LESSONS LEARNED IN DECOMMISSIONING OF NPP A-1 AFTER ACCIDENT

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ABSTRACT

Decommissioning of the NPP A-1 in Jaslovske Bohunice is encountered with great variation of the problems connected primarily with the high radiation fields and the high activity of the contaminated materials. Decontamination of the contaminated objects and the thorough radiological protection of decontamination workers are therefore the tasks of top priority. The successful realization of these jobs is based on the experience, good working practice and the utilization of all proven methods together with the newly developed ones. Since 1996, AllDeco Ltd. has applied the decontamination methods and processes in a wide scale in the decommissioning and dismantling of the NPP A-1 in the cooperation with SE – VYZ Inc.

The monitoring of the radiation situation and the investigation of the type and character of the radioactive waste were first steps in the decontamination of all objects. For this works, remote controlled mechanical manipulators and remote controlled electrical carriage equipped with instruments recording the levels of dose rates and with telemetric data transmission system were used. The recorded data were used for the modeling and 3D visualization of the radiation fields and for following planning and preparation of the decontamination projects or "working programs" based on the ALARA principle.

The minimization of the radioactive waste was also taken into consideration.

A lot of time and energy was spent on the preparation and training of the staff including non-active trials of planned procedures. The gained experience was evaluated and lessons learned were given in the final reports.

INTRODUCTION

The NPP A-1 in Jaslovske Bohunice with a 150 MW gas-cooled, heavy water moderated reactor was constructed as an experimental demonstrational plant and all main components had a character of prototype. Despite this the NPP was included into the power system with determined plan of electrical power production and operated for 5 years with several outages. After the second accident in 1977, the NPP was definitively shut down. In 1992, the Slovak government adopted the concept and time schedule of NPP A-1 decommissioning but only in 1999, the permission for the first phase of decommissioning was issued. The decommissioning project is currently going on and planned to be finished by 2049. The objective of the first phase to be completed by the year 2007/8 is to reach the radiological safe state without spent fuel and without uncontrollable release of radioactivity into environment. Decontamination of primary circuit installations, auxiliary loops and other heavily contaminated objects of the facility is the task of top priority.

Since 1996, AllDeco Ltd. is the main subcontractor for decontamination and dismantling works and for deliveries of decontamination devices.

The process of decontamination as well as other decommissioning processes are slow, very complicated and they are connected with the great diversity of special problems. The leakage of fuel rod claddings as well as of primary circuit barriers and the accidents during the operation caused very high contamination of all primary circuit installations, infrastructures and also of the secondary circuit.

High radiation fields and high activity of the contaminated materials with high contents of alpha radionuclides highlighted the need to solve these problems case by case without looking for an universal method and accenting radiation protection and work safety.

In 2001, many partial projects were performed. From point of view of the radiation risk, the most important projects were dismantling and decontamination of the spent fuel storage pool cooling subsystem and other activities in the technological room of the spent fuel storage pool.

GENERAL STRATEGY FOR REALIZATION OF PARTIAL DECOMMISSIONING TASKS

The tasks in the NPP decommissioning are mostly non-routine and non-standard activities. In the meaning of the SE-VYZ Operation Instruction No. PP04, all these activities are permitted only after the elaboration and approval of the special Realization Program including an individual chapter "Radiation Protection".

The scenario of the single problems solution is the same.

The first step in the decontamination of all objects is the thorough *mapping of the radiation situation* and investigation of the type and character of the radioactive waste. The dose rates are measured, followed by the *modeling and 3D visualization of radiation fields*. The main sources of the radiation are identified and localized. For this work, remote controlled mechanical manipulators and remote controlled electrical carriages equipped with instruments recording levels of dose rates and with telemetric data transmission system are used. The new software tools for more precise radiation doses planning ALPLANNER were developed (Fig. 1).

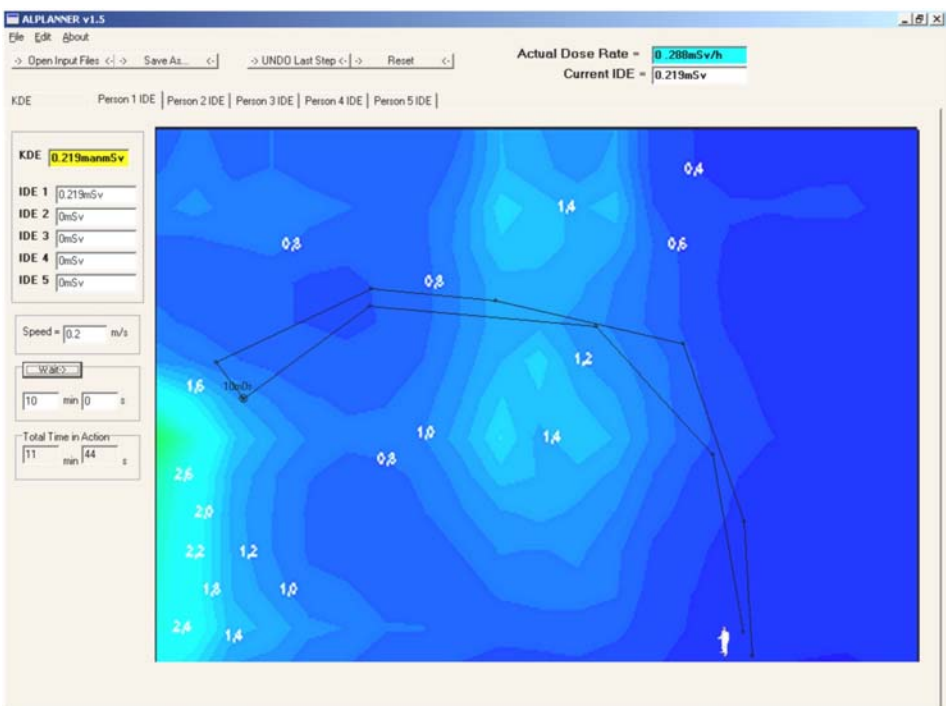

Fig. 1: ALARA planning tool ALPLANNER

In compliance with the given criteria and aim of the task, the analysis of working procedures being considered is performed and the optimal procedure is chosen. The whole procedure is divided into e.g. phases, tasks, basic operations (according to its complexity) and each is linked with data comprising manpower requirements and average dose rate in the working place. The Collected Dose Equivalent (CDE) and maximum Individual Dose Equivalent (IDE) are calculated for the whole working procedure and it is stated whether those values exceed the given limit or not that requires a judgment of the working procedure by the ALARA commission being established by the NPP entrepreneur for the purpose to minimize radiation load of the staff. If the judgment is inevitable the next step is assignment and description of measures for minimization of radiation load, generation and spreading of the contamination in the sense of the ALARA principle. These measures are based on e.g. use of special protective aids, clothes as well as shielding and so on.

The *minimization of the radioactive waste* is also taken into consideration. The choice of the appropriate decontamination method that produce low amounts of low activity radioactive waste is of the high priority together with an adequate time spent on the development of the equipment and the *preparation and training of the staff*. This also includes the non-active trials of the methods.

Decontamination works are described in the *"Working programs"* or in partial decontamination projects. The work program has the standard structure with the following content:

- Aim and reason of the program
- Specification of preparatory works
- Initial state description
- Specifications of work package, works progress and review
- Safety management and emergency planning
- Waste management
- Assignment of roles and responsibilities
- Determination of success criteria for the realization
- Assignment of responsibility for the program evaluation

Decontamination works start after approval of the working program by ALARA commission and competent responsible persons. During works, data important from point of view of radiological protection and ALARA are collected, evaluated and recorded. These data are evaluated and lesson learned are given in the final program evaluation.

DECONTAMINATION AND DISMANTLING OF COOLING SYSTEM OF FUEL STORAGE

Problem determination and initial state characterization

Cooling system of fuel storage consisted from 3 basic parts:

- Distribution pipes in spent fuel storage
- 2 pipes (inlet and outlet) in the entrance corridor in NPP A-1
- Room No. 417 (cooler, pumps and pipes of cooling system)

The pipes of the cooling system were made from the carbon steel and contaminated by corrosion products and other deposits. Cooling system was not in operation but 2 pipes in the entrance corridor were the main (95 %) contributors to the total dose rate values in this room (Fig. 2.). Average duration of total general works in the corridor was about 2 man-hours per week or 100 man-hours per year. Resulting actual average collected dose equivalent from works in the corridor was ~20 man.mSv/year.

The measurements with ultrasonic gauge confirmed, that the pipes were filled in full volume with contaminated water from the cooling system and a possible leakage of radioactive liquid was very important risk for extension of actual stage but for the dismantling works, too (1).

The unfavorable radiation situation with direct influence on surrounding areas was in the room No. 417, too. In this room, there were technological parts of the cooling system (2 pumps, cooler and stainless steel collector of leakages in the floor) and lot of stored, unnecessary, contaminated objects. A possible leakage of liquid radioactive waste of supposed volume activity 10^6 - 10^7 $Bq.dm^{-3}$ from pipes and cooler in amount about 3 - 5 m^3 was a real risk factor.

A part of dismantling works had to be performed directly in the spent fuel storage where the high dose rates had had to be reduced.

Monitoring of the radiation situation

The actual radiation situation was monitored and gained data were evaluated (Fig. 2, 3).

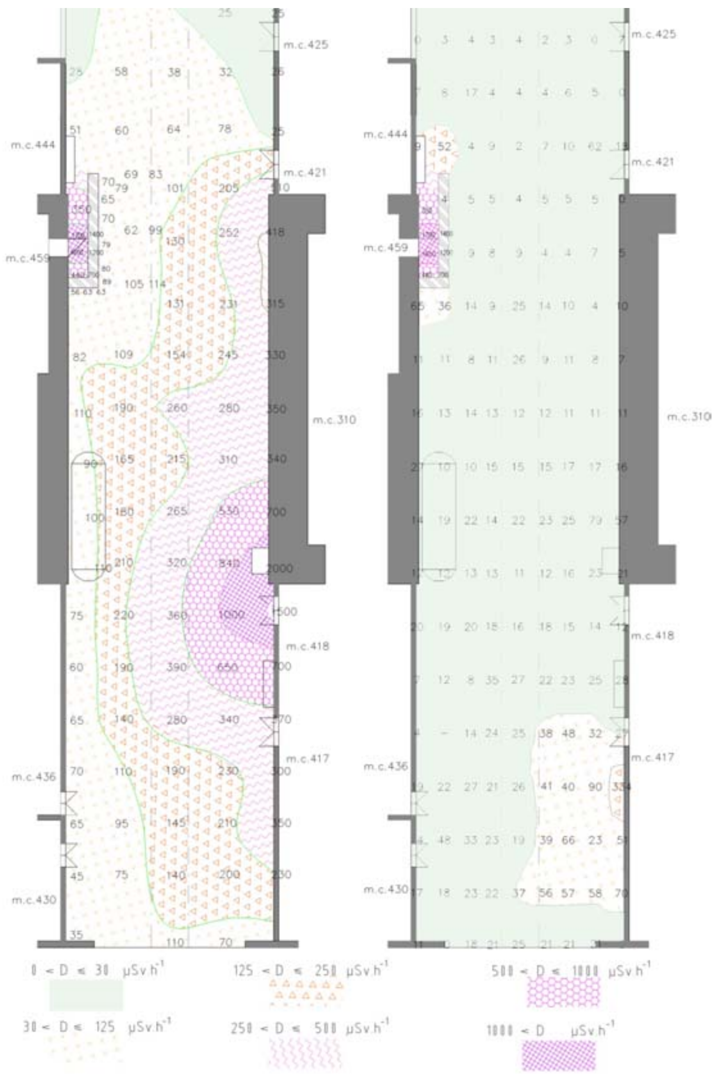

Fig. 2: 2D model of the radiation situation in the entrance corridor

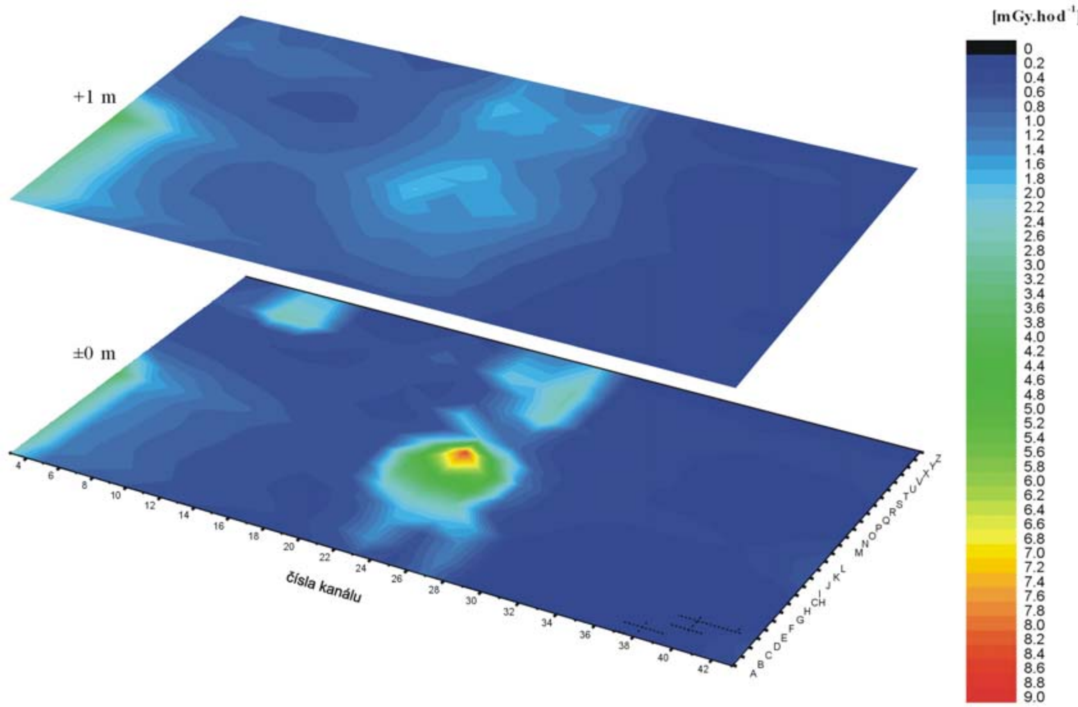

Fig. 3: 3D model of the radiation situation in the spent fuel storage

The measured data were used for the estimation of IDE and CDE for proposed variant solutions.

Working programs for realization

Two individual working programs were elaborated for the dismantling of the cooling system: 1st program for the decontamination and dismantling of technological parts of the cooling system in the room No. 417 and 2nd program for drainage, decontamination and dismantling of the part of the cooling system pipelines.

The program for the decontamination of the room No. 417 was relatively simple and the solution was explicit. The performance was divided into single working phases and for each phase a realization procedure was proposed and expected IDE and CDE were calculated.

When dismantling pipes in the entrance corridor, two basic approaches were possible. The pipes could be drained, dismantled and fragmented using single or dual robotic arms for handling and cutting or the pre-dismantling circuit decontamination should be performed followed by manual dismantling of the pipes. The second method was less expensive and the risk of the negative influence on other adjacent technological systems was substantially lower. This was the main reason for the choice of this approach not considering expected values of IDE and CDE.

If several variant solutions were available the ALARA commission had chosen the optimal method. The estimated values of individual effective doses and collected effective doses (e.g. Tab. I) were crucial criteria in the decision.

Table. I. Overview of estimated collected effective doses CDE of AllDeco workers during the drainage, decontamination and dismantling of cooling systems pipelines

Work package	Average dose rate [$mSv.h^{-1}$]	Average works time in radiation field [h]	Average number of workers in radiation field	Man-hours	Partial CDE [man.mSv]	Period CDE [mSv]
Period No. 1	1	0.5	2	1	1.00	1.50
	0.5	0.5	2	1	0.50	
Period No. 2 Alternative No. I.	1	1.5	2	3	3.00	3.70
	0.2	2.0	1	2	0.40	
	0.05	3.0	2	6	0.30	
Period No. 2 Alternative No. II.	0.2	0.5	1	0.5	0.10	1.36
	0.6	0.5	1	0.5	0.30	
	0.03	32.0	1	32	0.96	
Period No. 2 Alternative No. III.	0.05	16.0	2	32	1.60	2.56
	0.03	32.0	1	32	0.96	
Period No. 3	0.01	10.0	2	20	0.20	0.70
	0.05	5.0	2	10	0.50	
Period No. 4	1.00	1.0	1	1	1.00	3.00
	2.00	0.5	2	1	2.00	
Period No. 5	0.10	4.0	2	8	0.80	4.35
	1.00	0.5	1	0.5	0.50	
	0.50	0.5	1	0.5	0.25	
	0.50	1.0	2	2	1.00	
	0.05	10.0	2	20	1.00	
	0.05	8.0	2	16	0.80	
Period No. 6	1.00	0.5	1	0.5	0.50	4.35
	0.50	0.5	1	0.5	0.25	
	0.05	20	2	40	2.00	
	0.03	20	2	40	1.20	
	0.02	10	2	20	0.40	
Period No. 7	0.02	10	2	20	0.40	2.30
	0.03	25	2	50	1.50	
	0.02	10	2	20	0.40	
Total alternative CDE	Period No. 2, alternative No. I				19.90	
	Period No. 2, alternative No. II.				17.56	
	Period No. 2, alternative No. III.				18.76	

The valid program comprised preparation (Periods 1, 2, 4), drainage of the active liquid from the system (Periods 2/III, 5), pre-dismantling decontamination of the pipes (Period 6) and dismantling and fragmentation of the pipes (Period 7).

Pre-dismantling chemical circuit decontamination

In the case that the main source of radiation danger is the inner surface contamination of dismantled installations (pipes, fittings, pumps, small vessels), pre-dismantling closed circuit decontamination is suitable method for improving radiation-hygiene situation for dismantling tasks.

Closed circuit decontamination means that decontaminated pipes, vessels or loops are connected to a circulating loop with circulating pump and other fixed or flexible connections.

Special equipment for circuit decontamination (Fig. 4) consists of four modules:

- feeder;
- circulating module;
- filtration module;
- control module;

Fig. 4: Portable modular equipment DEZA OD for pre-dismantling chemical circuit decontamination

All of them are connected to the decontamination loop. Each of the modules has certain function and none of them can be omitted from the system. Modular construction has following advantages:

- decontamination equipment can have optimum layout in given circumstances, necessary working place is minimal;
- control module can be fitted at place with the lowest dose rate at given working area since the service personal will spend most of the work time there;
- technical outfit of each module makes it possible to use this equipment for decontamination of different systems (piping, vessels, circulating loops);

- equipment can be easier transported to hardly accessible places (narrow passages, corridors, split levels, etc.);
- possibility of extending the equipment with other modules (e.g. ion exchange filter);

The following chemical solution was used in the case of pre-dismantling decontamination of the cooling system's pipes:

cooling system's pipes:	oxalic acid	(4 - 10 %)
	NTA	(0,5 - 2 %)
	corrosion inhibitor	(0,05 %)

The inlet pipe (carbon steel, ϕ 260 – 320 mm, 9 m long) was decontaminated in 4 cycles followed by 7 water-rinsing steps, the outlet pipe (carbon steel, ϕ 150 mm, 35 m long) was decontaminated in 1 cycle and 2 water-rinsing steps.

Results evaluation from point of view of DF and the radioactive waste minimization

Total activity removed from the inlet pipe was about 3.10^{10} Bq; 30 % of this activity was trapped on filters in the filtration module. Total activity removed from the outlet pipe was about 10^{10} Bq; 20 % of this activity was trapped on filters in the filtration module.

In the phase of pre-dismantling decontamination of the inlet pipe cca 600 dm^3 of the decontamination solution were used in each cycle.

The pipes after decontamination were cut by the remotely controlled and hydraulically powered mechanical saw.

The cut pipes were decontaminated in the bath using chemical solution with simultaneous action of ultrasound and iron oxides deposits with thickness of 0.5 – 2 mm were removed from whole inner surfaces. More than 95 % from total surfaces of pipes were decontaminated below 0.3 $Bq.cm^{-2}$ and released into environment.

The oxalic acid in spent decontamination solutions was decomposed to CO_2 using H_2O_2 and neutralized; reduction factor up to 5 was achieved for chemical agents in secondary radioactive wastes.

ALARA evaluation

Resulting changes of the measured dose rates on the pipes before and after pre-dismantling decontamination are in Tables II and III.

Table II. Dose rates on inlet pipe of CS

Measuring points	Dose rates before decontamination [mGy/hour]	Dose rates after decontamination [mGy/hour]	$DF_{parc.}$
1A	6. 3	0.6	10.5
1B	8.6	0.7	12.3
2A	8.2	0.45	18.2
2B	9.1	0.7	13
3A	10.6	0.3	35
3B	11.5	0.4	28.7
4A	11.9	0.35	34
4B	11.0	0.3	36.7
5A	12.9	0.4	32.2
5B	16.5	0.45	36.7
6A	12.1	0.2	60.5
6B	13.6	0.15	90.7
7A	9.4	0.3	31.3
7B	9.7	0.2	48.5
8A	11.5	1.1	10.5
8B	11.2	0.95	11.8
			$\overline{DF}$ = 31.9

*** A - midpoint of pipe   B - bottom of pipe**

Table III. Dose rates on outlet pipe of CS

Measuring points	Dose rates before decontamination [mGy/hour]	Dose rates after decontamination [mGy/hour]	$DF_{parc.}$
1	0.800	0.10	8
2	1.000	0.05	20
3	1.300	0.1	13
4	0.500	0.2	2.5
5	1.700	0.2	8.5
6	2.500	0.100	25
7	2.400	0.070	34
8	4.200	0.180	23
9	6.000	0.053	11.3
			$\overline{DF}$ = 27.4

Results from the evaluation of estimated and actual CDE for individual phases and for the whole realization are in the Table IV.

Table IV. Collective dose equivalents

Stage of work	Collective dose equivalent [man.mSv]	
	Plan	**actual**
1. Preparation	5.2	3.98
2. Drainage	6.91	7.372
3. Decontamination	4.35	18.917
4. Dismantling	2.3	11.0
Total	**18.76**	**41.269**
Evaluation for dismantling without decontamination	121.352	**saving = 80.083**

Owing to the pre-dismantling decontamination cca 80 man.mSv were saved.

With the exception of the preparation phase, the planned CDE for single steps were exceeded, most in the phase of the decontamination and dismantling.

In the future, the estimation of IDE and CDE should be preformed with better understanding and considering of the character of "historical" radioactive wastes when the contamination is heavy fixed and its removal requires several repeated decontamination cycles or "harder" parameters.

The exceeding of CDE during the dismantling was caused mainly by the human factor - wrong installation of the hydraulic saw, its disassembly and new installation. This operation was many times trained in model condition and thoroughly planned. It was performed by the most experienced operators.

CONCLUSIONS AND LESSONS LEARNED

The smaller systems to be dismantled especially adjacent to other important equipment are advantageously decontaminated using the circuit pre-dismantling decontamination as the first step. In comparison to the direct manual dismantling significant reduction of IDE and CDE is achieved. The solution is safer, faster, more operative and economic than using of the manipulator. The amount of secondary radioactive waste is minimal.

Every working operation performed in the area with high radiation load is to be thoroughly trained. The above IDE and CDE were estimated on the base of time data from the non-active model training and from measured values of dose rates. The incorrect time estimation was the main reason of differences between the plan and reality. The works took more time than in model conditions even though they were performed by well-trained experienced operators.

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