontamination utilizes a chemical process by means of oxidation and reduction to remove the corrosion layers, hence removing the activity from the system or component. This is usually done in a multi-cycle process, each cycle including an oxidation and a reduction step. For example, in Germany a popular process is the CORD process from Areva. CORD is an abbreviation for Chemical, Oxidizing, Reduction, Decontamination. The CORD process uses permanganic acid for oxidation and oxalic acid for reduction.

When comparing those three techniques it is clear that one of the main differences between them is the depth of the layers they remove from the contaminated area. In general, the configuration of the systems surfaces is such that on top of the base material there are fixed iron and chromium rich layers (CRUD), and on top of them there is a layer of loosely deposited material.

- High pressure water jet decontamination removes the layer of loose deposits, but is not able to remove the CRUD effectively;
- Chemical decontamination, which is designed for CRUD removal, is able to remove those layers up to the base material;
- Mechanical decontamination goes even deeper, as it is able remove the base material itself, including activity that has diffused into the outer layers of the base material or has activated the base material.

High Pressure Water Jet Cleaning	**Mechanical Decontamination**	**Chemical Decontamination**
Pros • Fast • Good decontamination results • Water is compatible with most materials	Pros • Fast • Well established • Automation possible	Pros • Good decontamination results • Small waste volume • Scalable • Complex geometries
Cons • Access; Geometry • Blasting unit can get stuck	Cons • Destructive • High particle production • Waste	Cons • Time consuming • Complex assembling / disassembling • Material incompatibility

Fig. 2 – Comparison of three decontamination techniques

As shown in Fig. 2 the main advantage of water jet decontamination is that it is fast, easy to install and it uses water which is compatible with most of the materials used. The problem with water jet decontamination is that it is always dependent on the accessibility and geometry of the system as the nozzle cannot be too far away from the access point, especially when the piping has many bends in it. In some geometries the blasting unit could become stuck, such that its removal requires a lot of effort and increases the risk of damaging the equipment.

The main application for mechanical decontamination is during the dismantling of systems. As previously stated, it usually removes the base material and is therefore a destructive decontamination technique. Additionally many of the mechanical processes cause high particle production and large waste volumes.

Unlike high pressure water jet decontamination, chemical decontamination can be used for complex geometries. It is scalable, so that the decontamination of single components up to full systems are possible. It generates relatively small waste volumes while producing good decontamination results. However, it is a time consuming process. Assembly and disassembly of the decontamination equipment is complex and each cycle usually requires between ten and twenty hours. Material compatibility has to be considered due to the chemicals being used and because process temperatures near 100°C are common.

3 TECHNICAL OVERVIEW

Chemical decontamination is commonly applied in a multi cycle process. In each cycle multiple process steps are executed. There are the previously mentioned steps of oxidation and reduction, plus additional steps to remove the activity from the system - usually via ion exchangers - and to passivate/dissolve the chemicals used.

Fig. 3 – Chemical decontamination equipment

Fig. 3 presents an overview of the components needed for the chemical decontamination and the usual input / output of the decontamination equipment. In the mixing unit, chemicals and deionised water are mixed to produce the decontamination medium and to establish the correct concentrations for each decontamination step in each cycle. The decontamination medium is moved through the contaminated system and back to the decontamination equipment by a pump. As process temperatures near 100°C are needed, a heating unit is integrated in the decontamination circuit. The activity is removed from the decontamination medium by ion exchangers. To monitor the process, a sampling unit is needed. After the last decontamination cycle, the process water is disposed of via a releasing unit.

4 ACTIVITY - INVENTORY, FLOW, CONTAINMENT

The activity inventory prior to decontamination depends on the system that is to be decontaminated. However, most of the activity that is to be removed by means of chemical decontamination is generally fixed on the surfaces of the system. During the oxidation and reduction steps, the activity will change into ionic states and therefore will be dissolved in the decontamination medium. The dissolved activity will be distributed through the whole decontamination circuit (i.e. the contaminated system, the decontamination equipment and the piping). Therefore, the decontamination circuit will contain higher levels of mobile activity than the contaminated system had prior to decontamination. Finally, the activity will be removed from the decontamination medium by the ion exchangers and fixed in the ion exchange resins.

Typically most of the activity will be removed in the first decontamination cycle. With additional cycles the activity removed per cycle will reduce exponentially. Fig.4 shows the removed activity for a part-system decontamination of a volume control system. The system was operating for 30 years, had a volume of 4.0m³, a surface of 328m² and an activity inventory of 1.7 for part-system decontamination of 1.7E5 Bq / cm².

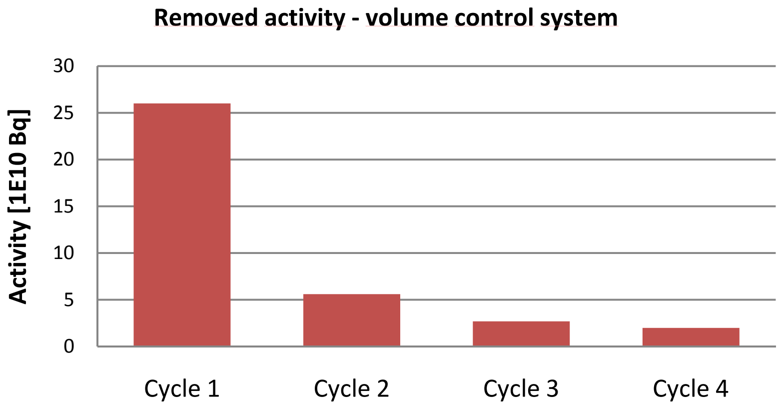

Fig. 4 – Removed activity per cycle

5 RESIDUAL RADIOACTIVE MATERIALS AND WASTE

As shown in Fig. 3 three types of waste are produced during chemical decontamination. First to mention is the process water that needs to be disposed of after the last decontamination cycle. Activity concentration in the process water can vary. If no ion exchangers are used to remove the activity, the whole activity removed from the decontaminated system will be in the process water and it will have to be handled accordingly. Usually the process water is released from the decontamination circuit to waste water tanks and subsequently handled by the plants waste water system.

In the chemical reactions, gas will be evolved and need to be taken care off. Usually mobile filters are used, or the off-gas is piped directly into the plants off-gas systems.

If ion exchangers are being used - which is most commonly the case - most of the removed activity will be fixed in the ion exchange resins. This creates solid waste of very high activity concentrations. In the above example, decontamination of the volume control system resulted in ion exchange resins with a volume of 0.5m³ and an activity inventory of 3E11Bq. Such high active waste has to be handled with care and appropriate radiation protection measures.

6 RADIATION PROTECTION ISSUES

Radiation protection issues can be separated into those to be considered during the planning stages and those that shall be considered during the decontamination process. However, measures to limit the doses due to direct radiation have to be considered during the planning phase.

6.1 Separation of high activity and low activity areas

The first way to manage radiation protection requirements is by separating high activity areas and low activity areas. All components of the decontamination equipment contain little or no activity prior to the decontamination, but during the decontamination process many of them will contain the decontamination medium with high activity concentrations. Therefore, it is preferable to install such components away from the operators working place as this is where the monitoring and controlling equipment will be. Also, during decontamination operations the operators will spend as little as possible time in the area of high activity.

6.2 Shielding

Sometimes geometry limitations do not allow enough distance between areas of high and low activity. In such cases, shielding has to be considered to “separate” the areas. A common way is to erect leaded walls between the areas, so that direct radiation can be significantly reduced. If there are walkways near the decontamination area additional shielding may be appropriate. Another reason for the use of shielding is to reduce or prevent interuption of adjacent operations.

6.3 Restriction of access

Another measure to limit the dose due to direct radiation is the restriction of access. Usually the set up area of the decontamination equipment – especially the high activity parts – are closed off. Often the decontamination equipment cannot be installed adjacent to the systems that are being decontaminated, so extensive piping is necessary. This piping can cross walkways and rooms that house neither the contaminated system or the decontamination equipment. The restriction of access to those areas also has to be considered.

6.4 Limitation of contamination / internal dose uptake

In order to limit the internal dose uptake of the operators, measures to prevent the spread of contamination have to be taken. Usually the wearing of protective clothes, especially overshoes in the setup areas of the decontamination equipment, is required.

The most important factor for the limitation of contamination during chemical decontamination is the inspection of leak tightness. The whole decontamination circuit, including the piping, has to be checked several times for leaks. Multiple checks are done during start up, usually when the system is cold, then after it is heated to operational temperature and again after the chemicals are inserted. During the decontamination process there is need for additional periodic checks of the whole decontamination circuit. It is appropriate to perform these checks after every change of state of the decontamination circuit, i.e. after every step in each decontamination cycle.

6.5 Analysis of the radiological impact of accidents in the environment and operators

Another important step in the planning stage of the decontamination project is the limitation of the impact of accidents to the operators and to the environment. The primary concerns are leakages, as described in the previous paragraph. Another accident to be considered is the failure of the decontamination circuit circulation pump. Without this pump operating, the decontamination medium containing high levels of activity will fill the whole decontamination circuit, so safe ways to dispose of this process water even after a pump failure have to be available. The failure of the heating unit must also be considered. As the process temperature is near to 100°C, fail-safe mechanisms to prevent additional heating of the process water to temperatures greater than the temperatures the equipment and piping is designed for have to be included.

6.6 Monitoring of direct radiation

After the planning stage, i.e. during the chemical decontamination, the direct radiation levels have to be monitored. This can be done by either continuous monitoring or by periodic checks. A common method is to define measurement points at various areas of the decontamination circuit including equipment, contaminated system and piping, then checking those points periodically in fixed tours of the operators. Dose rates near the working places, walkways and, in later stages, near the waste containers are of particular importance.

7 QUANTIFYING DECONTAMINATION RESULTS

To quantify the decontamination result, it is common practice to define a decontamination factor. This decontamination factor is calculated by dividing the average dose rate before the decontamination by the average dose rate after the decontamination. To obtain the average dose rate, measurements are taken on various representative positions at the decontaminated system, using the same measurement points before and after the decontamination. Typical decontaminations factors range from 5 to 50 and they depend on variables such as geometry (dead ends), material, surface structure, number of cycles etc.

8 DOSE REDUCTION

As stated in the Introduction, one primary goal of chemical decontamination is the reduction of the [collective] operator dose during future operation and maintenance. To illustrate the potential dose reduction, Fig. 5 shows the results of a feasibility study to compare doses for the 2010 to 2014 planned shutdowns in a German PWR with and without full system decontamination (i.e. decontamination of the whole primary water circuit).

Estimated collective dose for future maintenance without decontamination: **4780 mSv** (100%)	Estimated collective dose for future maintenance with decontamination: **1570 mSv**	Estimated collective dose of the chemical decontamination: **250 mSv**	Estimated saved collective dose: **4780 mSv** (100%) **-1570 mSv** **- 250 mSv** **2960 mSv** (62%)

Fig. 5 – Estimated collective doses with and without full system decontamination for the planned shutdowns 2010 to 2014

The estimated collective doses were calculated using the known average collective doses of past (long and short) planned shutdowns. To calculate the doses after full system decontamination, estimates of the expected decontamination factors were used. When calculating the saved collective doses, the collective dose of the personnel executing the chemical decontamination has to be considered. This collective dose includes the dose uptake during the installing, operating and dismantling of the decontamination equipment.

Using these figures, it is estimated that up to 3 Sv collective dose could be saved in the next 4 years, if chemical decontamination of the primary water circuit is used. These numbers are preliminary, and only valid for this single power plant example, but they do indicate the magnitude by which chemical decontamination can reduce collective doses.

9 ROLE OF THE TECHNICAL SUPPORT ORGANISATIONS DURING CHEMICAL DECONTAMINATION

Technical Support Organizations (TSOs) can provide valuable input for every step of the decontamination project. Most of the consultation work that the TSO provides will be in the planning stages. As mentioned above, there are different radiation protection issues to be considered, where the expertise of the TSOs can ensure safe operation of the decontamination equipment and optimum methods of addressing waste management.

Furthermore, in the later stages of the process, TSOs can provide the necessary inspections during

- Installation;
- Commissioning;
- Operation;
- Dismantling;
- Waste treatment.

10 CONCLUSION

One of the objectives in radiation protection is to reduce the occupational exposure of the operators. One way to achieve this objective is to remove activity from the nuclear systems, and this can be done effectively by chemical decontamination. This is why in the last few years an increasing number of applications of chemical decontamination worldwide has been observed.

This experience has shown that chemical decontamination in nuclear systems is already a proven and well tested method. With more nuclear power plants having operation times of a few decades, it can be expected that the number of applications of chemical decontamination will continue to rise.

Chemical decontamination leads to good decontamination results in a wide variety of systems, up to whole primary water circuits. There is the potential of reducing collective doses of maintenance work up to the Sievert magnitude.

Although there are a wide range of radiation protection issues that must be considered when applying chemical decontamination, this paper shows that there is already substantial knowledge and experience available to provide safe operation. TSOs can assist with most of the issues encountered through consultation and inspection.