General Distribution

September 1997

ISOE INFORMATION SHEET

OCCUPATIONAL EXPOSURE AND REACTOR VESSEL ANNEALING

ISOE European Technical Centre - CEPN Information Sheet No. 12

1. INTRODUCTION

The thermal annealing is one technique used to reverse the ageing process which causes NPP pressure vessels to lose some of their ductility over time. This embrittlement is caused by the constant bombardment of the steel vessel with neutrons released during the fission process. Reactor vessel annealing consists in heating the vessel (up to 500 °C) and then cooling it slowly to ambient temperature in a controlled fashion. This technique has already been implemented on thirteen VVER civil vessels in Russia and Eastern countries using Russian electrical heating technology.

Experimental reactor vessel annealings were performed at Novovoronezh-3 in Russia and at Armenia-1 in Armenia. Subsequent commercial operations were performed by a Russian consortium (MOKHT-Otjig RM) at Kozloduy-3 (May 1989), -1 (October 1989) and -2 (March 1992) units in Bulgaria, at Kola-1 and -2 units in Russia, and at Greifswald-1, -2 and -3 units in the former East Germany.

The two most recent operations have been undertaken by another consortium from January to May 1993 in Slovakia at the two Bohunice-1 and -2 units (VVER-440/230 design) and in August 1996 in Finland at Loviisa-1 (VVER-440/311 design). These reactors have a circumferential weld which is at the level of the reactor core and is thus affected by the neutron irradiation.

Some preliminary experiments have been performed also in Western countries; at two US military reactors in Alaska (1967), and at the Belgian research Reactor-3 (1984). In July 1996, the United States performed a first demonstration of thermal annealing at the unused Marble Hill-1 NPP in the State of Michigan, but the second project, which was planned at the unused Midland-2 facility in the State of Indiana, was suspended when it was 75% complete, because US DOE funding for vessel annealing demonstration ceased with the signing into the American law of the Energy and Water Appropriation Bill on 30 September 1996. Moreover, AEA Technology of the United Kingdom has recently carried out studies on fluence analysis for

Consumer Power Company, owners of Palisades Pressurised Water Reactor in the USA. These studies demonstrated that the plant could continue to operate until 2007 without the need for a costly vessel annealing.

As reactor vessel annealing entails significant works around the reactor vessel, one could expect high collective doses. Unfortunately, the dosimetric data for the first ten operations is not available. This ISOE information sheet summarises the information on collective doses and radiation protection issues in the last two plants where this operation was performed - Bohunice (Slovakia) and Loviisa (Finland). In fact, it appears that this operation, with good radiological protection, now corresponds only to a few tens of millisieverts on VVER plants.

2. BOHUNICE REACTOR VESSEL ANNEALING

Following a period of preparation, which started in 1983, the Bohunice -1 and -2 reactor pressure vessels were annealed in 1993. The annealing procedure followed the former Czechoslovak Atomic Energy Commission's (CSKAE) « Regulation Act No. 5 », extended by the Slovak Nuclear Regulatory Act No. 51/93. Detailed technical information was presented at an international conference organised by the Slovak Nuclear Regulatory Authority and the IAEA in Zavazna Poruta (Slovakia) in March 1994, and was also published in the proceedings of the meeting « Irradiation and embrittlement, optimisation of annealing » in Paris (France) in September 1994.

The heating rate was 20°C/h, the maximum annealing temperature was 505°C, this temperature was held for a duration of 168 hours and the cooling rate was 20°C/h. The annealing device was equipped with 13 resistance heated, controlled heating sections arranged into three groups, with a total nominal heat output of about 1000 kW.

Radiological Data and Results

Before placing the heating device into the reactor, the pressure vessel was decontaminated by using water spraying. A biological shielding cover was put on the annealing assembly. Only the core of the vessel was annealed. Ventilation in the reactor hall was off during removal of the heating device, and during its transport. The gasket of the heating device was disposed of as radioactive waste.

The following tables show the radiological conditions at various steps of the operation for both units, and the collective dose results, broken down into the different tasks for unit 2. The dose rates at workplaces did not exceed 0.5 mSv/h except in the refuelling pool above the reactor vessel (about 50 mSv/h). The total collective dose for the operation was 11.5 man.mSv. The maximum individual dose was 0.82 mSv.

Table 1. Radiological conditions at Bohunice Unit 1 and 2

	BOHUNICE UNIT 1	**BOHUNICE UNIT 2**
<u>During the placement of the heating device</u>		
Dose rates		
On the reactor platform	0.l-0.5 mSv/h	0.l6 mSv/h
In the refuelling pool (above the reactor pressure vessel)	45 mSv/h	30 mSv/h
Near the reactor platform (RP stand)	0.025 mSv/h	0.020 mSv/h
<u>After the placement of the heating device</u>		
Dose rates		
On the shielding slab of the heating device	0.3 mSv/h	0.07 mSv/h
At 1 meter above the shielding slab	0.15 mSv/h	0.030 mSv/h
Above the reactor (reactor platform level)	0.050 mSv/h	0.020 mSv/h
<u>During heating</u>		
Dose rates		
On the shielding slab of the heating device	0.3 mSv/h	
At 1 meter above the shielding slab	0.070.15 mSv/h	0.030 mSv/h
Above the reactor (reactor platform level)	0.050 mSv/h	
Aerosol activity		
In the refuelling pool (over the reactor vessel)	< 10 Bq/m^3	< 10 Bq/m^3
<u>During the removal of the heating device</u>		
Dose rates		
On the reactor platform	0.l-0.5 mSv/h	
In the refuelling pool (above the reactor vessel)	45 mSv/h	
Radiation prot. service stand point near the reactor platform	0.25 mSv/h	
Aerosol activity		
Reactor hall	< 10 Bq/m^3	< 10 Bq/m^3
In the refuelling pool (over the reactor vessel)	10 Bq/m^3	35 Bq/m^3
Surface contamination		
Heating device before decontamination	0.3-40 Bq/m^3	0.3-800 Bq/cm^2
Gasket of the heating device	< 1000 Bq/cm^2	
Heating device after decontamination	0.3-17 Bq/cm^2	0.3-15 Bq/cm^2

Table 2. Collective effective dose during the reactor vessel annealing of Bohunice Unit 2

Preparation of the heating device	0.33 mSv
Measurements made on the reactor pressure vessel before annealing	1.16 mSv
Placement of the heating device in the reactor	4.43 mSv
Installation of thermocouples	0.19 mSv
Heating device removal	0.97 mSv
Removal of cabling and equipment from the reactor	0.57 mSv
Measurements made on the reactor pressure vessel after annealing	3.83 mSv
Total collective dose for one pressure vessel annealing	**11.48 mSv**

3. LOVIISA 1 REACTOR VESSEL ANNEALING

The recovery annealing was performed using the electrical heating device owned by the Bohunice nuclear power plant and used during the two Bohunice vessel annealing operations (the main contractor was Skoda from Slovakia). It should be noted than the staff of workers came from Slovakia, and therefore benefited from its own feedback experience.

The heating started on the 4th of August 1996, with a rate of 20°C/h. The maximum annealing temperature was 475°C, and the temperature was held for a duration of 100 hours, with a smooth cooling beginning on 9 August with a rate of 13°C/h. Additional ventilation allowed the cooling to be performed in only two days instead of five. The annealing has restored about 90% of the ductility of the weld material. The total operation lasted 12 days.

Radiological data and results

Dose rates at various locations before the decontamination and shielding were too high to allow human entrance (see also Figure 1):

- Inside the reactor vessel at height of the core: 4000 mSv/h
- Inside the reactor vessel at height of the main pipes: 1700 mSv/h
- Above the reactor vessel at the flange level: 290 - 600 mSv/h
- At the level of the reactor hall close to the reactor shaft: 12 mSv/h
- At the level of the reactor hall close to the wall: 0.02 mSv/h
- At the polar crane 30 meters above the reactor: 1.3-1.8 mSv/h

All draining and washing efforts were performed by remote control. While the reactor vessel was drained and before the annealing unit was in place, only a few jobs were authorized in the reactor hall.

The entire primary system was drained. A pump was used to drain the reactor vessel below the main pipes of the primary circuit. As the water level dropped, the inner surface of the vessel was sprinkled by clean water in order to remove contamination. The remaining sludge was sucked into a small tank (contact dose rate 140 mSv/h). The upper part of the annealing unit constituted a thick radiation shield which considerably reduced the dose rates.

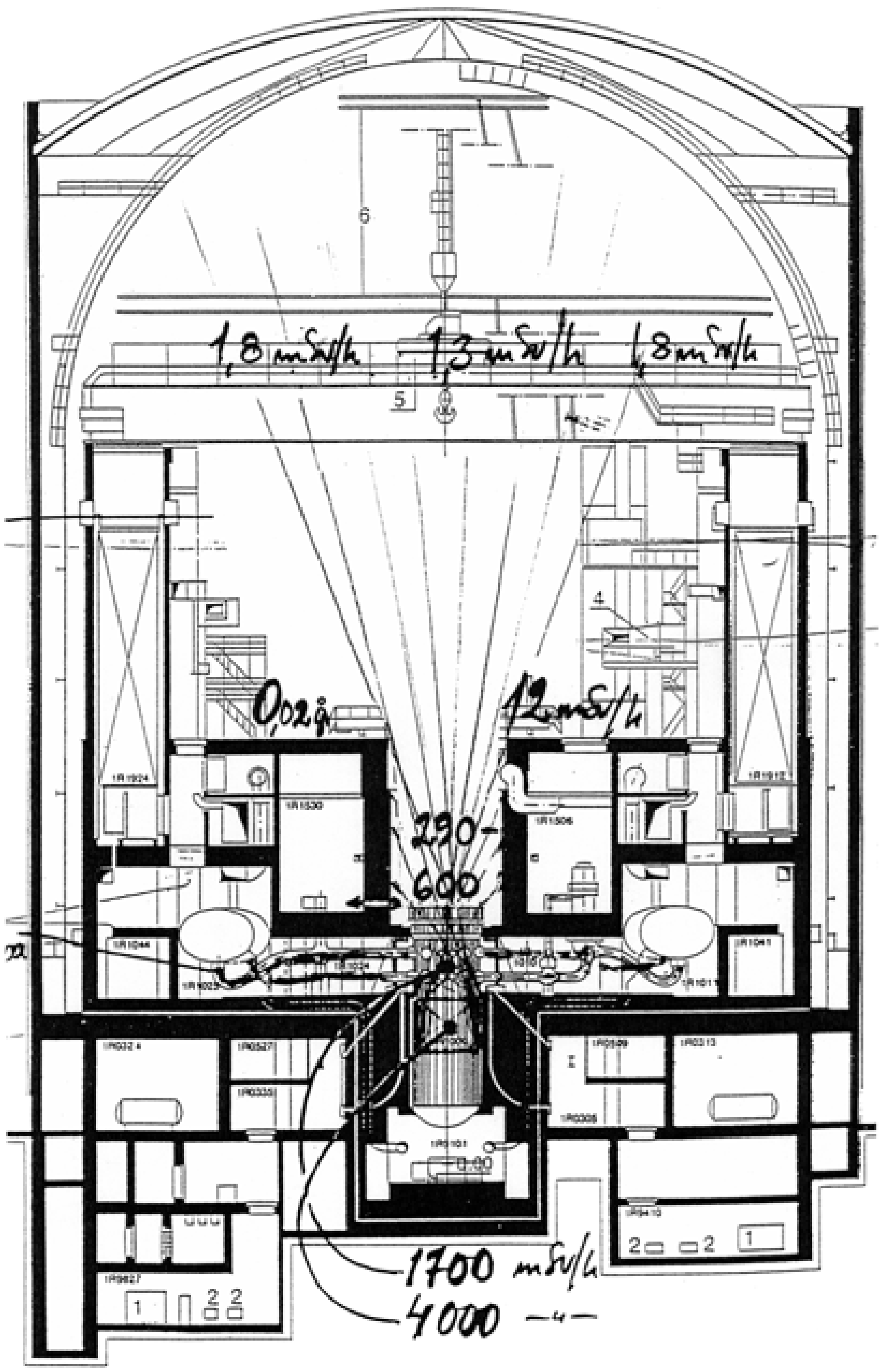

Figure 1. Loviisa 1 dose rates before annealing

During the annealing, work was restricted in areas influenced by the direct radiation from the primary circuit loops (cold and hot legs) because the dose rate close to the primary systems was about 40% higher when drained as compared to when it was full.

The highest doses were received on jobs performed below the bottom of the reactor vessel. The most dose causing job was the installation and removal of heat sensors on the outside of the vessel at the height of the reactor core. The maximum individual dose was 5 mSv. The total collective dose was 20 man.mSv. No problem with contamination occurred (when putting down and lifting up the annealing unit into and out of the reactor vessel, the ventilation was shut off in order to prevent possible airborne contamination from spreading). There was no need for any special decontamination of the equipment.

4. CONCLUSION

After sixteen performances, VVER reactor vessel annealing is now a well understood operation. Dosimetric results are very low (between 10 and 30 man.mSv) because workers are not required to spend long periods in high dose rates areas. However, it is not so evident to extrapolate these results to western PWR NPPs, even if ambiant dose rates at workplaces seem to be of the same order of magnitude, the dose prediction made for Palisades reactor vessel annealing was one hundred times higher than for VVERs (see Annex).

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ANNEX. DOSE PREDICTION FOR THE REACTOR VESSEL ANNEALING AT A WESTINGHOUSE PWR IN THE USA: PALISADES

Works Programme	Location	Duration h	Average Dose Rate mSv/h	Total Collective Dose person-mSv
Complete Containment Walkdown (1995)	*DECK*	*100*	*0.05*	*20*
Install Instrumentation Around Vessel (1995)	*SUMP*	*2.5*	*40*	*100*
Install temperature resistant RV stud hole plugs	DECK	12	0.05	2
Move equipment into containment	DECK	60	0.05	12
Assemble furnace in preparation for test	DECK	144	0.05	29
Install/set-up support equipment	DECK	276	0.05	55
Complete furnace ducting	DECK	24	0.02	2
Install instrumentation around reactor	**SUMP**	**40**	**40**	**1600**
Place UGS into temporary storage stand	DECK	6	0.1	2
Remove CSB and place into temporary storage stand	DECK	8	0.3	10
Place temporary shield around cavity/move upper guide structure to core support barrel	DECK	8	0.6	19
	DECK	3	0.2	2
Install temporary shielding internals and top cap	DECK	12	0.6	29
	DECK	8	0.3	10
Perform reactor vessel internals pre anneal measurements	DECK	24	0.3	29
Perform furnace containment test	DECK	48	0.1	19
Remove annealing capsules from the RV	DECK	12	0.3	14
Drain reactor cavity to vessel flange	DECK	18	0.6	43
Install nozzle plugs if required	CAVITY	12	0.6	29
Cavity decontamination/ventilation hookup/RV purge/ cavity seal ring removed	CAVITY	9	5	90
Lower furnace into RX/drain RV/system walkdown	CAVITY	0.5	5	3
	DECK	4	0.6	7
System heatup to temperature	DECK	45	0.15	7
Anneal reactor vessel	DECK	168	0.15	25
Cooldown to ambient using forced air	CAVITY	144	0.15	22
Pull furnace fill reactor vessel and cavity	CAVITY	4	5	40
	DECK	24	0.15	4
Remove internals shielding-remove upper guide structure to temporary stand	DECK	12	0.3	14
Make confirmation measurements	DECK	24	0.3	29
Complete moveout of containment	DECK	24	0.05	5
TOTAL DOSE ASSESSMENT				**2270**

RV = reactor vessel