Decontamination of V1 NPP primary circuits WWER 440

CASE STUDY

KP-JAVYS-005

25/10/2023

javys
jadrová
a vyraďovacia
spoločnosť, a.s.

Foreword

In 2021, the European Commission (EC) adopted a new proposal for a Council Regulation[1] establishing a dedicated financial programme for decommissioning nuclear facilities and managing Radioactive Waste (RAW). This instrument covers the co-funding of the decommissioning programmes of Bulgaria, Slovakia, and the decommissioning of the Joint Research Centre (JRC). A separate Council Regulation[2] was adopted for the decommissioning programme of Lithuania.

The EC JRC is mandated to foster the spread of decommissioning knowledge across all the European Union Member States and facilitate knowledge sharing arising from implementing the abovementioned decommissioning programmes, funded by the Nuclear Decommissioning Assistance Programme (NDAP).

The decommissioning operators from the NDAP (NDAP Operators) implemented and tested a knowledge management methodology in 2021 through Project ENER/D2/2020-273. Using this methodology, the NDAP Operators can develop Knowledge Products that are currently available to share with other European stakeholders. In addition, this methodology is under implementation in the JRC Nuclear Decommissioning and Waste Management Directorate (NDWMD), which becomes a knowledge generator extracting the knowledge from the ongoing decommissioning activities at the different sites (Geel, Ispra, Karlsruhe, and Petten).

The JRC NDWMD aims to become a Centre of Excellence in nuclear decommissioning knowledge management and develop a decommissioning knowledge platform which allows exchanging information and building on the best practices in the EU inside the multi-annual financial framework (2021 – 2027) strategy. The operational phase of the project is expected to start in 2024 to develop ties and exchanges among EU stakeholders and document explicit knowledge and make it available through multi-lateral knowledge transfers on decommissioning and waste management governance issues, managerial best practices, technological challenges, and decommissioning processes at both operational and organisational level, to develop potential EU synergies.

This is a Knowledge Product prepared by JAVYS, a.s. for the JRC NDWMD.

Document code	KP-JAVYS-005		
Performed by	Ing. Eva Hrašnová		
Revised by	Nuclear Decommissioning Knowledge Management Team		
Version	V0	09/05/2023	Initial version
	V1	02/08/2023	Reviewed version
	V2	25/10/2023	Final version
Sent to	Andrea PIAGENTINI		
Approved by	Andrea PIAGENTINI		

[1] Council Regulation (Euratom) 2021/100 of 25 January 2021 establishing a dedicated financial programme for the decommissioning of nuclear facilities and the management of RAW, and repealing Regulation (Euratom) No 1368/2013

[2] Council Regulation (EU) 2021/101 of 25 January 2021 establishing the nuclear decommissioning assistance programme of the Ignalina nuclear power plant in Lithuania and repealing Regulation (EU) No 1369/2013

PRODUCT DESCRIPTION

The Decontamination of primary circuit WWER - case study report was prepared by a team of experts from JAVYS, a Nuclear and Decommissioning company in Slovakia.

The product conveys the experience gained during the execution of the BIDSF Projects D2 and D2-A Decontamination of the primary circuit, sponsored by the European Commission via the Nuclear Decommissioning Assistance Program (NDAP) and Slovak nuclear fund between 2013 - 2017.

The case study presented in this report aims to assist nuclear power plant personnel in planning the decommissioning. The knowledge about the project, decontamination process, and operation needs of such a complex project will help to prepare personnel for decommissioning and successfully implement the primary circuit decontamination project. Even in the implementation stage of the decontamination project, this case study helps to identify adequate implementation progress.

When studying this case study, it should be considered that it describes applying a selected type of chemical decontamination. In the case of a different application of chemical decontamination, the chemical process and sequence of steps will be different. Common to all types of decontamination is the sequence of project steps and lessons learned.

This product was developed as part of an effort to disseminate and share with all EU State Members the knowledge acquired during the decommissioning and RAW management activities performed with NDAP funding.

ABSTRACT

The Decontamination of primary circuit WWER 440 case study provides Decommissioning and Waste Management (D&WM) organisations with:

- The setting of the project phases, from the preparation of the project, the creation of technical specifications, and procurement of executor of decontamination works, from the side of the employer/customer/owner of the facility
- The definition of the necessary steps to achieve the project objectives: setting the project objectives through the design phase, permitting process, verification of equipment parameters, how to evaluate decontamination results, and achieving optimal results.

After overcoming the initial problems in the implementation of the project for the decontamination of the primary circuits of V1 NPP in Jaslovské Bohunice, the project was one of the most successful projects in the decommissioning of V1 NPP. This project resulted in the condition and predecessor of further dismantling a fragmentation of two primary units type WWER.

Implementation of the decontamination of primary circuits V1 NPP proved the necessary steps to implement system decontamination process to be done safely in a short time with goals to decontaminate primary circuit in defined scope, produce minimal quantities of RAW, and produced RAW must be treatable by available processing technologies.

OBJECTIVE

This Knowledge Product aims to provide an example of implementing a primary circuit decontamination project from the customer's perspective, identifying the necessary steps, division of responsibilities, and essential project details critical to the project's success.

APPROACH

This document was developed by the JAVYS project team from the division responsible for the implementation of decommissioning of V1 NPP. The project team incorporated experiences from preparing and implementing the execution of the Bohunice International Decommissioning Support Fund (BIDSF) Projects D2 and D2-A Decontamination of the primary circuit.

Initial failures in implementing the decontamination project led to identifying essential steps for completing the decontamination of the primary circuits of NPP V1. The study describes the basic aspects from the perspective of the customer, such as aspects of project management, preparation of project documentation, monitoring and daily management of the performance of chemical decontamination, control of the resulting RAW, tracking of the progress of the decontamination, evaluation of the results of the work. The implementation of decontamination of the primary circuits of the NPP has its specifics, which depend on the chosen scope of decontamination, i.e., which parts of the technology will be included in the decontamination.

The primary sources for the composition of this study were the personal experiences of the project team, which were recorded in the form of materials for the decisions of the JAVYS senior management, the technical reports that were part of the project documentation for the D2 and D2-A projects, EPRI's evaluation of the D2 project, the completion reports of the D2 and D2-A projects, continuously compared with approaches and lessons learned from the implementation of the DFD in other NPPs. In this case study, we focus on standard features from other decontaminations, which compliance with which led to successful decontamination.

RESULTS, FINDINGS, AND INSIGHTS

To successfully complete the defined scope of whole system decontamination while maintaining safety criteria and minimizing the produced RAW, it is important to look at the project as an interplay of technical, managerial, and human aspects.

Detailed knowledge of the technical aspects will enable personnel supervising the implementation to distinguish typical operating characteristics of chemical decontamination from anomalies.

The technical aspects of a decontamination project include:

Engineering and chemistry:

The basic part is process selection, considering material composition and changes caused by the operating parameters of the nuclear power plant. For NPP V1, WWER 440, the combination of NITROX E + DFD EPRI process has proven to be a good choice. The application of this method was tested in the laboratory on samples taken directly from the steam generator. In practice, the tests were confirmed during the decontamination of six double loops with twelve steam generators (SG) and the necessary decontamination factories were achieved (6.2 Results).

The modular composition of the DFD line, connected by hoses, proved a good choice regarding operability, allowing for fast transfer from unit to unit without precision requirements. The basic circuit of the DFD line provided the required flow and temperature parameters and chemical dosing, while the secondary circuit provided filtration and regeneration of the decontamination solution. It is necessary to ensure the same flow rate and temperature in all parts of the circuit to achieve homogeneous decontamination results throughout the entire circuit.

The key in terms of modifications to the original primary circuit is to separate the primary circuit from other connections and material weak points and to provide venting during the filling of the circuit and the ongoing chemical reaction. Measuring the pressure in the double loop will contribute to controlling the safe progress of the decontamination. A spider has proved to be a good choice for connecting the double loop and bypassing the RPV, whose design allowed for variable repositioning between the twin loops and shielding against radiation from the reactor.

Safety analysis:

Safety analysis was performed to evaluate the risks and mitigating measures associated with the decontamination of primary circuits V1 NPP and fixation of spent resins directly at the reactor hall. The safety analysis developed (method: Hazard and Operability Study) by the independent experts was prepared to consider the operational experience of interrupted decontamination in the scope of the D2 project. Risks were divided into categories: radiological safety, operational safety, environmental safety, and industrial safety.

Safety analyses were evaluated for the following situations: leakage of decontamination solution after hose rupture between modules of the DFD line, leakage of ionex, line failures without leakage, and transport failures during the transfer of modules from block to block. No off-site exposure and no risk of off-site contamination of contaminated liquids were expected.

ALARA measures

Adherence to the ALARA principles was based on the respect of radiation safety rules, which JAVYS radiation technicians supervised:

- Technical measures were important to ensure the safety of the personnel at all times, and water shields were installed around the ion exchange filter columns where the removed activity remained.
- Remote control of the DFD line: the operating computer was in a container with a permanent operator's station. In the second container was a chemical laboratory with permanent operation. Chemical dosing was via a mix and vent tank with a suitable radiation situation.
- Transport of the spent ionex and contaminated water after regeneration was provided by connection to the NPP contaminated water system. Utilization of the equipment reduced the contaminated quantity of equipment involved in chemical decontamination.

The **morning meetings with the participation of radiation protection** were crucial when the whole team was repeatedly informed about the daily work and tasks. Maximum activity in circulating decontamination solution was controlled and limited in terms of the storability of the fixed RAW at the Mochovce national repository.

The total effective cumulative collective exposure of the workers involved in the work was 15,411 man.mSv. The highest cumulative individual exposure during the execution of the work was 1,595 mSv. None of the workers involved exceeded the maximum planned cumulative IED.

Process results

A thorough preparation phase, including the training of all personnel involved with the decontamination regulations and work programmes for execution, was a prerequisite for coping with both the implementation process and any unexpected situations.

The initial assumed number of cycles for one decontamination circuit was three cycles of NITROX-E and one to two cycles of DFD. The number and assignment of decontamination cycles were adjusted depending on the level of decontamination factors achieved or the level of contamination removed. Implementing these additional cycles was subject to mutual agreement between the contractor and the Client.

Although decontamination was successful, it was found that the shorter PG tubes from the inside of the bundle were decontaminated better than the longer outer tubes. Therefore, when decontaminating the other double loops, the flow rate in the loop was increased to achieve a higher flow rate in the outer tubes. It was also found that the second DFD cycle produced only a tiny improvement in activity removal, so it was decided to perform four cycles of NITROX-E and only one cycle of DFD on the next double loops, 3 and 6. Each extra degree of decontamination solution (from 85-96°C) contributed to better decontamination. The particles produced during decontamination were captured directly on the ion exchangers; particle production is part of the decontamination process.

During implementation, no leaks were encountered on the line or decontamination circuit; potential spots identified during D2 were repaired before proceeding to D2-A. Nevertheless, we were prepared for leakage, accepting this as part of the work. The average removed activity achieved on SGs was 92.1%, and activity removed from the primary circuits was 98.15%.

Operational team

For a project of similar scope and complexity, the contractor's onsite organisation should comprise an overall project manager, an experienced supervisor for each shift, a professional process chemist for each change, and two or more operators for each shift. More importantly, these personnel have to be on-site during equipment testing through to the end of the decontamination process application and would not be replaced unless under exigent circumstances. It is necessary that by experience and use of the fully developed and detailed operating procedure, the personnel performing the application on-site would be qualified to make all process decisions in real time without the need for external consultation. The onsite organization can not be subject to changes in key personnel, and personnel experienced in process application must be consistently on site.

Human aspect

This type of project includes the engineering phase, licensing, testing, and operational; RAW management cannot be successfully implemented without the symbiosis of the personnel of the implementer, the operator of the nuclear facility, the people in charge of decommissioning, radiation protection and the responsible state authorities.

The decontamination contractor had to become familiar with the V1 NPP environment, and the client had to make efforts in the licensing phase and help prepare the documentation according to Slovak legislation. The client had to understand the natural decontamination process and its outputs. Teams on both sides had to overcome language and cultural barriers.

Progress at any stage of the project would be impossible without mutual understanding and letting go of exaggerated expectations.

Handling this project required patience, sobriety and collaboration. Considering a communication and safety culture during testing and operations is essential.

Continuation

Implementing this complex project by the selected contractor, who met the set criteria, was successful. Lessons learned were applied with the support of JAVYS staff in KNPP, Bulgaria. The success of this combination of DFD equipment from D2 and the selected experienced contractor has continued with even more decontamination scope and better decontamination results at the four WWER KNPP units in Bulgaria.

TARGET USERS

Potential beneficiaries of this product are any entity involved in a primary circuit decontamination project before its fragmentation. It can be decommissioning phase planners where decontamination and subsequent fragmentation of the primary circuit are planned, and the timing of all phases of the project needs to be determined from the preparation of the implementation design, the procurement of equipment for the specific parameters of the primary circuit, the actual performance of the chemical decontamination, to the management of the RAW produced. Two main target users have been identified:

- The State Supervisor, who must be able to assess the submitted project from the point of view of safety.
- The operator of the NPP in decommissioning who must cooperate during the preparation, execution and supervision of the work and determine the prerequisites for successful implementation.

APPLICATION, VALUE, AND USE

The decommissioning phase is typically characterized by the departure of professional operating personnel who, in practice, have routinely performed decontamination during nuclear plant shutdowns, and, naturally, these personnel have been familiar in detail with all aspects of chemical decontamination. In practice, new personnel are deployed for decommissioning and, after training, can do the decommissioning. There is a wide range of decommissioning activities, which are usually applied for the first time at a given nuclear installation. This was also the case for the complete system chemical decontamination of NPP V1, WWER 440.

This Knowledge Product value describes the specifics of full-circuit decontamination for disassembly, whose goals regarding the achievement of decontamination factors for subsequent fragmentation of primary circuit components are much more challenging.

The presented case study describes this complex project in the phase of project preparation, equipment testing, chemical method testing, active commissioning, and results from the full-circuit decontamination of twelve SGs and primary sinks and volume compensators of NPP V1.

Application of the main principles from the successful application helps avoid the decontamination activity's negative impact on the following decommissioning works. This Knowledge Product will allow the user to define:

- Realistic decontamination goals
- Decontamination strategy
- RAW produced by decontamination
- Effective division of the responsibilities between the employer and the contractor
- Information about the time schedule of the project
- The sequence of steps that lead to successful decontamination.

KEYWORDS

DECOMMISSIONING, DISMANTLING, DECONTAMINATION, NUCLEAR POWER PLANT, WWER, VVER, V1NPP, FULL SYSTEM CHEMICAL DECONTAMINATION.

TABLE OF CONTENTS

LIST OF ACRONYMS AND DEFINITIONS

ALARA	As low as reasonably achievable
BIDSF	Bohunice International Decommissioning Support Fund
EBRD	European Bank for Reconstruction and Development
EPRI	Electric Power Research Institute
D2	The project consists of decontaminating the primary circuits of the two reactors of V1 Bohunice NPP.
D2-A	The project consists of decontamination of the primary circuits of the two reactors of V1 Bohunice NPP and the continuation of works with the selected contractor.
DF	Decontamination Factor
DFD	Decontamination For Dismantling: the process used by the contractor to decontaminate the Primary Circuit
D&D	Decontamination & Decommissioning
D&WM	Decontamination & Waste Management
JAVYS	Jadrová a vyraďovacia spoločnosť a.s.
KED	Collective effective dose
NRA SR	Nuclear Regulatory Authority of the Slovak republic
OTNI	Onet Technologies Nuclear International, leader of the Consortium
P&ID	Process and Instrumentation Diagram
RAW	Radioactive Waste
RH	Reactor Hall
RIS	Reactor Internal Structures
ROBO	ROBO, a.s., member of the Consortium
RP	Radiation protection
RPV	Reactor Pressure Vessel
SG	Steam generator
TRB-Z	Technician of radiation protection on shift
TSÚ RAO	Technologies of RAW processing and treatment
V1 NPP	V1 Nuclear Power Plant, Jaslovské Bohunice

LIST OF FIGURES

LIST OF TABLES

1. BACKGROUND

V1 NPP at Jaslovské Bohunice Site, located in the Trnava District in western Slovakia, was finally shut down in 2006 (Unit 1) and 2008 (Unit 2). V1 NPP comprises a two-unit reactor Soviet-design WWER-440/V-230 commissioned in 1978 and 1980. Each one has a design electrical power of 440 MW_e. The reactor was defueled in January 2008. The fuel was transported from the reactor's spent fuel pool to the ISFSF in February 2009. The last spent fuel from the pools was transported to the ISFSF in January 2011.

Immediate Decommissioning Option (IDO) was chosen for decommissioning V1 NPP - Decommissioning strategy with immediate and continuous dismantling of equipment and facilities, demolition of buildings including the foundations and site preparation for industrial reuse. The implementation of the IDO is conditional on the decontamination of the primary circuits before fragmentation to facilitate decommissioning activities by reducing general area dose rates and lowering contamination levels to reduce disposal costs.

Figure 1: Reactor Hall at Bohunice V1

The BIDSF project D2 and D2-A carried out the decontamination of the V1 NPP primary circuits. The presented case studies describe the progress and lessons learned from the implementation of these two projects by two different contractors. The scope of the chemical decontamination for one unit included the six steam generators (SGs) and associated main reactor coolant loop piping, as well as the pressurizer. The reactor vessel was bypassed using jumper piping between the reactor vessel inlet and outlet connections (known as the “spider assembly”). It was planned to decontaminate two loops at a time (“double-loop” approach) so that three applications are planned for each unit.

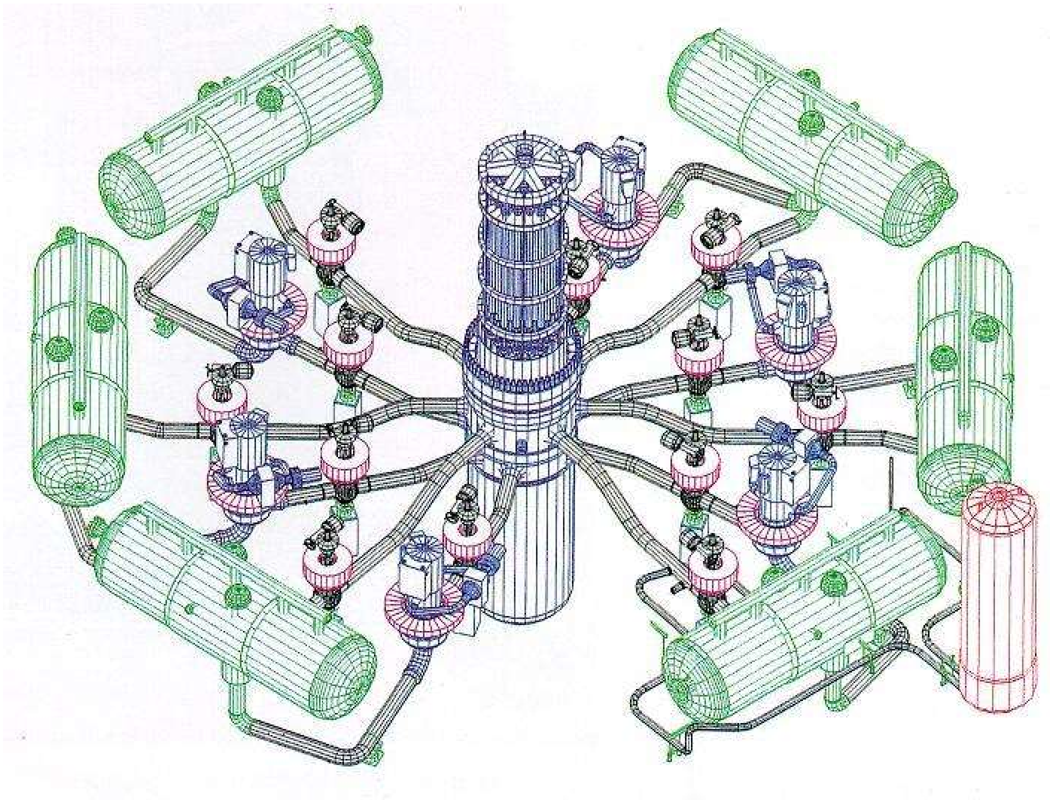

Figure 2: Primary Circuit of V1 NPP

1.1. Description of the Challenges or Problem

The immediate dismantling option of the V1 NPP primary circuit could not have been implemented using the currently available methods and means without the pre-dismantling decontamination of the primary circuit. Without decontamination, workers would have been exposed to ten to one hundred times higher dose rates during dismantling and fragmentation works than anticipated in the V1 NPP Decommissioning 2nd Stage Plan.

The unsuccessful implementation of Project D2 and the need to terminate the cooperation with the contractor significantly impacted the delay of the Bohunice Programme. The Contract with the contractor of the D2 project was effective from January 2013 and was supposed to be completed in March 2016. Implementation of the D2 project was not completed due to the departure of key experts from the project and subsequent service provided by inexperienced personnel operating the decontamination line, which resulted in repeated equipment failures, loss of chemical processes and production of higher quantities of RAW. Due to the production of liquid RAW with an activity exceeding the expected values, a new transport container for liquid RAW had to be procured. The contractor failed to meet the project's objective - to decontaminate the primary circuit of V1 NPP Units 1 and 2. In March 2016, based on expert opinions and with the support of the EBRD, company JAVYS prematurely terminated the Contract for the D2 project.

Implementation of the D2 project in the period 2013 - 2016 brought the following **positive outcomes**:

- The effectiveness of chemical decontamination on the V1 NPP primary circuit material was laboratory-demonstrated.
- A decontamination line was designed, manufactured and tested together with connecting pipelines for the application of chemical decontamination.
- Knowledge about the specifics of the chemical decontamination implementation at the primary circuit of NPPs (WWER 230 type) was gained.

The project team subsequently applied this knowledge when modifying/updating the technical specification of the project, thus ensuring the subsequent feasibility of the D2-A project.

1.2. Constraints

After the interruption of the decontamination of the NPP V1 primary containments in 2015, it was necessary to find a company to use the supplied DFD equipment for the application of EPRI chemical decontamination, which will bring time savings compared to repeating the project, including the design of a new decontamination line. Using unknown designed and manufactured equipment predisposes risk to the user.

Specialists with experience in circuit-wide decontamination of primary circuits are scarce and time-strapped, with their activities scheduled according to the shutdowns of operating plants. In addition, part of the project budget was spent on the completed scope of the D2 project. The challenge was finding an experienced company to manage the technical risk and the time and cost constraints. The advantage for the potential contractor was the vision of the future implementation of these decontaminations in the WWER decommissioning market, in Bulgaria and Germany. On the JAVYS side, the project team was very involved, which helped the project implementation.

1.3. Relevance

This case study helps the project team responsible for decommissioning in a **chemical decontamination project's preparation and implementation phase to create a good technical specification**. It is a practical example of how to set decontamination objectives concerning feasibility, the primary purpose, and keeping a high safety standard.

The implementation phase of the case study projects D2 and D2-A is an example of project managers recognising and looking for solutions in seemingly unsolvable situations. To soberly evaluate the achieved status, define the needs, and look for opportunities with the remaining budget to assist the contractor so that in the end, he will have a profit, if not financial, then the prospect of further work and gain. It is essential to look at the project as an **interplay of technical, managerial, and human aspects** to complete the defined scope of system decontamination while maintaining safety criteria and minimizing the produced RAW. Detailed knowledge of the technical elements will enable personnel supervising the implementation to distinguish typical operating characteristics of chemical decontamination from anomalies.

The decommissioning phase is typically characterized by the departure of professional operating personnel who, in practice, have routinely performed decontamination during nuclear plant shutdowns, and, naturally, these personnel have been familiar in detail with all aspects of chemical decontamination. In practice, new personnel are deployed for decommissioning and, after training, can do the decommissioning. A wide range of decommissioning activities are usually applied for the first time at a nuclear facility, as was the case for the whole system chemical decontamination of NPP V1, WWER 440, whose specifics of full-circuit decontamination for disassembly, whose goals regarding the achievement of decontamination factors (DFs) for subsequent fragmentation of primary circuit are much more challenging.

The presented case study describes this complex project in the project preparation phase, equipment testing, chemical method testing, active commissioning, and results from the full-circuit decontamination of twelve SGs and primary pipelines and volume compensators of NPP V1. Application of the main principles resulting from the successful application helps avoid the decontamination activity's negative impact on the following decommissioning works. This Knowledge Product will allow the user to define and recognize:

- Realistic decontamination goals and decontamination strategy.
- Safety aspects and ALARA measures.
- Effective division of the responsibilities between the employer and the contractor.
- Information about the schedule of the project and the sequence of steps of the decontamination project that leads to successful decontamination.
- Basic chemistry features, the design of modular DFD line and line standard operation.
- Evaluation of decontamination results and RAW produced by decontamination.

An essential part of the case study is the lessons learned specific to D2 and D2-A from the implementation phase of the projects.

2. SCOPE

The scope of this case study - lessons learned is to emphasize the project setup from the perspective of the operator of a nuclear facility in the decommissioning phase, who has the legal responsibility for the safe and cost-justified decommissioning of a nuclear installation - in this case, a WWER V1-type nuclear power plant. The ambition is to highlight what is critical that leads to project success or failure in terms of safety, cost, and damage to equipment.

The case study is conceived from the customer's point of view; it is not about the actual chemical decontamination process and specifics such as exact dosing parameters. It emphasizes what is important, what is to be supervised by the ordering party, which indicates the high professionalism of the chemical decontamination contractor, whether it is ensured that the chemical decontamination will be carried out safely, without damaging the primary circle or the contractor's equipment, people's health. It is essential to know the magnitude of the risk of implementing the chemical process when chemical fumes are produced, recesses on the equipment, and the production of hydrogen and other dangerous gases. It is also necessary to know the actual quantities and types of secondary wastes, with the main emphasis on reducing contamination of the primary circuit within the scope of work.

3. OVERVIEW OF THE CASE STUDIES

The two related case studies can be briefly summarized as follows:

Case Study #1 – D2 2013 – 2016

The implementation since 2013 has verified the correctness of the assignment and has shown the weaknesses of the project in the area of performance. As the decontamination of the V1 NPP primary circuits was on the critical path of decommissioning, it was necessary to re-evaluate the implementation aspects in Project D2 and adjust it to meet the project objectives - to prepare the V1 NPP primary circuits for fragmentation by improving the radiation situation. The proficiency of the chosen decontamination method and the ability to use the results of the D2 project - decontamination modules designed for the parameters of the primary circuit of NPP V1 - proved crucial.

Case Study #2 – D2-A 2016 – 2017

This case study involves the continuation of the decontamination of the V1 NPP primary circuits through the D2-A project after the failure of the implementation through the previous D2 project when it was necessary to identify the causes of the failure, but also the positives of D2 to build on.

The fundamental prerequisite for implementing the decontamination of the primary circuits is a high level of professionalism and specialisation in decontamination using the D&D decontamination method. It was essential to find such a specialised contractor on the market and to procure the project directly through direct tendering. JAVYS withdrew from the open competition and, after a market survey, awarded the contract to the selected contractor with a proven track record of decontamination using the D&D decontamination method.

A condition of the implementation was using the decontamination modules already delivered from the D2 project to the extent specified by the selected contractor, as the contractor would take responsibility for all areas of the implementation.

D2-A improved engineering, safety analysis, decontamination equipment, control of the decontamination process, involvement of operators' staff, project management, and decontamination results evaluation.

4. SUMMARY OF LESSONS LEARNED

4.1. General Conclusions and Lessons Learned

This knowledge product contains two interrelated case studies, from both of which the following lessons learned are common:

<u>Engineering phase</u>

- Determining the scope of decontamination of NPP V1 primary circuits decontaminating the primary circuit without pressure vessel and reactor internals ensured that the planned DFs were achieved under the condition of minimizing secondary RAW. This strategy was based on the available world experience with full-circuit decontamination.
- Such a complex project is only feasible through close cooperation between the primary circuit operator and the decontamination contractor. The most significant assistance was in the creation of licensing documentation, which the contractor would not be able to finalize due to the authorization of activities by the state authorities of the Slovak Republic.
- Open communication and close cooperation with state permitting authorities (Nuclear authority, Health authority) is a prerequisite for smooth permitting activities.
- In addition to the material composition, the technical specification included available analyses from operations on the internal surfaces of the primary pipe, which indicated the thicknesses of the protective and corrosion layer material that would need to be removed and predicted the amount of waste.
- Originally it was planned to measure the deco-factor via telemetry, which in practice proved to be an unnecessary time luxury, which is also problematic to operate. Later, the deco-factor was checked at predefined and marked locations with hand probes based on a set methodology.
- Artefact tests must be directly from the steam generator; the connecting pipe to the primary line was not in the same operating conditions as the pipes in the steam generator, which make up more than 90% of the decontaminated surface. Take a proper artefact for the artefact test (primary circuit contamination is represented by the steam generator tube).
- The design shall include venting based on the decontaminated and attached modular circuits' layout and elevation differences. The venting is required for filling and emptying the circuit and during the ongoing chemical decontamination process when gases are produced. Inadequate venting is a severe safety hazard that will cause shocks in the system, cavitation of the pumps and sealing of the system with all the consequences of a leak of contaminated solution.
- Decontamination was carried out in double loops, saving time and minimizing the decontamination solution. This loop was still quite prominent in achieving the same flow rate in all steam generator parts. It was necessary to increase the flow rate of the decontamination media to perform consistent decontamination.
- Using equipment with many construction joints will introduce potential leak points and leakage of decontamination solution.
- Pressure measurements must be arranged throughout the circuit to monitor and control the process. During the chemical process and temperature rise, gases are produced, which cause a pressure change in the circuit.
- All parts of the decontamination line must be made of a base material resistant to the decontamination solution and temperature.

Safety

- Developing safety analyses for all chemical decontamination activities is standard before this activity. Safety analysis was performed to evaluate the risks and mitigating measures associated with the decontamination of primary circuits V1 NPP and fixation of spent resins directly at the reactor hall. The safety analysis developed (method: Hazard and Operability Study) by the independent experts was prepared to consider the operational experience of interrupted decontamination in the scope of the D2 project. Risks were divided into categories: radiological safety, operational safety, environmental safety, and industrial safety.
- Safety analyses were evaluated for the following situations: leakage of decontamination solution after hose rupture between modules of the DFD line, leakage of ionex, line failures without leakage, and transport failures during the transfer of modules from block to block. No off-site exposure and no risk of off-site contamination of contaminated liquids were expected.

Technical ALARA measures

- The design of the DFD line must first and foremost respect the operator's protection from radiation.
- The trouble-free operation of a massively sized plant with containment baths is a prerequisite.
- The design must allow rapid modifications when moving from one circuit without provisional, inactive testing for each configuration.
- As standard, remote control of equipment from a designated shaded permanent operator location. Remote control of the DFD line - the operating computer was in a container with a permanent operator's station; a chemical laboratory with permanent operation was in the second container. Chemical dosing was via a mix and vent tank with a suitable radiation situation.
- Water shields were installed around the ion exchange filter columns where the removed activity remained to ensure the personnel's safety.
- Transport of the spent ionex and contaminated water after regeneration was provided by connection to the NPP contaminated water system. Utilization of the equipment reduced the contaminated quantity of equipment involved in chemical decontamination.
- While the circuit is being examined for potential leaks, the Execution Team needs to be aware of the risk of potential leaks that may occur on any part of the primary circuit during the process as well as on the DFD line itself. The operating rules must include a procedure for dealing with the leak by reducing the flow rate and measures to plug the leak and remove the contamination.

Organization ALARA measures

- Adherence to the ALARA principles was based on the respect of radiation safety rules, which JAVYS radiation technicians supervised.
- The operating procedure for decontaminating V1 primary circuits was developed based on ALARA principles and included a separate safety and radiation protection section.
- The morning meetings with the participation of radiation protection were critical when the whole team was repeatedly informed about the daily work and subsequent tasks.

Process phase

- The level of detail in the system setup, testing and operations procedures must be consistent for field application, considering the projects of similar scope and complexity. Detailed, step-by-step procedures are critical to ensuring project safety and effectiveness. Moreover, detailed procedures are required to support oversight by personnel less familiar with the decontamination process (such as station supervision).

- Ensuring the continuity and control of the chemical process regarding correct dosing, temperature and flow rate is a prerequisite for gradually dissolving the activity into the decontamination solution. Despite following all procedures, the production of insoluble particles with higher activity must be considered. Industry experience shows that 5 to 10 per cent or more of the plant oxide may be removed as particulate.

- For deciding on the continuation of decontamination, the Customer chose to proceed with the decontamination based on establishing a decision-making process based on the decontamination parameters achieved, the activity removed and the amount of RAW produced. The original decision to proceed with decontamination was strictly based only on the established DFs of 100 in the SGs and 30 in the primary pipeline.
- Maximum activity in circulating decontamination solution was controlled and limited in terms of the storability of the fixed RAW at the Mochovce national repository.
- The site operator supervised the actual production of RAW compared with the quantity and quality of produced RAW.
- The transport of spent ion exchanges contaminated water after regeneration of ion exchange columns through the original V1 facilities - transport pipelines of the V1 sewage system saved time, contamination of other facilities and reduced the doses to the operating personnel.

- Review cooling times and use water from the secondary side of the SGs for cooling instead of natural cooling. To reduce the cooling time of the decontamination solution (up to 36 hours) after decontamination was completed, the SGs were filled with cold water from the secondary side to save time.

Organisation and human aspect

- A prerequisite for successfully implementing this complex project is an experienced contractor with chemists skilled in decontaminating PWR circuits, mechanical engineers to ensure smooth operation of pumps, heaters, and flow changes, and an engineer to set up remote controls. In addition, the contractor must staff two shifts - 24-hour operation - with highly qualified personnel. (The decontamination process, filling, and heating are continuous, lasting 96-168 hours continuously for a V1-sized circuit). In addition to the DFD line operation and chemical regime, the spider operator and RAW management personnel were part of the execution team.
- More importantly, these personnel must be on-site during equipment testing through to the end of the decontamination process application and would not be replaced unless under difficult circumstances. It is necessary that by experience and use of the fully developed and detailed operating procedure, the personnel performing the application on-site would be qualified to make all process decisions in real-time.
- The onsite organisation cannot be subject to changes in key personnel, and personnel experienced in process application must be consistently on site. Any activity is subject to the responsibility of the owner of the nuclear installation; therefore, from the customer's side, the project team must be familiar with the operating regulations and risks.
- It is essential practice to have daily meetings of the contractor's, employer's, and Radiation Protection's working team before the commencement of the day's work and prior to the execution of any task that has not been sufficiently discussed at the daily meetings.

- This project includes the engineering phase, licensing, testing, operational, and RAW management. It cannot be successfully implemented without the symbiosis of the implementer's personnel, the nuclear facility's operator, the people in charge of decommissioning and radiation protection and the responsible state authorities. This close cooperation should be based on a rational division of roles and responsibilities in the contract so that project teams focus on the technical aspects of the project without contractual constraints. In addition, both parties had to accept some variations from the contract to implement and achieve the project objectives in time and cost.
- The decontamination contractor had to become familiar with the V1 NPP environment. The client had to make efforts in the licensing phase and help prepare the documentation according to Slovak legislation. The client had to understand the natural decontamination process and its outputs. Teams on both sides had to overcome language and cultural barriers.

4.2. Summary of Specific Lessons Learned from Each Case Study

The table below contains specific lessons learned categories from case studies D2 and D2-A.

Table 1: Summary of Specific Lessons Learned from Each Case Study for DFD at V1 NPP.

Category	BIDSF Project D2	BIDSF Project D2-A
Chemistry	<u>DFD EPRI, including regeneration of resins</u> Artefact tests proved the efficiency. But, during the application, the permanganic acid step was not applied, and the whole process of DFD EPRI was not used.	<u>NITROX E + DFD EPRI, including regeneration of resins</u> Artefact tests proved the efficiency. Root cause analysis of particulate generation during application at D2. Application of the proposed chemistry was proved to be efficient in practice.
Equipment design	Modular DFD line connected by fixed piping, capable of achieving the temperature, flow and filtration parameter of the decontamination solution used the regular sampling during the process. The basic concept of the project was correct. It dealt with decontamination after double loops, designed a spider that applied to all double loops, a reverse module to change the flow, and used the available knowledge. The FATs demonstrated full functionality, but during commissioning, on-site deficiencies were identified: ▪ System vibration is caused by insufficient venting after connection to the double loop during filling and decontamination. ▪ Need for reinforcement of the interconnecting device – spider. ▪ The particulate prefilter - a source of high doses due to the capture of uncontrolled production of active particles. ▪ Leakage of the plate exchanger due to coating and design. ▪ Failure of dose rate measurement on teledosimetry.	Modular DFD line from D2 (a condition of the contract) but identified design errors have been rectified: ▪ WES heater modules were used (steam plate replaced with electric heaters), ▪ WES ion-exchange columns and ▪ a mix and vent tank that replaced the dosing module and improved venting. ▪ Simple modifications achieved a significant improvement in venting. ▪ WES used a hose with quick-connect hoses of solid construction for the new connections and the connection to 1 unit, which is routinely used for decontamination. This solution was quick and did not demand the precision fitting of the modules. ▪ WES also used a proven, simplified chemical dosing and sampling approach.

Artefact test	DN50 mm 2 pc pipe sections taken from the cleanup system supply lines from one loop of each reactor (two specimens total).	DN 13.2 mm, two pc tubes directly from the steam generator.
Safety and ALARA	SA has been produced to support the delivery of new equipment to enable the implementation of chemical decontamination and mitigating measures associated with decontamination of primary circuits V1 NPP. The risk resulted from the operation of the newly designed facility, which was equipped with all the latest protection systems and containment baths and sensors in the event of a failure. SAs were developed, and the basic principles followed, but due to inadequate ventilation, vibrations were generated, which caused media leakage. All leaks were identified and corrected on time, and some improvements were also implemented. Inexperienced personnel could not identify the cause of the particulate production and implement corrective measures.	Repeated SA by independent specialists was performed to evaluate the risks and mitigating measures associated with the decontamination primary circuits V1 NPP and the fixation of spent resins directly at the reactor hall. The safety analysis developed (method: Hazard and Operability Study) by the independent experts was prepared to consider the operational experience of interrupted decontamination in the scope of the D2 project. Safety analyses were evaluated for the following situations: leakage of decontamination solution after hose rupture between modules of the DFD line, leakage of ionex, line failures without leakage, and transport failures during the transfer of modules from block to block. No off-site exposure was expected, and there was no risk of off-site spread of contaminated liquids.
Operation	The level of detail in the system setup, testing and operations procedures was inconsistent with those included in methods used for field application projects of similar scope and complexity. Detailed, step-by-step procedures are critical to ensuring project safety and effectiveness. Moreover, complex procedures are required to support oversight by personnel less familiar with the decontamination process (such as station supervision). Following the departure of key experts from the project, operation by inexperienced chemical decontamination personnel began, which resulted in work being stopped by the client. The operators constantly troubleshoot partial failures and could not confidently resolve the biggest particle and vibration problem.	Confident two shifts operation based on detailed operating procedures based on safety, process continuity and failure handling. Operators were experts in the decontamination field who did not need the manual; it provided information on the correct operation for standard and non-standard situations for the client's team and state regulators. To reduce particulate matter, it is necessary to carry out the chemical process: the proper solution concentration and optimum flow rate, smoothly, without interruptions and avoid air in the pipeline.

Safety Culture of Operation	In the initial phases of the project, there was a good level of safety culture intercommunication, which changed after the departure of experienced specialists. The work was carried out according to the work programme and according to the operating procedure, which was to be finalized after the active testing was completed, which has not been implemented. The contractor's lack of experience was evident in all areas and nervousness. Despite the necessary training and efforts of the operators, the shortcomings were immediately recognised by the client, and this was one of the factors that led to the change of project objectives and termination of the project after delivery of the equipment.	The high safety culture resulted from the high proficiency of all staff members who focused on routine and non-routine situations calmly. The operators were specialists in nuclear activities, aware of the risks and working with judgment. After overcoming initial misunderstandings arising from the need to meet the client's licensing requirements and the later start of work on the project (the contractor was executing a different project), communication was respectful on both sides. The operators had the operating procedures, and the work programme drawn up and knew them by heart. Daily coordination meetings in the presence of the daily decontamination operator, the client's project team, and dosimetry addressed issues of daily tasks, safety, RAW handling, work plan and corrective actions.
Decontamination results	The DFD EPRI decontamination process was not completed under D2 (prematurely completed in Phase 1), so we cannot evaluate its adequacy for chemical decontamination of WWER 440.	The desired results have been achieved concerning RAW production. The average removed activity achieved on SGs was 92.1%, and activity removed from the primary circuits was 98.15%.
Produced RAW	Another waste was produced: Large particulates from the interrupted decontamination caused a more significant production of high-activity particulate filters, and the DFD line had to be cleaned before work could resume.	Cleaning work and replacing used ion exchangers had to be done before the DFD line modifications began. RAW production was according to the planned activity parameters. A slightly higher amount of contaminated water was produced from the regeneration of the ionexes due to lower regeneration efficiency at higher temperatures. Insoluble particles were captured directly in the ionexes. The project included the fixation of ionexes. Contaminated waters were used for active grouting in a treatment centre.

5. CASE STUDY I: PROJECT D2

5.1. Sources of Information

The sources of information used to develop the case study are the technical specifications of the D2 project, EPRI assessment, and Project D2: Project completion report.

5.2. Background

From 2013 till December 2015, BIDSF project D2 Decontamination of the primary circuit was implemented by a consortium comprising OTNI (ONET Technologies Nuclear International SAS (France; lead contractor)), ROBO Piestany a.s. (Slovak Republic) and Chemcomex Praha a.s. (Czech Republic)). The consortium has been contracted to perform a full system chemical decontamination to substantially reduce radiation fields around the primary circuits of the reactors. The chemical decontamination was performed using the EPRI Decontamination for Decommissioning (DFD) process. The chemical decontamination application began on 9 March 2015 but has been suspended since 22 July 2015 due to sub-optimal initial results, including several system leakage events and higher than anticipated generation of particulate material. JAVYS has requested that the contractor modify the approach for the decontamination. However, the contractor repeatedly failed to redesign and application of corrective measures. This D2 project was terminated without achieving the original project objectives. The objective of the decontamination project D2 was to perform pre-dismantling chemical decontamination of primary circuits of both V1 NPP units to:

- Remove contamination from the primary circuit components to reduce dose levels around piping and equipment. The installation becomes more accessible this way, facilitating hands-on techniques for dismantling rather than the more expensive robotics or manipulators.
- Minimize the potential for spreading contamination during decommissioning activities.
- Reduce the contamination of components to such levels that they may be disposed of at a lower, and therefore more economical, waste disposal category.

Based on unsolved problems of the decontamination process, the project's scope was modified. The Consortium finished its activities with the hand-over of the decontamination equipment and training of personnel of JAVYS, a.s. Since the decommissioning process of V1 NPP could not proceed without decontamination of the primary circuits, it was necessary to identify and eliminate the failure's causes and plan the project's continuation.

During the repeated failures, several project assessments were carried out by JAVYS. Also, EPRI specialist Rick Reid commissioned a review by the EBRD, responsible for financing the project. Assessments consider the adequacy of applied methodology, equipment, and organisation, particularly concerning DFs in the steam generator, primary circuit, and pressuriser. The JAVYS project team and the EPRI specialist agreed that the conceptual approach was consistent with the technique used for similar applications (including equipment selection). However, the detailed design engineering level nor the contractor organisational structure was inconsistent with that applied for similar applications.

Based on the results of the assessments, JAVYS agreed on changing the scope of work and objectives of the D2 project and terminating the contract with the consortium by an agreement that ensures the continuation of decontamination using equipment designed, manufactured, and tested in the D2 project.

The implementation of the D2 project failed due to design and human incompetence; however, this resulted in the identification of needed improvements, which, when applied in the continuing D2-A project, led to the achievement of the objectives of the chemical decontamination project.

5.3. Description of implementation of Project D2

Based on lessons learned from other decommissioned plants, a decontamination scope was selected that does not include the reactor pressure vessel (RPV) and reactor internals. The decontamination boundary included the six Reactor Coolant Loops (RCL) of the Reactor Coolant System (RCS) for each one of the two reactor units. All major primary side systems, except for the RPV and the reactor internals, were included in the decontamination flow path: SGs, main coolant pumps, main gate valves, pressurizer, and primary coolant pipes.

The contractor of the D2 project - consortium proceeded with the implementation of the project according to the technical specifications of the D2 project, which divided the performance of the D2 project into four main phases, in the frame of which the individual tasks considering the main objectives of the project were solved:

- Phase 1: Study for adapting the DFD process to V1 NPP specificities.
- Phase 2: Preparation of detailed documentation and procedures.
- Phase 3: Preparation of chemical decontamination.
- Phase 4: On-site chemical decontamination.

Phase 1: Study for the adaptation of the DFD process to V1 NPP specificities

In phase 1, the contractor followed up on a technical offer that respected the requirements in the technical specification. The technical proposal of the consortium included a description of the decontamination process, including proposed systems line-up and usage of existing plant equipment, estimation of waste production, design of decontamination line with the use of inter-reactor connection "spider", use of existing plant equipment and systems during decontamination works, factory and on-site tests, DF monitoring. The most important outputs from this phase were:

A. The **Quality Assurance Plan (QAP)**, which defined:

- Scope of the project.
- Responsibilities and competencies – basic organisational structure of the project, organisational structure of the consortium project team, basic contact data on members of the project teams.
- Quality requirements general and transversal – project management, project schedule, communication, documentation management, record management
- Quality requirements in particular phases – licensing, design, engineering, purchasing, manufacture, commissioning, personnel training, and decontamination works.

B. The **inception report** including the following information on project management:

- Basic contractual data
- Schedule of payments
- Scope of works – division of the project into phases and tasks with their description
- Project organisation and human resources – description of project organisation structure, determination of contractor´s operation team and tasks and responsibilities for its members
- Baseline schedule with time planning of the project
- Risk identification and management, which were identified in the tender phase

- Identification of internal project interfaces and their management
- Approach to quality assurance
- Method of project progress monitoring and monthly progress meeting reporting
- Overview of DFD process – process description and decontamination strategy.

C. The **material compatibility report** identified in the report confirmed the compatibility of the DFD solution with the construction materials of the main cooling primary loop.

D. The **testing of representative samples (artefacts)** of the materials under the decontamination scope to demonstrate the feasibility of the proposed process and adjustment of relevant parameters (e.g., number of cycles) samples from the pipeline of coolant off-take collectors on the cold legs loop no. 4 unit 1 & 2 were cut off. These samples were used for testing by company Bradtec in its laboratory premises in Bristol. The pipe decontamination results confirmed the DFD process's success in cleaning pipe samples and transferring radioactive contamination to resins.

E. The **system interface analysis** identified the plant system's modifications required to perform the work. The study contained different connections needed during the operation of the DFD process and required changes in the employer´s equipment and operational systems.

F. The **process design report** describes the development and principles employed to design the DFD decontamination process for the PC in V1 NPP and the equipment necessary to perform the decontamination application. The content covers the following DFD Process information:
   - The DFD chemistry.
   - The decontamination strategy.
   - The decontamination application design.
   - An overview of the decontamination process system.
   - Process design principles – flow, temperature, pressure, radiological and chemical safety.
   - Details of the equipment to be employed on-site.

G. The **radwaste evaluation report**: Issues related to the estimated volume and types of byproduct RAW storage and transportation limits and conditions, the kind of regeneration acid used, and the pH level of the regenerated concentrate were solved after several technical meetings between members of the contractor and employer's project teams.

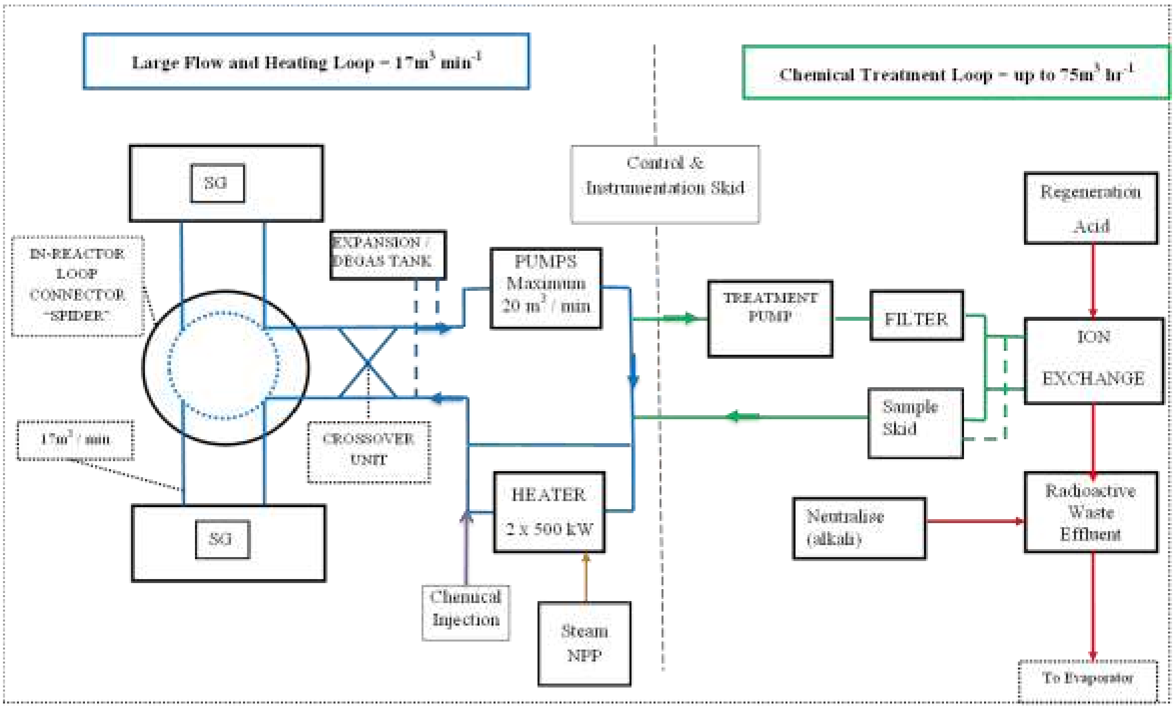

Figure 3: Functional scheme of DFD modular line with connection to double loop via RPV.

<u>Phase 2: Preparation of detailed documentation and procedures</u>

The results from phase 1 were adopted to detailed documentation submitted as an appendix to the application for approval of the work to Nuclear Regulatory Authority of Slovak Republic (NRA SR), and Public Health Authority of Slovak Republic (PHA SR). Detailed documentation comprises:

- Revised project schedule
- Process Design Report
- Material Compatibility Report
- Radwaste Evaluation Report
- Safety Analysis Report
- Complete Detailed Engineering documentation
- Health and Safety Plan
- Pre-operational Tests Procedures
- Pre-operational Tests Report
- Detailed Design/Engineering
- Interface Control Manual
- Licensing Plan
- Systems Interface Analysis
- Artifact Testing Report
- Inception Report

The employer started the licensing process according to Act No. 541/2004 Coll. (Atomic Act) on the peaceful use of nuclear energy according to point 5 of NRA Regulation No. 400/2011. The employer submitted the operating procedures or work programs related to these activities 30 days before work implementation, and on 22.09.2014, NRA SR issued approval for the execution of decontamination.
The employer applied for the decision of PHA SR according to Act No. 355/2007 Coll. on the protection, support and development of public health, and PHA SR issued the decision with approval of technological change on 29.07.2014.

<u>Permanent modifications of primary circuits</u>

Detail design is divided into two separate parts. The first part includes permanent modifications of the existing V1 technology, and the second part is related to the implementation of decontamination operation.

It was necessary to consider all routes and systems directly connecting to the PC pipelines for decontamination. Therefore, systems where uncontrolled leaks of the decontamination solution (including radioactive substances) could not be eliminated, or where drains and rinse could not be performed, were permanently separated - cut off and blinded before the start of decontamination. Detailed documentation for the performance of these activities divided by existing DPS was elaborated and executed.

Phase 3: Preparation of chemical decontamination

- **Procurement of consumables required for the connection and operation of the contractor equipment and additional equipment necessary for the specific decontamination**

  Individual equipment of the DFD line and hardware consumables (hoses, gaskets, cabling, mock-up loop, resins, laboratory devices, toolboxes, filters, sensors, contingency spare parts) were delivered to the employer´s premises in IP containers in July 2014. Later, a water shielding wall was delivered. Teledosimetry equipment was supplied and installed before the commencement of decontamination works.

- **Chemicals procurement and transport to the site, following the applicable quality certifications and transport safety regulations for hazardous materials**

  All chemicals required for decontamination were purchased from the Slovak supplier, which held appropriate transportation authorizations and attests to valid legislation to the employer´s premises. Decontamination chemicals were transported and stored directly in the reactor hall to be immediately in hand for the decontamination process, which was planned to run continuously for seven days for each PC double loop. The first partial delivery of decontamination chemicals occurred in January 2015. A few chemicals required for laboratory operation, which were purchased directly in France, were delivered to the employer´s premises as well.

- **contractor's decontamination equipment and personnel mobilization, including the equipment transport permit arrangements and personnel qualification according to V1 NPP requirements for external contractors**

  Individual equipment of the DFD line was transported from France to the employer´s premises in eight IP containers and stepwise positioned in the reactor hall in July 2014. Material for interconnecting equipment – spider and shielding bottom plate was transported to the reactor hall, and installation was carried out in August 2014. All Consortium workers participating in the works within the D2 project took part in the required training and held all valid certificates for works in the employer´s general competence certificate on psychical competence for entry to a nuclear facility.

- **Qualification/ training of the personnel involved in the decontamination execution**

  In April 2014, the consortium workers participated in training dedicated to operating the DFD line equipment. Later, in July 2014, all Consortium workers were familiarized with operational procedures for chemical decontamination and were trained on the operation of the DFD line and then directly at the D2 workplace in April 2015.

Phase 4: On-site chemical decontamination

Removal of the reactor head and reactor internals from the reactor pressure vessel and location in the projected places in the reactor hall was performed at the second reactor unit. Installation and set-up of contractor decontamination equipment at the Bohunice NPP site included final positioning of DFD skids, shielding wall and interconnecting pipeline, installation of platforms and equipment to RPV shaft, installation and connection of pipelines/hoses and connecting cable to the employer´s connecting points, installation of feeding and controlling cabling, installation of probes for measurement of DF and monitoring of DFD equipment, modifications of pipelines of pressurizer system.

Pre-operational tests, including pressure test of new DFD equipment and pressure test of all decontamination circuits, including the V1 primary circuit, were performed for DFD equipment, for interconnecting equipment – spider. Comissioning using demineralized water was performed on 22.-28.01.2015 and confirmed the tightness and functionality of DFD line equipment connected to loops two and five.

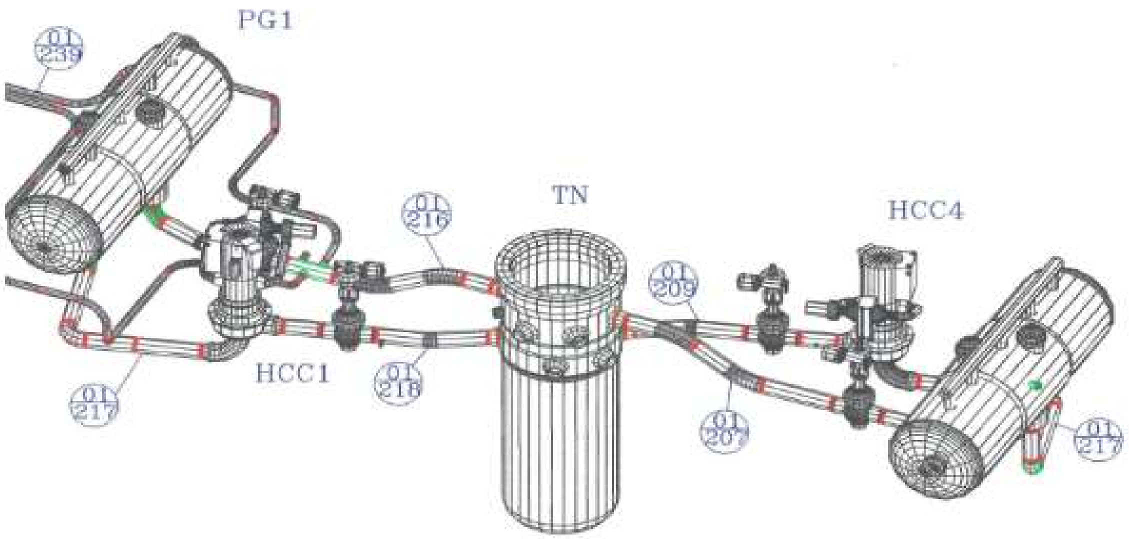

Figure 4: Doubleloop configuration of the primary circuit.

Figure 5: Spider prepared for insertion into the RPV (left) and insertion (right).

Decontamination of loops 2 and 5 started after the removal of several incidents (presence of air bubbles in the PC system, decrease of pressure in the spider´s sealing bag, leak on the spider´s nozzle) on 09.03.2015 according to the approved program of works for decontamination activities V1 NPP Unit 2. The double loop was filled, and the reheating process started after eliminating the leaks at the double loop-spider connection pipe and implementing corrective measures (pressure control in the interspace was installed).

On 11.03.2015, a leak of radioactive liquid from the heater and displacement of the spider from the RPV occurred. Works were stopped until the contractor performed corrective measures. After a successful pressure test undertaken on 28.05.2015, an inactive testing operation followed, during which a leak from the heater plates occurred. After analysing leak causes and change of the heater plates, a pressure test was repeatedly performed, followed by inactive testing operation on 17.-21.06. 2015.

Decontamination was re-started on 23.06.2015. Due to the high dose rate on the filter units, decontamination was stopped on 25.06.2015, and consequently, a single recirculation through filters was allowed to catch solid particles that occurred in the primary circuit system. Decontamination continued on 20.7.2015.

Finally, decontamination works were stopped on 22.7.2015 due to a leak of radioactive solution from two employer´s valves and a high dose rate at the D2 workplace. Decontamination of loops 2 and 5 was an active test of the system decontamination of the primary circuits of NPP V1. The active test was not completed for safety reasons.

During this phase, the JAVYS project team identified the inability of the contractor to perform the system decontamination and, therefore, terminated Project D2 with a project amendment in agreement with the contractor. The addendum allowed the decontamination line to be put into a safe condition and the decontamination equipment to be taken into the employer's ownership. The contractor acknowledged that it could not implement such a project - system decontamination.

Premature termination on-site chemical decontamination primary circuits V1 NPP

Project D2 has been completed in the active testing phase. It was necessary to put the equipment in a safe condition. According to the original scopes, the contractor was supposed to implement in the final stage of the project a final flushing of affected systems, including RPVs, if their conditions are affected as the result of the decontamination process and activities, including specific treatment for dead-ends and localized hot-spots and draining the systems within the decontamination boundary.

Since the project's original objective – decontamination of the primary circuit – was not fulfilled and scope of the project was substantially modified by Amendment no. 6, final flushing works were executed in a smaller scope as planned.

After the stop of decontamination, the DFD solution was drained from the system to the employer´s tank. The DFD line was safely shut down on 30.7.2015 after finishing regeneration, sampling, drainage of the regenerated concentrate and drainage of the secondary part of the DFD line. Due to Amendment no. 6 to the contract, flushing of the decontaminated loops 2 and 5 was not performed, nor were cleaning works that would eliminate occurred hot spots in the DFD loop and PC loops 2 and 5.

The state of the loop was similar to that achieved on the artefact test samples after about 8-10 hours of decontamination. It would be expected that the decontamination of the whole system would take a little longer than the artefact test (which is done in perfectly controlled laboratory conditions). Despite months, the application of the process in proper conditions had not yet been more than 48 hours, and no oxidation cycle had yet been performed. Accordingly, the process worked on the primary circuit (internal surface of the loops) surfaces, as in the artefact test, albeit for a very short time in proper conditions. High-flow areas of the system had already been quite effectively cleaned. The average DF led to 4.95 in absolute, which means more than 80% relative progress.

The spider was removed, and a mock-up was set in place. The entire equipment was full of demineralized water, residual particle filters were changed, and resins were regenerated. A precise status was drawn up between the employer and the consortium describing all transferred equipment, the radiation protection situation and the result of the employer´s team training.

5.4. Evaluation of the Project D2 Aspects

Engineering and chemistry

The world's experience from previous decontamination has been applied in this phase. The feasibility of the prescribed decontamination strategy, i.e., decontaminating the primary circuit without the RPV using the EPRI decontamination method for DFD, was verified. EPRI DFD chemical decontamination dissolves surface contamination, and the process is based on using a dilute fluoroboric acid (HBF4) solution. For stainless steel surfaces contaminated in the high temperatures and pressures of a PWR to solubilise the enriched chromium content in the stainless steel oxide layer, potassium permanganate is dosed.

The product solution contains manganese dioxide, which can be removed by adding oxalic acid to produce soluble manganese ions and carbon dioxide from the oxalic acid, which is vented to the atmosphere. The metal ions manganese and chrome are removed from the solution to an ion exchange resin. However, by processing the spent acid (within decontamination solution) through an ion exchange column, the dissolved metal ions and radioactivity are removed, and the acid is regenerated back to its original concentration, thus allowing the acid to be returned to the system where it can be used to dissolve more surface contamination.

To apply the decontamination solution while maintaining the scope, the contractor designed and implemented a double-loop decontamination for which he created, fabricated and tested the interconnecting piping for the TNR spider bypass and the modular DFD line. This design allowed for efficient flow through the double loop, achieving the physical and chemical parameters of the decontamination solution while minimizing the volume of the decontamination solution, yielding an effect for flow assurance and heating and reducing the chemicals used. The equipment design has been developed from existing modular equipment in the UK. Additionally, new process equipment (main circulation loop) was explicitly deployed to undertake the decontamination of the V1 NPP PO of Unit 1 and Unit 2 reactors.

Connecting the loops with a spider pipe was the right choice. Here, the principle was applied as in the chemical decontamination projects at Maine Yankee, where the "spider" had six "legs", and at Connecticut Yankee, where it had eight. In the case of V1, it was a double loop decontamination - four legs, which was efficient in terms of the size of the decontaminated circuit in terms of heating times, cooling times, the application of the decontamination solution, and the basic goal of achieving consistent flow in all parts of the double loop.

The modular decontamination line will allow the transfer of individual modules from one block to another without time loss and the eventual replaceability of individual components and rapid maintenance. The contractor managed this phase, as verified by FAT at the manufacturer and tests on the first connected double loop.

Artefact testing demonstrated the effectiveness of the proposed use of the EPRI Decontamination for Decommissioning (DFD) process to perform the chemical decontamination. Artefact testing was performed on pipe sections taken from the cleanup system supply lines from one loop of each reactor. After completion of the equipment's set-up and pre-commissioning testing, the initial double-loop chemical decontamination application began on 9 March 2015.

During a short period of active DFD line operation and failure, the DFD line design improvement needs were identified in the following areas:

- **Off-Gas System and Pressure Control**
  During the operation of the DFD line from 9 March 2015 to 11 March 2015 and then in June, the need to improve the venting of the double loop during the filling process and also during the chemical reaction process when gas generation occurs was identified. There was also a lack of pressure monitoring on the different parts of the double loop. The imperfect venting of the system was causing vibrations in the double loop, also on the modular DFD line, and was also affecting the spider connection to the reactor nozzle. Mainly, given that the plant is being decommissioned, there are several relatively simple modifications for the installation of venting pipes that can be made to improve significantly venting capability.

- **Inappropriate choice of material to cover the plates of the plate heat exchanger**
  The surface of the individual plates of the exchanger was coated with Teflon, which was intended to provide higher resistance during the flow of the chemical solution through the exchanger. The Teflon was disturbed by the abrasive particles, and the exchanger sealed. Replacement of the exchanger plates was quickly resolved, and the fault was rectified. Plastic shutters were installed in case of leakage. However, the question remained about the suitability of using this type of exchanger for the DFD chemical decontamination process.

- **Filtration System**
  The filtration system of the DFD line included not only ion exchange columns but also particulate pre-filters. Replacing these proved critical in terms of high dose rates. Design of the filtration system for the decontamination was based on an assumption that minimal particulate would be generated during the decontamination. This assumption was wrong, contrary to industry experience that shows 5 to 10 per cent or more of the plant oxide may be removed as particulate. Unscheduled interruption of decontamination, failure to complete the decontamination procedure, and exposure of the disturbed surface to air for about two months also contributed to the production of more particles during the decontamination of the first double loop. Consequently, the installed filtration system was not designed to manage the larger-than-anticipated quantity of particulate observed during the application thus far. It should be noted that even if the original prediction of particulate release were accurate, the unshielded filter design would substantially limit the quantity of material that could be effectively loaded on the filters.

<u>Plant modification</u>

All planned modifications of both primary circuits within the decontamination – necessary cutting and blinding of pipelines, which should prevent undesired spreading of decontamination solution and therefore spreading of activity in Units 1 and 2 at V1 NPP (the so-called dead legs), were implemented by the contractor of the D2 project in line with the submitted and approved detailed design. The connection of the DFD line to the contaminated wastewater system and the modification of the route for the transport of depleted ionex were implemented. The extraction above the dosing and venting tank was also implemented. Connection of the DFD line to the demi-water and pressurised air pipelines was carried out. Additional simple modifications for improvement of ventilation of the double-loop were needed to install as mentioned in the “Engineering and Chemistry” section.

<u>Review of contractor’s procedures</u>

A thriving chemical decontamination is carried out by an experienced team that follows procedures but at the same time has mastered these procedures and non-standard situations. A detailed manual and training are essential if the operating unit is inexperienced. A detailed operating manual should result from a completed active trial where the basic manual is supplemented according to the trial facts. In this case, the active test was never conducted. The operating procedures and on-site operations have been reviewed by specialist EPRI Rick Reid, who identified points to be improved:

- **Inadequate detail in operating procedures**
  The level of detail in the procedures for system setup, testing and operations is not consistent with that included in procedures used for field application of projects of similar scope and complexity. Detailed, step-by-step procedures are critical to ensuring project safety and effectiveness. Moreover, detailed procedures are required to support oversight by personnel less familiar with the decontamination process (such as station supervision).

- **Lack of up-to-date piping and instrumentation diagrams (P&IDs)**
  Several system modifications (for example, installation of additional pressure instruments and modification to the high point vent system) are not reflected on the current system drawings. It is expected that the system operators would use the drawings in conjunction with the operating procedures, and it is important that both the drawings and procedures are up-to-date.

<u>Review of on-site operations, process controls, and operational team</u>

Chemical decontamination implemented with the unique design for the primary circuit of the specific type of nuclear power plant is a complex project. During the design phase (Phase 1 and Phase 2), the experienced specialists designed the decontamination concept, DFD modules, spider, and hydrodynamic calculation of the decontaminated loop. Good quality documents were produced during the first phase, which resulted in the approval of the JAVYS and Slovak authorities. After two years of the project started, the experienced specialists left the consortium, which was finally the main reason for the failure of the on-site operation of Project D2.

- **Onsite organization**
  For a project of similar scope and complexity, a fully staffed 24-hour operation requires two shifts, an experienced supervisor, a professional process chemist, and a minimum of two operators for each shift. Even during the operation of the DFD line, the chemists were not on site for the entire operation. More importantly, it would be expected that these personnel would be on-site during equipment testing through to the end of the decontamination process application and would not be replaced unless under exigent circumstances. It would be further expected that by experience and use of the fully developed and detailed operating procedure, the personnel performing the application on-site would be qualified to make all process decisions in real time without the need for external consultation. Thus far, the on-site organization has been subject to changes in key personnel, and personnel experienced in process application are not consistently on site. The lack of detailed procedures exacerbates this. It should also be noted that the onsite organization should include key station personnel intimately familiar with the project, including a station project manager for each shift that serves as the primary contact with the contractor.

- **Poor communication between consortium members**
  The individual members of the consortium found it difficult to reach agreements with each other while constantly worrying about responsibility for the work as a whole. Everyone was strictly focused on their part of the implementation, which negatively affected the overall progress, causing delays in the project.

Waste generation

During the short, non-standard operation, wastes other than those planned by the Technical Specification and the RAW Production Plan of the D2 Project were produced. The resulting wastes had to be dealt with in non-standard ways. The liquid wastes had higher activity than the allowable limit for transport by the available transport container. For this reason, two containers and a transport vehicle had to be procured. Also, the problem with the produced particulate filters had to be solved, which made more than the plan for the whole decontamination during the short operation.

Disrupted decontamination D2 project generated volumes of RAW:

- **Liquid RAW**

  Regenerated concentrate from the decontamination process drained to the JAVYS tank constitutes approx. 132 m3.

- **Solid RAW**

  During decontamination, 109 filters with different dose rates were generated. 35 filters, whose dose rate was higher than 10 mSv/hour, were placed in special packages and transported to Mogilnik. 74 filters with a lower dose rate than 10 mSv/hour were inserted into the employer-licenced metallic drums for storing RAW, filled with concrete debris and handed over for further treatment by compaction and cementation).

Total activity removed from the affected systems

The global activity removed on the 14th of August 2016 was 90 GBq put inside resins and regeneration liquor. A part of the activity has been put in mechanical filters, estimated at 2 GBq. This activity was removed only from the first double-loop.

5.5. Results

As of August 2015, a solution was being investigated for the continuation of decontamination, as this was an activity on the critical path of decommissioning. The reality of the situation was recognised, and a correct assessment was made that the contractual relationship with the D2 contractor needed to be terminated by agreement. The agreement on ending the D2 project resulted in a project amendment in March 2016, whereby JAVYS owned the DFD line and selected personnel were trained to operate the decontamination line. By this date, an essential task for the D2 project contractor was to treat and hand over to JAVYS the RAW (produced mechanical filters) from its previous operations.

Implementing the decontamination of the primary circuit, in particular, requires experience from previous full-circuit decontamination. Therefore, it was necessary to continue the performance of the decontamination of the primary circuit by a selected qualified and competent contractor. The opinion of EPRI was also in favour of this option. EPRI dated 15.1.2016 stated:

- The performance of decontamination through an alternative contractor who will perform decontamination using the supplied decontamination equipment is considered a feasible approach.
- A detailed project review - design of the decontamination equipment, improvement of the decontamination procedures (development of a comprehensive operating procedure) and modifications to the decontamination system must be performed before decontaminating the primary circuit of NPP V1. EPRI strongly recommends that the detailed project review be performed by personnel with direct experience in performing system chemical decontamination at nuclear power plants." i.e. modifications and review of the plant are necessary (thinking of the decontamination solution, propose changes to the filtration part of the plant with emphasis on the doses received during plant operation and the processability of the RAW produced).
- EPRI also strongly recommends that the engineers responsible for developing operating procedures and system modification designs and the key experts on the executive team (project manager, shift manager, and lead chemists on each shift) have direct experience in system decontamination.

A market survey was conducted seeking a **contractor with direct experience** in the whole system chemical decontamination, the EPRI DFD process.

A sole bidder tender was applied because of a combination of conditions: an unsatisfactory response to open or selective tenders had been carried out following the EBRD's procurement rules, a product can only be provided by a single supplier because of exclusive capabilities or rights, and it was a case of extreme urgency brought about by unforeseeable events not attributable to the procuring entity.

Before the continuation of decontamination works, the **summary of the achieved status of V1 NPP** primary circuit decontamination was the following:

- The effectiveness of the decontamination method EPRI DFD solution was tested in the laboratory on two samples taken from the V1 NPP primary circuit.
- Based on testing - project documentation was prepared for the implementation of decontamination works (Artefact Testing Report, Process Design Report, and Radwaste Evaluation Report). Developed documentation for already implemented decontamination activities will serve as a base for continuing and implementing the V1 NPP primary circuit decontamination.
- All planned modifications of the primary circuit within the decontamination – necessary cutting and blinding of pipelines, which should prevent undesired spreading of decontamination solution and therefore spreading of activity in Units 1 and 2 at V1 NPP (the so-called dead legs), were implemented by the contractor of the D2 project in line with the submitted and approved Detailed Design.
- DFD decontamination facility was designed, manufactured and installed, and interconnecting equipment – spider, which can be used for decontamination works. The overflow, pressure, and decontamination fluid temperature were achieved by employing this equipment.
- The weaknesses of the project were identified, and learning of critical aspects to proceed were identified, based on which the technical specification was revised, identifying as initial status: the delivery of a modular line to be checked and analyzed for the use of each module and the design of the modification for the safe implementation of decontamination.

6. CASE STUDY II: PROJECT D2-A

The D2-A case study, built upon Project D2, allows comparison between projects in selected aspects and highlights what is essential for this type of project.

6.1. Sources of Information

The sources of information used to develop the case study are the technical specifications of the D2-A project and the project completion report with the evaluation of the program of works for decontamination of primary circuit V1 NPP.

6.2. Background

BIDSF project D2-A, “Decontamination of the primary circuit - II. Stage”, was defined due to the need to complete the chemical decontamination of the primary circuit on both V1 NPP units at Bohunice nuclear power plant site. The decontamination activities for primary circuits of V1 NPP started within the implementation of the D2 project "Decontamination of the primary circuit", which had not been completed. Chemical decontamination was carried out using the EPRI decontamination process for pre-dismantling decontamination and commenced on March 9, 2015. The chemical decontamination was aborted on July 22, 2015, due to non-optimal behaviour, including several system leaks and insoluble particle production that was higher than planned. Based on unresolved decontamination issues, the project's scope was changed, and the consortium terminated its activities by handing over decontamination equipment and training the personnel of JAVYS Project D2-A, “Decontamination of the primary circuit - II. Stage”, follows the previous D2 project.

Company Westinghouse has proposed its patented NITROX-E process with the subsequent DFD decontamination process (according to EPRI) to decontaminate the PC loops of both reactors (VVER type) at V1 NPP. The decontamination was designed to optimize the chemical process and to use the supplied DFD line delivered in the scope of the D2 project. Both criteria were explicitly applied to the V1 NPP project for mobile devices that can be used in other power plants, WWER, in the future. Westinghouse has then implemented modifications and adjustments of already supplied decontamination equipment, and equipment developed by Westinghouse replaced some parts of the decontamination line. Thanks to experienced staff, Company Westinghouse decontaminated both V1 NPP reactors. The decontamination works were completed in December 2017 before starting dismantling and fragmentation works on primary circuits V1 NPP.

6.3. Description of implementation of Project D2-A

The D2-A implementation is built upon the achievements of the D2 project. It used the results of the design and construction phase of the modular DFD line and the licensing documentation. The D2-A contractor reviewed all the results of the D2 project, and the weaknesses of the project were eliminated. The contractor of D2-A could use equipment delivered in the scope of the D2 project.

<u>Preparatory phase</u>

- **Engineering and licensing process**

  The D2-A contractor had an easier starting position because the complete licensing documentation was prepared within the scope of the D2 project. Due to the uniqueness of the experts at this stage, the project was delayed because the experts were conducting a different NPP decontamination. At the end of March and beginning of April 2017, the contractor completed the documentation in close cooperation with the employer´s technical experts in required quality documentation, including all detailed information necessary for issuance of the decision from the NRA and PHA of the Slovak Republic.

The engineering tasks included the following:

- Development of the programs of works:
  - Engineering review
  - Remove the hot spots on DFD equipment by cleaning the DFD line by dissolving/removing particulates
  - Sample collection from the SGs
  - Inspection, modification and partial relocation of the DFD line
  - Decontamination of the primary circuit at both V1 NPP units
  - Removal and processing of used ion exchange resins
  - Demobilisation of the DFD line
- Management of transport of the Samples from the SG (transport to USA)
- Delivery of the additional DFD line equipment on-site
- Development of the Analysis of the status achieved during the implementation of the D2 Project in the period 2013-2015 and independent Safety analysis
- Preparation of the Operational procedures and programs for the execution of decontamination
- Preparation of the Detailed Design and licensing documentation to obtain permissions according to legislative requirements (Act No. 541/2004 Coll., 355/2007 Coll.), including revision of the thermo-hydraulic analysis
- Modifications of the DFD line according to the approved Detailed design documentation.

On 26.7.2017, the approval for implementing the BIDSF D2-A became effective.

- **Procurement of goods and works**

Westinghouse prepared, tested and packed the chemical decontamination equipment and shipped it to JAVYS site during the engineering phase of the project. The decontamination equipment was tested for functionality, and leaks were checked by connecting it to a water source. The electric heaters were inspected to ensure operability. Instrument and electrical tests were also performed. Field-proven hoses and components (D2 project) were checked to ensure all water was drained and radiation and contamination levels were acceptable following NRA SR and JAVYS, a.s. requirements. Equipment was re-tested for relevant pressure tests, the electrical revisions were performed, and, finally, the safety equipment certification was carried out. Recertification of the line was repeated after it was partially relocated from the Unit 2 to the Unit 1.

- **Changes in the technology of the original DFD line**

One of the main tasks at the beginning of the project was the identification and specification of problems that occurred during the implementation of the D2 project. These were the main identified problems and actions that had to be taken to eliminate the problems:

- Plate heat exchangers had not been tested and were replaced by two 500 kW electric heaters designed for chemical decontamination and verified under real conditions.
- Too many filter inserts have been produced. We have faced this problem in three ways. First of all, it was avoided that sulfuric acid was mixed with DFD reagents, resulting in many solid particles (precipitations). Further, by applying the NITROX-E process, the removal of oxide deposits before using the DFD process to achieve the dissolution of the parent metal is achieved. Thirdly, the filter columns have been replaced by ion exchange columns constructed as a deep-bed filter (i.e. they capture dirt throughout the volume, not only on the filter surface).
- The imperfect design of the venting system had caused unstable flow conditions and damage to the device. Separate venting tanks have been installed to deaerate SGs and the whole system. This has been achieved by installing special single-purpose venting valves on the SGs vent pipeline and introducing them into the ventilation tank.
- The operation and control of work in the controlled area and the chemical process were not adequately followed. The remedy for this problem was that during the D2-A project, Westinghouse specialists were present at the workplace, supervised the work and monitored the chemical process. All work has been done regarding approved detailed work operations and procedures.

- **Analysis of the samples from the steam generator and set up of the decontamination process**

  The sampling of the tubes from the steam generator 61, from the part of the heat-exchange pipeline of the steam generator (stainless steel 321, austenitic Cr-Ni steel), were then analysed in Westinghouse's RSC laboratories in Richland, Washington. The main objective of the tests was to determine the optimal sequence of NITROX-E and DFD decontamination cycles for removing the oxide layer from steam generator tubes.

  As the result of the test for the decontamination of the primary circuit of NPP V1, it was then recommended to apply three cycles NITROX-E, with a fourth cycle as a possible option if needed, followed by one cycle of DFD or one more DFD cycle if required. Based on its results, the subsequent decontamination of both V1 NPP units was successfully executed. The numbers and types of individual cycles were performed based on control measurements of the dose rates at defined locations as well as the success of the previous cycle.

- **Removal and processing of ion exchange resins from the D2 project and removal of hot spots in the DFD line**

  At the beginning of the project, it was necessary to prepare a DFD line for the decontamination process to remove all hot spots and ion-exchange resins used during the D2 project. At the bottom of the Degassing tank, the presence of hot spots with dirt and sludge, with a dose rate of more than 130 mSv/h, was confirmed by monitoring. From the previous decontamination (project D2), 4 m^3 of ion-exchange resins remained on-site. A separate program was prepared for the sampling and analysis of ion exchange resins, and a different program was prepared to treat the ion exchange resins with the sludge from the venting tank.

  This works were made before modifying the DFD line. 41 drums were produced with fixed ion-exchange resins produced in the D2 project. Finally, all the drums of the final solid product were transported to the facility for treatment and conditioning of RAW, where they were inserted in the FCC and grouted in a cement matrix.

- **Modification of the DFD line**

  Within the DFD line modification, a part of the DFD lines equipment by the D2 project was dismantled and placed in the assigned location. Subsequently, the equipment supplied by Westinghouse, the module and pipeline interconnection, the updating of the necessary electrical revisions, the pressure test and the equipment certification by certification company were installed. Modification of the DFD line consisted of the following activities:

  - Removing two pieces of original steam heaters and replacing them for two electric 500 kW heaters.
  - Removing the module with the mechanical filters and putting them in the assigned place.
  - Removing the original ion-exchange module and replacing it with the new module.
  - Installation of a new Venting/Mixing Tank.
  - Installation of new adjustable pipes to connect the spider and its insertion into the reactor.
  - Updating the operating panel software and setting up the entire control system.

All works in the preparatory phase were implemented per the relevant programs of works. The initial phase also included developing the detailed design and corresponding applications to be submitted to the NRA SP and PHA SP. It was possible to start decontaminating the primary circuit in both V1 NPP Units after obtaining the necessary permits and decisions from the regulatory authorities.

Implementation phase

- **Decontamination of the V1 NPP Unit 2**

  Within the decontamination, the individual double-loops of the PC at Unit 2 were decontaminated in the following order - 1 and 4, 3 and 6, 2 and 5 (previously decontaminated as part of the D2 project). The decontamination of the Pressurizer and Relief tank (Bubble tank) at Unit 2 was carried out, and finally, the decontamination of the Pressurizer at Unit 1 (Relief tank at Unit 1 was not decontaminated due to the low level of contamination found during the initial dose rate monitoring).

  The initial predicted number of cycles for one decontamination circuit (double-loop or Pressurizer with Relief tank) was 3 cycles of NITROX-E and 1 to 2 cycles of DFD. The number and incorporation of decontamination cycles were operatively adjusted as necessary depending on the level of DFs achieved, respectively, removed contamination levels. Implementing these additional cycles was subject to mutual agreement between the contractor and the employer.

  Decontamination activities of PC loops at Unit 2 and Pressurizer with Relief tank at Unit 2 and Unit 1 of the V1 NPP continuously followed the completed active commissioning, which was applied one cycle of the NITROX-E process to the double-loop no. 1 and 4. Subsequently, the active commissioning results were evaluated; it was continued on the same double-loop of the PC (no. 1 and 4) by applying the successive 2 cycles of NITROX-E. At the end of the third NITROX-E cycle, two DFD cycles were applied. This was followed by cooling the solution below 55 ° C, draining the system, dismantling the spider from the original double-loop and attaching it to the next double-loop, where the decontamination process was repeated.

  Similarly, within the decontamination of double-loop no. 3 and 6, 5 cycles NITROX-E and 1 cycle DFD were performed. As part of the decontamination of double-loop no. 2 and 5, only one NITROX-E cycle was completed, as the decontamination of this double-loop was partly done within the D2 project.

  After the decontamination of the individual double loops, the pressurizer and relief tank at Unit 2 and then the Pressurizer at Unit 1 were decontaminated via a separate circuit connected through Module 17. None of the DFD line modules were relocated for decontamination of the pressurizer at Unit 1. In the decontamination of the pressurizer and relief tank at Unit 2, 2 cycles of NITROX-E and 1 DFD cycle were performed. Only one cycle of NITROX-E was performed in the framework of decontamination of the Pressurizer at Unit 1.

- **Decontamination of the V1 NPP Unit 1**

  After transferring part of the DFD line to Unit 1, returning the reactor internals to Unit 2, and removing reactor internals in Unit 1, double-loop decontamination in Unit 1 continued. Individual double-loops of the Unit 1 primary circuit were decontaminated in the following order – double-loops 1 and 4, 3 and 6, and 2 and 5.
  As part of decontaminating the double-loops 1 and 4, 3 cycles of NITROX-E were performed. As part of the decontamination of the double-loops 2 and 5, 2 cycles of NITROX-E were performed. As part of decontaminating the double-loops 3 and 6, 3 cycles of NITROX-E were performed. During the individual decontamination cycles, cation-exchange and anion-exchange columns were depleted. Regeneration was performed as required to recover the effectiveness of the ion exchange.

  On 6 December 2017, the chemical decontamination of both units was completed. The separation of the cold PC loops from the TNR at Unit 1 was performed by cutting and welding the stainless steel plates at the designated locations after the decontamination works were completed. After separating the cold primary circuit loops, the internal structures were inserted into the reactor, a rotating platform was placed on the sealing ring, and a reactor shaft protection lid was installed.
  After decontamination, the ion-exchange resins from the columns were pumped into 200L MEVA drums, which were processed by fixation into the SIAL matrix. Then, the DFD line was dismantled; its parts supplied by Westinghouse were packed into transport ISO containers. The original DFD line and its relevant equipment, mobile laboratories, part of the reactor hall and spider were returned to company JAVYS, a.s. at the end of the project.

Figure 6: Chemical dosing into the Venting/Mixing Tank.

Figure 7: DFD line at Unit 2 V1 NPP.

Figure 8: Measurement of dose rate after individual decontamination cycles.

6.4. Evaluation of the project D2-A aspects

Engineering and chemistry

At this stage, the contractor WES proceeded quickly and confidently, as it was intimately familiar with the process of chemical decontamination of the PWR circuits and the associated risks. This phase corresponded to two conditions: the use of D2 modules to the maximum extent possible and the application of the EPRI chemical process on which the line was built. Before signing the contract, WES had already advised using the Westinghouse NITROX-E process in combination with EPRI DFD. As a prevention for failure, as in the case of D2, WES made measures:

- NITROX-E / EPRI DFD combination
- Westinghouse experts on-site for decontamination
- Engineering/Procedural/Validation Controls to prevent the addition of sulfuric acid
- Increased IX flow capacity to maintain low metals in solution
- IX resin used as a filter bed
- Better system design to minimize equipment failures

The NITROX-E process consists of the cyclic application of oxidizing and reducing chemistries applied as different solvent steps to dissolve the deposited and grown-on oxide film. The oxide film contains the entrapped radionuclides that cause elevated dose rates throughout the system. The NITROX-E process has been demonstrated to be effective at dissolving most stainless steel oxide films.

The oxidizing step is typically applied first in the NITROX-E process. The oxidizing solvent used in the NITROX-E process generally is a dilute solution of potassium permanganate applied under acidic conditions with nitric acid. The nitric acid permanganate solvent is effective for the dissolution of chromium-containing oxides for decontamination of subsystems in commercial nuclear power plants. The reducing solvent used in the NITROX-E process is a dilute oxalic acid solution.

The NITROX-E process is applied at approximately 90°C. The NP oxidizing step is used with no ion exchange online. As the NP step continues, it generates solid manganese dioxide as a reaction product, or byproduct, of the reduction of permanganate. The oxalic acid phase is applied in a regenerative mode by continually passing the solution through cation exchange resin to remove dissolved metals/activity and regenerate the oxalic acid. Using the solvent in this manner reduces chemical usage, maintains low system radiation levels, reduces solvent corrosion, minimizes the risk of metal-oxalate precipitation, reduces waste generation and reduces carbon dioxide generation during the byproduct destruction phases of the process. After the oxalic acid step, a stoichiometric amount of permanganate is added to oxidize the residual oxalate to carbon dioxide.

> The process of complete chemical decontamination usually consists of several phases:
>
> - An oxidation step is generally applied at the beginning.
> - Carrying out the dissolution of the deposited and accumulated oxide layer.
> - A reducing solvent reducing agent and a complexing agent cause reductive dissolution of the iron-containing oxides.
> - Filtration on ion-exchange columns.

One NITROX-E cycle comprises an NP step, an NP destruction step, an oxalic acid step and an oxalic acid destruction step. Each NITROX-E cycle requires 8 to 14 hours to complete, with variances determined by chemical trends monitored with routine sampling. The DFD process is described in part 5.4.

Because WES had agreed to the condition of using the supplied modules in D2 during the initial contract negotiations, he had to review them and decided to replace the problematic modules with his best practices. Overall, the design changes were aimed at simplification:

- Replaced plate heaters with electric ones and the ion-exchange columns with their own required a new electrical connection to the reactor hall.
- The automatic chemical dosing was replaced by an open mix and vent tank module, through which the operator manually dosed chemicals and took samples, and the module also served to vent the system.
- The module connections and transfer to unit 1 were handled primarily by its safe, robust hoses with quick connections.

- Developed and implemented a simple analysis for the improvement of the venting.
- It installed its program and algorithms to remotely control the DFD line from the control container.
- Other equipment, including the in-container lab and modifications, were sourced from D2.

Before starting work, the entire line was tested electrically, pressure and functionally.

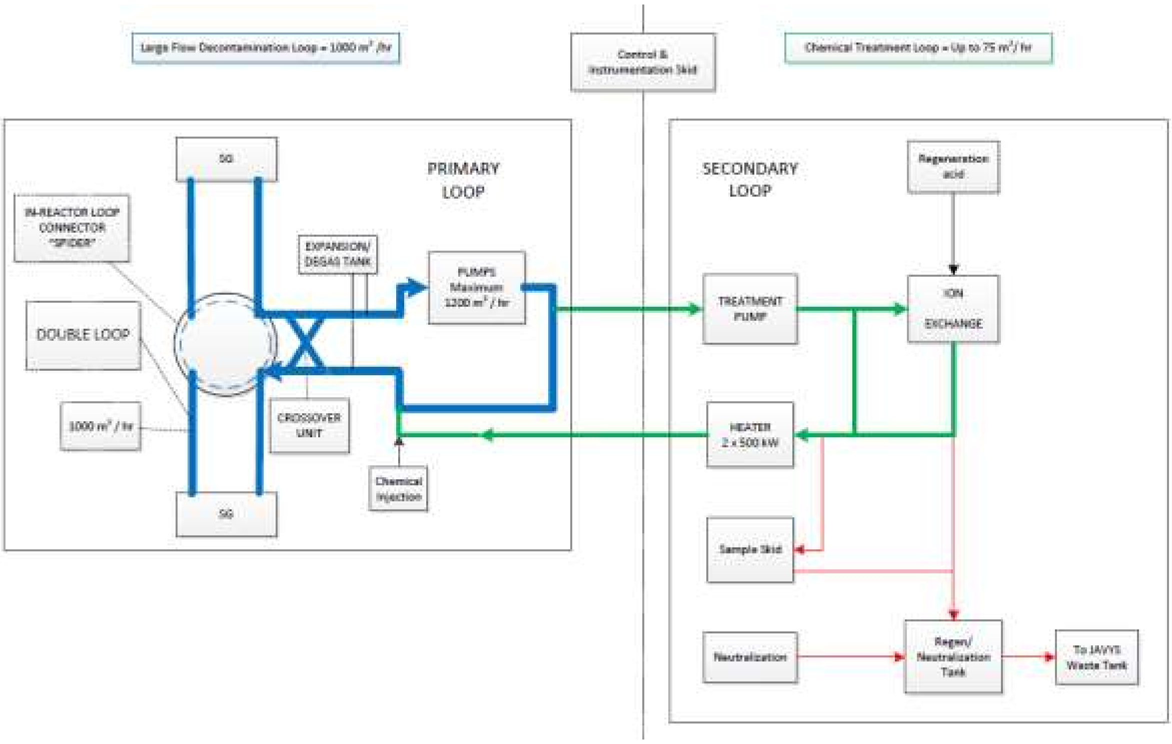

Figure 9: Functional scheme of DFD modular line modification by D2-A contractor.

Plant modification

Project D2-A benefited from the modifications and connections to the media implemented in D2. Only the electrical connection for the WES heater and the venting improvements were implemented in this project. In addition, the leak source at the DN50 primary circuit interconnect fittings was eliminated.

Figure 10: Modification of the blind pipe of the low-pressure emergency filling of the primary circuit.

<u>Review of the on-site operations, process controls, and operational team</u>

The smooth on-site operation resulted from a rigorous preparatory engineering phase and specifying the chemical process according to artefact tests. Based on the preparatory phase, a detailed procedure was developed for decontamination performance, emphasising operational safety. The regulation determined the responsibilities and roles of the team members, which were:

- Project manager
- Shift leader
- Shift chemist
- Decontamination Technicians/Operators

The operational procedure contained detailed procedures for whole circuit decontamination activities:

- Filling procedure for sorbents
- Waste sorbent removal procedure
- Procedure for abnormal conditions
- Procedure for installation and pre-operational testing 2. Block
- Procedure for installation and pre-operational testing Block 1
- Operating Procedure 1. Block
- Procedure for demobilisation of equipment.

In addition to the procedure, work programs were drawn up with set goals, nominal responsibilities on the part of the V1 operator and the decontamination team, the sequence of work, including the schedule, the planned amount of waste, safety conditions and planned doses of radiation - personal and collective. The teams carried out activities according to work programs for preparatory activities such as ventilation improvement, removal of identified potential places for leaks, cleaning, sampling of SGs, tests and commissioning, operation, transfer to Unit 1, processing of ionex waste, and demobilization of equipment. Individual modules and the complete DFD line were controlled by a remote control system, which was programmed according to the algorithms of future operation before the tests. Operation safety was ensured by online information on the screen about flow rate, pressure and temperature and warnings in automatic mode. Because the weak points of D2 were removed, the operation of the equipment during D2-A was without vibrations and significant technical failures. Also, the connecting device - the spider worked correctly and ensured a tight connection of the double loop with the decontamination line.

The operator focused entirely on the process and its improvements (see lessons learned). The key experts directly formed a well-coordinated team, which was at a high level in both technical and human terms. The teams on both sides were focused on achieving the common goal of decontaminating the primary circuits as best as possible while minimizing secondary waste. The capabilities of the team of experts were evident in the smooth running of the decontamination process once testing was completed. As shown in the implementation schedule, decontamination began with commissioning on 15/7/2017, and the second decontaminated circuit was completed on 6/12/2017.

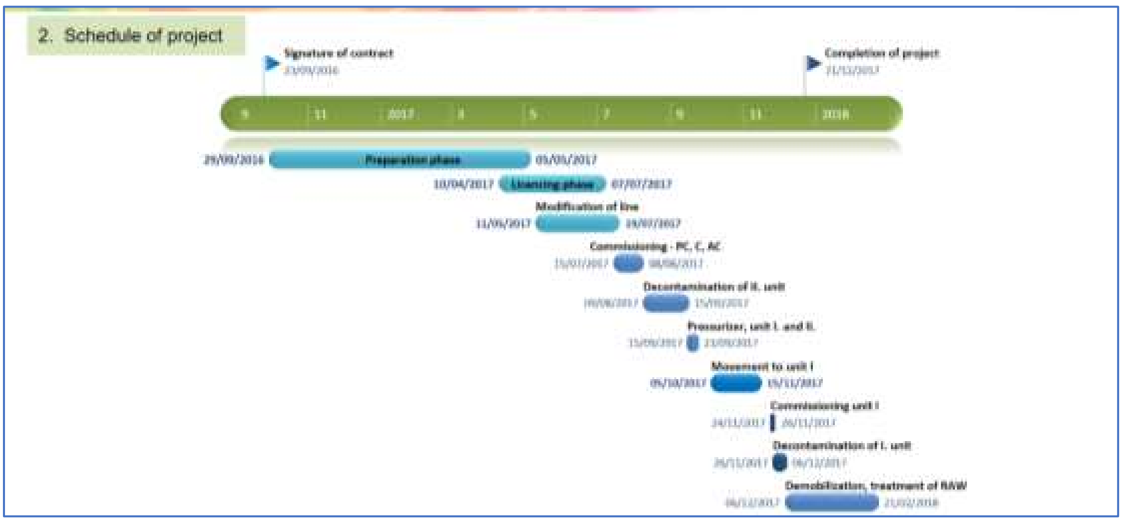

Figure 11: D2-A Project schedule of implementation – basic phases.

Waste generation

The spent ion exchange resins and sludge from the D2 project and spent ion exchange resins from the D2-A project were directly solidified to the SIAL® matrix in the reactor hall. Overall, 92 pieces of 200-litre drums were produced, all meeting the limits and conditions for storage on NRWR. The total quantity and types of RAW generated within the D2-A project "Decontamination of the primary circuit – II. Stage" is shown in Table 2.

Table 2: Summary of produced RAW within the D2-A project.

RAW type	Amount
Liquid RAW	**354.9 m^3**
Drums with solidified resins from the D2 project	**41 drums**
Drums with solidified resins from the D2-A project	**51 drums**
Solid combustible RAW	**1,600 kg**
Solid compressible RAW	**1,000 kg**

LRAW production was higher than predicted due to the lower regeneration efficiency of the ion-exchange columns; further contributing to the increase in liquid RAW volume was the initial use of the annexe column at high temperatures, which caused degradation of the annexes, making them even less effective and requiring more frequent regeneration and flushing.

The production of desiccated ionex was increased for the following reasons:

- Degradation of annexes due to high temperature.
- Capture of solid particles from the decontamination of loops 2 and 5 generated during the D2 project and the risk of release of the captured activity during the decontamination of the Unit 1 PC loops.

6.5. Results

Implementing this complex project D2-A by the selected contractor who met the defined criteria was successful. The success of this combination of the DFD equipment from D2 and the chosen contractor continued to another even more extensive decontamination at KNPP in Bulgaria. As part of the decontamination of individual PC loops, the pressurizer and relief tank, the achieved DFs, respectively, and portions of removed activity were evaluated. DFs were assessed based on a contact measurement of the dose rates before and after decontamination at defined points on the primary pipeline, SGs, pressurizers, relief tank and the connecting pipeline of pressurizers. The measurement technique and the dose rate measurement points were based on the approved methodology. The summary of the average DFs achieved, and the portion of removed activity from the individual decontamination circuits in the decontamination of the PC with the DFD line installed at Unit 1 and Unit 2 are shown in Table 3.

Table 3: Overview of achieved average DF and the amount of radioactivity removed from individual decontamination circuits of V1 NPP.

Decontamination circuit	Average DF in SG	Portion of removed radioactivity in SG	Average DF in the pipeline	Portion of the removed radioactivity in pipeline
Loop no. 1 Unit 1	245	99.6%	35	97.1%
Loop no. 2 Unit 1	16.4	93.9%		
Loop no. 3 Unit 1	6.7	85.1%		
Loop no. 4 Unit 1	11.4	91.2%		
Loop no. 5 Unit 1	25.8	96.1%		

Loop no. 6 Unit 2	9.1	89.0%		
Loop no. 1 Unit 2	15	93.3%	127	99.2%
Loop no. 2 Unit 2	24	95.8%		
Loop no. 3 Unit 2	23	95.7%		
Loop no. 4 Unit 2	6	81.8%		
Loop no. 5 Unit 2	32	96.9%		
Loop no. 6 Unit 2	8	86.8%		
Pressurizer loop – Unit 1	-	-	2.8	64.36%
Pressurizer loop – Unit 2	-	-	5.9	82.92%

6.6. Organization & Human aspects

Such a technically demanding project cannot be handled without good organisation and mutual understanding. Teams on both sides must be prepared for complex and unexpected tasks that cannot be dealt with without mutual respect and compromise. Both crews had to overcome language and culture barriers. A well-managed organisation and, sufficient human resources and working together with respect is a prerequisite for project teams to focus on the technical side of the project.

The preparatory phase for the client consists of preparing the technical specification, which is necessary based on the best world approaches, which requires studying the available information or personal meetings with people who have already implemented such a project. Using the experience of operations personnel who have done circuit decontamination before shutdowns and are familiar with the subject is a good idea. The preparatory phase must set the conditions that ensure the selection of an experienced implementer with key experts directly on site in the performance.

On the customer's side, the theoretical preparation of the project team is appropriate, which, after substantial support in the licensing phase of the process, will be able to recognize possible process anomalies and manage risks. The project itself consists of a preparatory phase and an application phase. Ideally, both project steps should be executed by the same key experts who can solve deviations between testing and commissioning under realistic conditions after connection to the primary circuit with real pipelines, equipment elevations, and current flow.

The decontamination team must be able to cover 24-hour operation. Typically, these are two complete teams with a mechanical supervisor, a lead chemist for process control and management, machine operators to operate the line and the interconnecting piping when changing the decontaminated double loop, chemical lab technicians, and personnel for waste management. On the client's side, operational radiation protection personnel were continuously involved, checking radiation protection conditions and regularly checking the dose rate at the control points after the decontamination cycles. The decontamination objectives were achieved through daily brief coordination meetings with plant operations personnel and the decontamination crew.

24-hour operation is a necessity once the decontamination process has started.

Close cooperation between the decontamination (specialist) contractor, operating personnel, dosimetry and chemistry is a prerequisite for implementing systemic chemical decontamination of the NPP primary circuit.

Problems and risky operations were dealt with only during the day after the morning meetings of both teams.

6.7. Regulatory and Licensing Aspects

Decontamination of the primary circuit is necessary to apply the Immediate Decommissioning Option (IDO). For this reason, this activity was present and permitted in outline during the EIA process, during the approval of the Decommissioning Concept Plan, the Phase 1 and Phase 2 Decommissioning Plan.

- Because the primary circuits were no longer the selected facilities (there was no contaminated media), the Nuclear Authority applied a graded approach to connecting the DFD line and starting the decontamination process.

- Safety analyses were performed based on a detailed implementation design and work programmes and procedures for the operation of the DFD line to obtain Nuclear Authority and Health Authority approval.

- The DFD line modules had to be certified following EC generic standards for the construction of pressurized equipment.

- Further certification followed after the entire decontamination circuit was connected from the point of view of safe operation (pressure and electrical equipment) following STN EN ISO/IEC 17020:2012. Meetings involving the nuclear authority, JAVYS and the contractor were held regularly, and the site inspector present checked the situation on-site.

	Be prepared to provide additional analyses to support a positive regulatory opinion.
	Due to the inability of D2 personnel to decontaminate the entire system, the Nuclear Authority questioned this decontamination method. JAVYS had to be prepared to demonstrate the safety of individual steps, contingency management, and the ability to stop the work at any time.

6.8. Benefits for the Operator

The decontamination of the primary circuit WWER 440 case study provides the following insights:

- The effective setting of the decontamination project phases from the preparation of the project – creation of technical specification, definition of decontamination scope, procurement of executor of decontamination works.

- Definition of the necessary steps to achieve the project objectives from setting the realistic project objectives through the design phase, permitting process, verification of equipment parameters, how to evaluate decontamination results, and achieving optimal results.

- Good knowledge of the chemical decontamination process, understanding of the risks, and lessons learned from other implementations will enable better direct control of the contractor and a safe implementation of the process.

- The description of failures in technical, process and organisational terms shows what is important for this kind of complex project.

- The provision of plant operational facilities (special drainage pipelines) reduces the contaminated inventory associated with the chemical decontamination execution.

- Involvement in the decontamination process and understanding of the process and results provided a good baseline for the following project for the fragmentation of large primary circuit components.

7. REFERENCES

[1] BIDSF D2, JAVYS, a.s., D2-TS-PMU-07001/EN Decontamination of the primary circuit, TECHNICAL SPECIFICATION, 2011

[2] BIDSF D2, JAVYS, a.s., D2-CR-PMU-07001/EN Decontamination of the primary circuit, PROJECT COMPLETION REPORT, 2016

[3] BIDSF D2-A, JAVYS, a.s., D2-A-TS-PMU-07001/EN Decontamination of the primary circuit, TECHNICAL SPECIFICATION, 2016

[4] BIDSF D2-A, JAVYS, a.s., D2-A-CR-PMU-07001/EN Decontamination of the primary circuit, 2017 PROJECT COMPLETION REPORT, 2017

[5] BIDSF B6.1, JAVYS, a.s., The V1 NPP Conceptual Decommissioning Plan, Final report 2006

[6] Rick Reid, EPRI Evaluation, Aproach to Chemical Decontamination at Bohunice V1, 2016