Learning lessons from a nuclear event

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Summary

A fuel-cleaning incident at the Paks Nuclear Power Plant in Hungary occurred twenty years ago on 10 April 2003. The event was reported to the International Atomic Energy Agency (IAEA) and was rated Level 3 — a serious incident — by the International Nuclear Event Scale (INES). There were no personal injuries caused by the event and only a negligible increase in activity concentrations were measured. This article will describe what happened, highlighting key findings and points to what can be learned from a nuclear incident that occurred twenty years ago. It may provide useful insights to those who do not work in the nuclear industry but still would like to implement these learning points in their operations, taking the opportunity of cross-sectorial learning. The article does not seek to go in-depth of the technical details but rather will explore organisational aspects and learning points that can be translated into other industries' safety practices.

Keywords: Nuclear, design deficiency, contractor management, management of change

Description of the event

Annual maintenance took place at Paks-2 unit (Unit 2) of the Paks nuclear power plant according to the schedule of 10 April 2003. It was necessary to clean fuel assemblies from magnetite deposits (crud[a] build-up removal). Thirty fuel assemblies had been removed from the Unit 2 reactor and placed in a special cleaning tank under deep water in a service pit connected to the spent fuel storage pool. The chemical cleaning of the assemblies was completed in the afternoon and the rods were being cooled in the spent fuel storage pool water by circulation. The first sign of fuel failures was the detection of some fission gases[b] released, although only a negligible amount escaped to the environment. Later, visual inspection revealed that most of the 30 fuel assemblies had suffered heavy oxidation and fragmentation. The first evaluation of the event showed that inadequate cooling had caused the severe fuel damage.

Deposits

The source of magnetite deposition on the fuel cladding was the high number of steam generator decontamination cycles performed. The reason for this high number of chemical decontaminations was the need to repair feed water collectors in the steam generator, because in the early 90s a corrosion and erosion phenomena were identified in these feed collectors. This decontamination was carried out 24 times within almost a ten year period. The deposits that necessitated the cleaning was a known phenomenon since 1996 and as part of a campaign in 1998, the full change of fuel assemblies occurred. The problem seemed to be solved until 2000 when new deposits were detected in Unit 2 and in 2002 they were also detected in Unit 3 so much so that it had to be shut down in February 2003 when all fuel exchange took place[c]. The magnetite deposit on the fuel assemblies had already been considered in the design of the plant.

WWER 440 reactor and the fuel assemblies

The Paks nuclear power plant operates four WWER-440 (water-moderated water-cooled) or VVER-440 (Voda Voda Energo Reactor) reactor units each of 440 MW original capacity. WWER is a pressurised water reactor where the water is both the coolant and neutron moderator. Nuclear fuel for WWER-440 reactors is manufactured and delivered in the form of fuel assemblies designed for the generation and transfer of thermal energy to the coolant flow (water) in the WWER-440 reactor core (see Figure 1).

The core of a WWER-440 reactor is loaded with working fuel assemblies and control fuel assemblies. Working fuel assemblies remain fixed during in-pile operation (see Figure 2).

A working fuel assembly consists of fuel rods, spacer grids, top and bottom nozzles and a shroud. The design of the fuel follower of control rods is similar to that of working fuel assemblies, the only difference is top and bottom nozzle design.

The cleaning process

This section gives an overview of the cleaning process and helps to understand the circumstances of the incident. In the years 2000 and 2001, the chemical cleaning of a total sum of 170 fuel assemblies was performed successfully in equipment which was capable of housing seven fuel assemblies simultaneously. This process operated effectively. In November 2002, the plant commissioned a nuclear company to design, construct and operate a new chemical cleaning equipment of larger dimensions than the previous instrument. With the new equipment it was possible to clean 30 fuel assemblies

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[a] *Crud - corrosion and wear products (rust particles)*

[b] *Fission gases – fission products that exist in gaseous state; it includes primarily noble gases such as Krypton and Xenon.*

[c] *Note: Unit 4 did not suffer the same deposition challenge because the strategy of physical shielding was applied for the feed collector replacement work*

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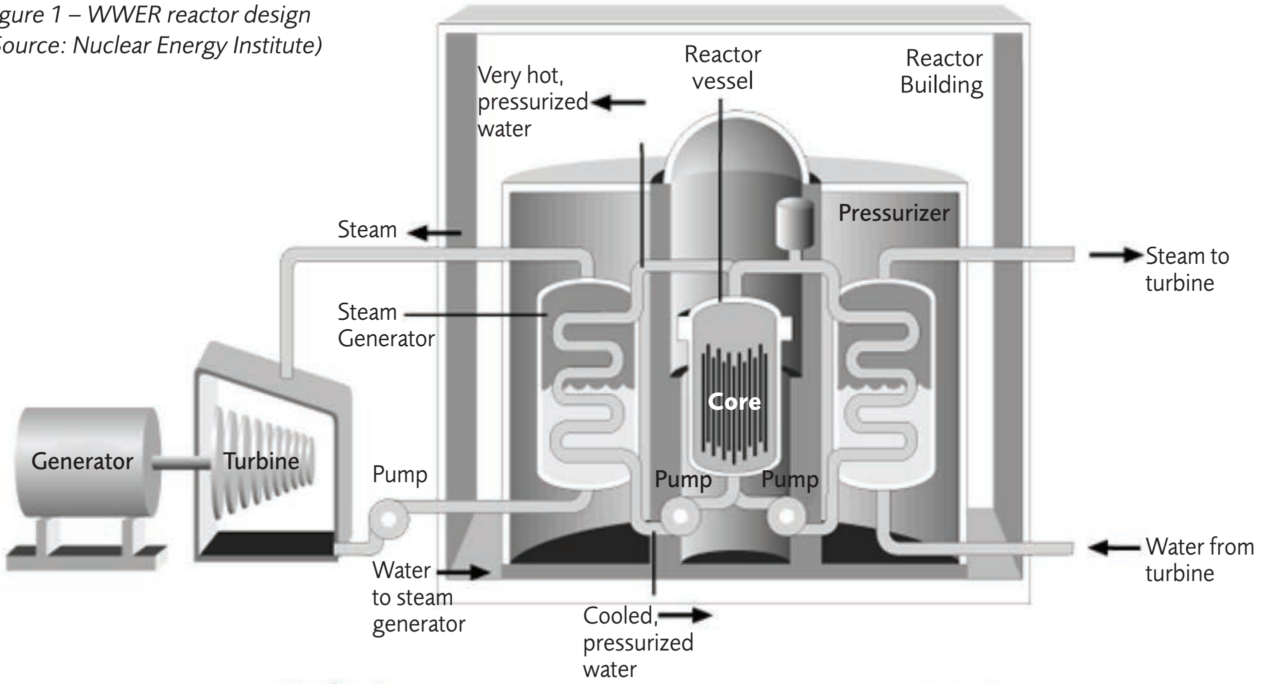
Figure 1 – WWER reactor design (Source: Nuclear Energy Institute)



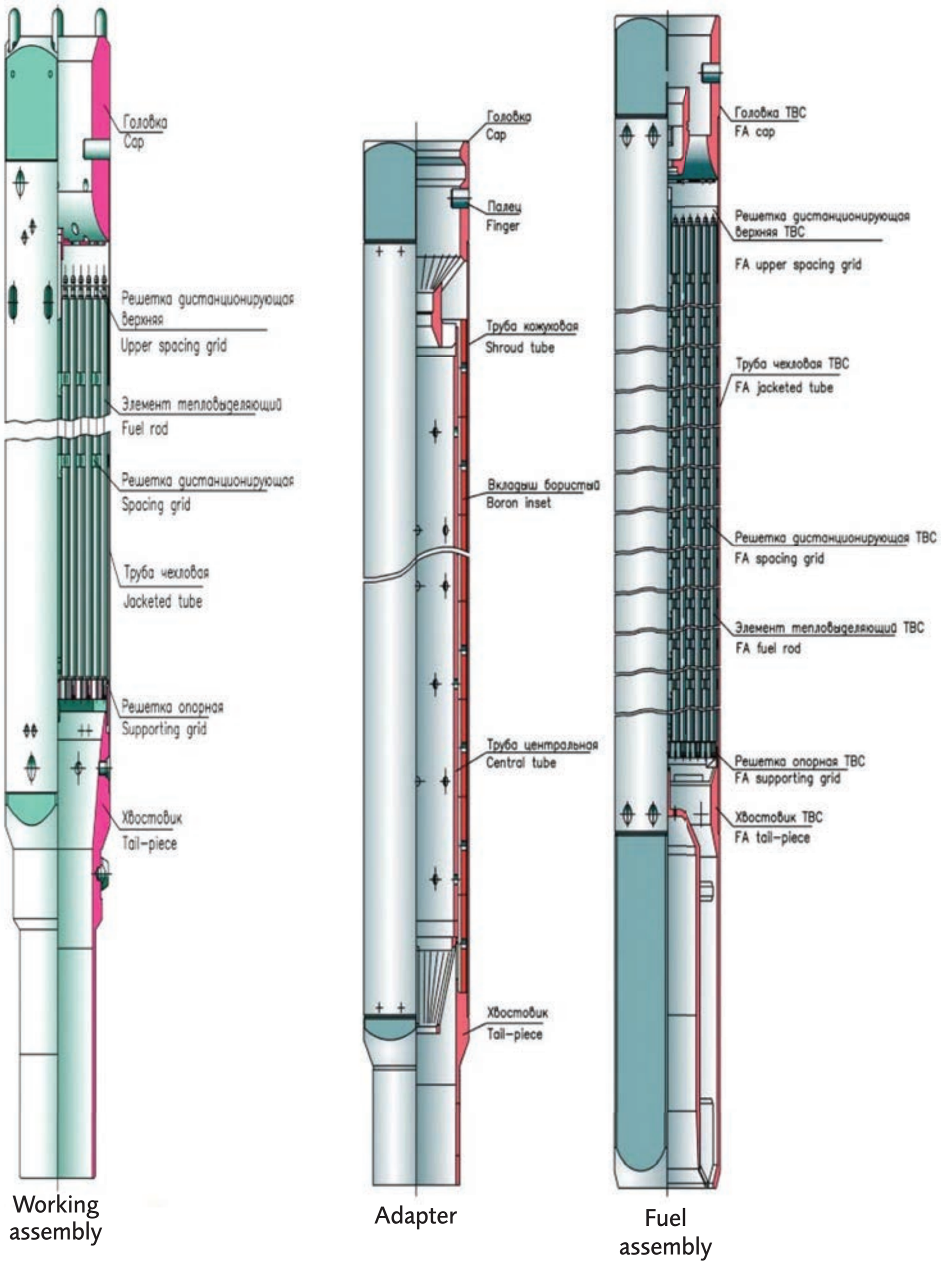


Figure 2 – Fuel assembly[6]

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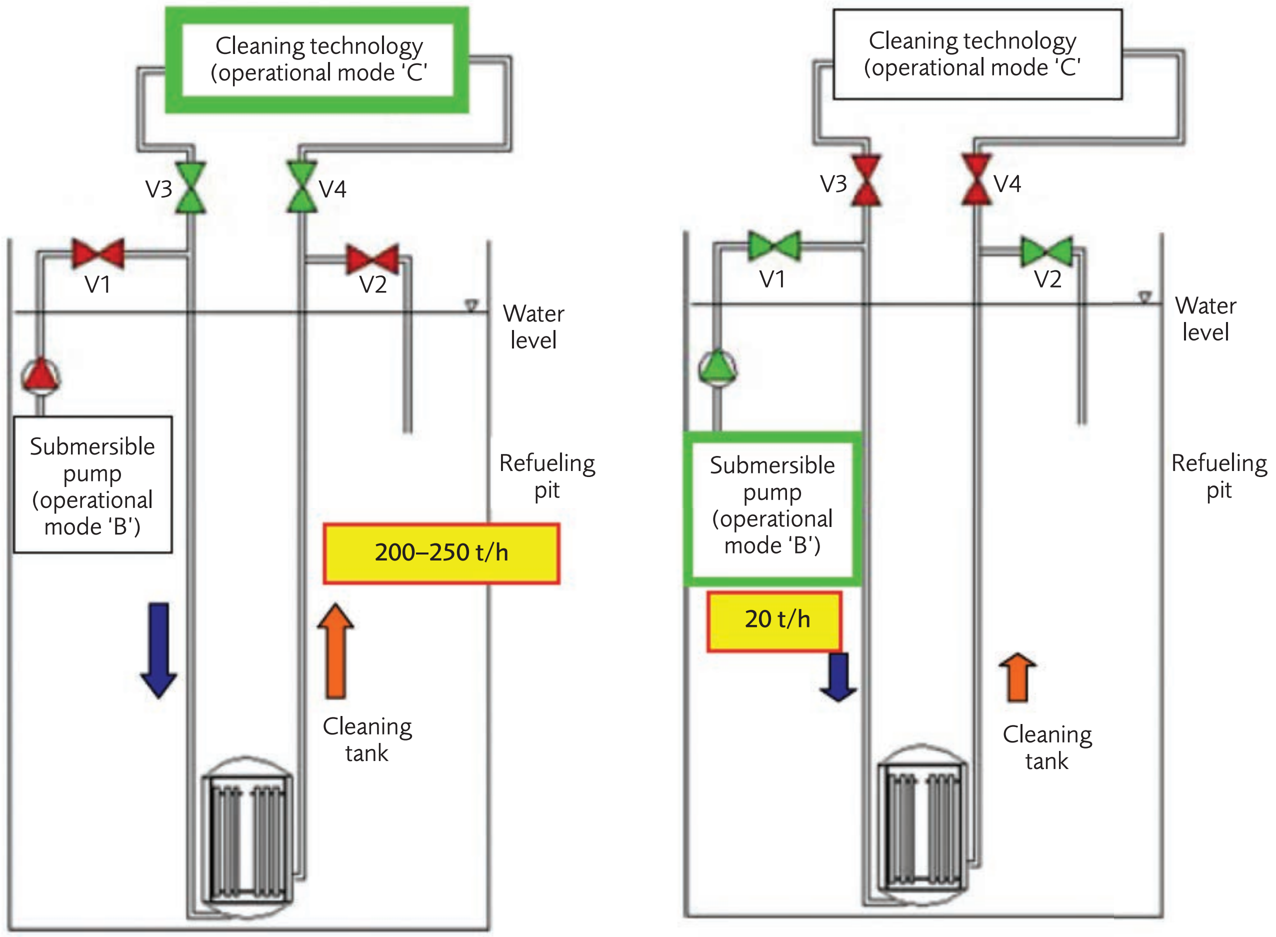

Figure 3 – Chemical cleaning process operational modes 'C' and 'B'[3]

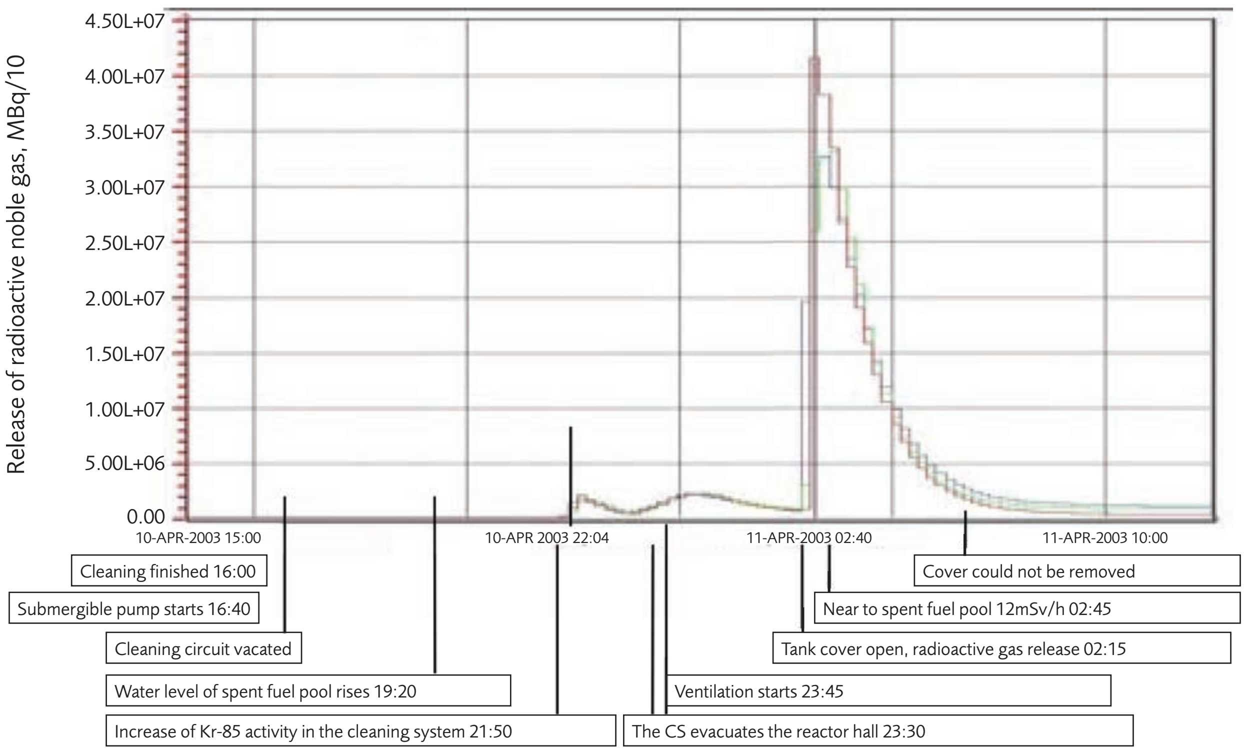

Figure 4 – Course of events[3]

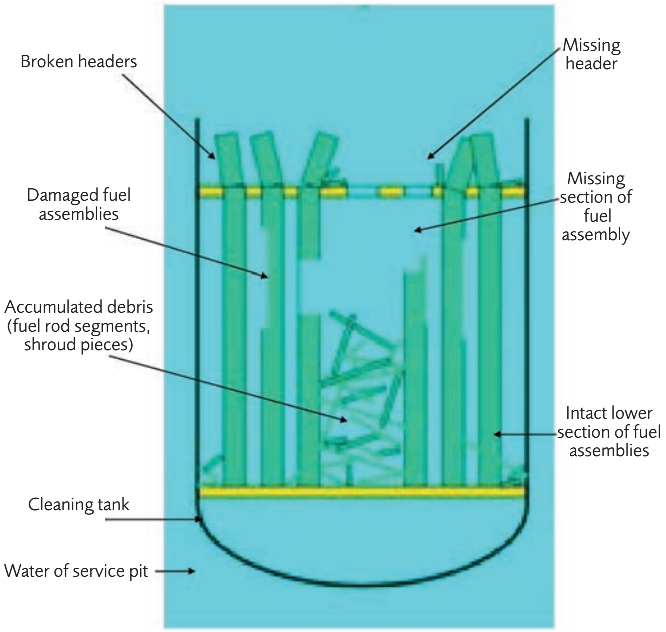

Figure 5 – Distribution of damaged fuel in the cleaning tank[3]

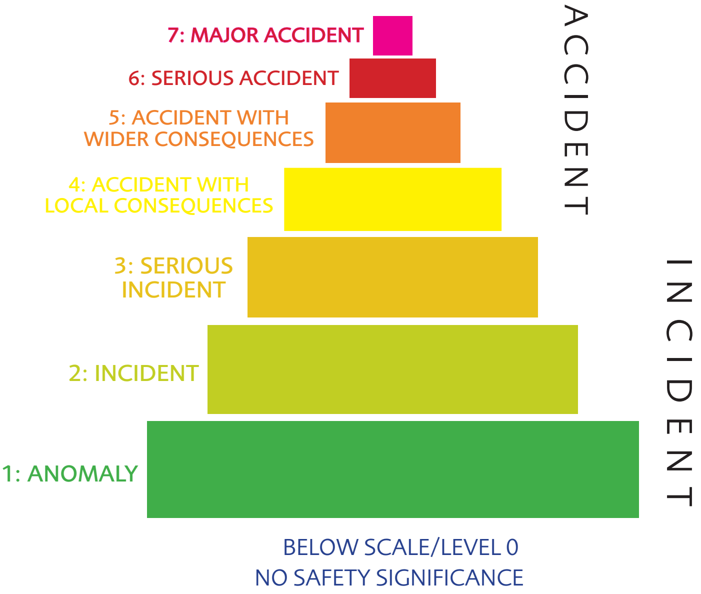

Figure 6 – IAEA INES scale[2]

simultaneously. The new, so-called AMDA instrument arrived and was placed in the refuelling pit beside the reactor of Unit-2 in the beginning of 2003.

It worked in two modes – operational mode 'C' and mode 'B' (Figure 3).

In mode 'C' the medium of mass flow rate of 200-250 t/h enters the cleaning module of the AMDA system, where the dissolved magnetite and heat are removed from the solute. After finishing the cleaning process, the system is changed over to mode 'B' where a submersible pump of 20 t/h mass flow capacity circulates the coolant of the refuelling pit through the cleaning tank in an open loop. On 10 April 2023, during the cleaning tank opening process – using the reactor hall crane – and during the loading and removing of the fuel assemblies, the AMDA system was cooled in the 'B' operational mode.

Figure 4 shows the sequence of events on 10 April 2003.

Damage to the fuel assemblies

The damage to the 30 fuel elements was very serious, as it appeared that elements had been broken and uranium pellets had fallen to the bottom of the cleaning system. Oxidation in high temperature steam took place in the cleaning tank for several hours, which resulted in the embrittlement of the fuel assembly shrouds and the fuel pin claddings. At the opening of the cleaning tank, the injection of cold coolant caused the breaking up of the embrittled shrouds and fuel pin claddings.

Consequences and the INES scale

The INES scale is applied for facilitating the information of the population based on a system which evaluates all safety-related events in unified, internationally established criteria. The classification of the events is helped by a manual published by the IAEA[2]. Although the INES scale was developed as a means of providing prompt information, there may be cases when full understanding and evaluation of the event is time-consuming or when detailed analyses may later lead to re-classification. The INES has seven levels: Level 1 contains anomalies; Levels 2 and 3 contain incidents, Levels 4-7 list accidents (see Figure 6).

The event in Paks nuclear power plant was first classified as INES Level 2 based on its environmental effects but after realising the extent of the fuel assembly damage on 16 April when the vessel lid could be lifted, the event was re-evaluated. It was characterised by the condition of the fuel assemblies rather than by the environmental effects whereupon the event was necessarily re-classified to INES Level 3.

Key findings

This section highlights some important findings from the investigation which could form a good basis for learning not only in the nuclear but in other process industries too.

There were different technical issues that contributed to this event; the most relevant findings are described below.

Design deficiencies

Apparently, the design of the cleaning system was deficient because the submersible pump provided for mode 'B' was inadequately sized and did not have adequate redundancy or back up. This is very similar to past incidents related to chemical runaway reactions when the cooling system of the reactor was inadequately sized and there was no redundant system in place. In other cases, the emergency relief system was inadequately sized and could not release the overpressure created by the exothermic reaction.

The bypass flows around the fuel assemblies were not fully considered in the thermo-hydraulic analysis of the design.

The operators were unable to follow-up the process because there were no temperature sensors installed in the tank. This is very similar to the past events within the process industry,

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where lack of proper instrumentation led to blind operation (level, pressure, or temperature sensors).

It was believed that the fuel assemblies seating misalignment was due to only one fuel guide plate utilised in the cleaning tank to align the bottom of the fuel assembly in its correct seating location. Slight misalignment would reduce cooling flow.

Contractors

The investigation team determined that there was over-reliance on the contractor that had been selected for the design, management and operation of the fuel cleaning system. The responsibility for operation of the fuel cleaning system was turned over to the contractor.

The investigation found that the contractor worked without proper supervision of the plant. In general, personnel involved did not receive adequate training in the safety aspects of this specific operation. Additionally, operating and emergency procedures were not sufficiently developed.

Management of Change

The team found that the design and operation of the fuel-cleaning tank and system was not accomplished in the manner prescribed by the IAEA Safety Standards. The new cleaning process was untested — it was first used at Unit 2 at Paks NPP in 2001. Changes in the configuration of the cleaning tank design going from a 7-assembly cleaning tank to a 30-assembly cleaning tank was not considered to be significant.

Temporary procedures for the cleaning process completed by the contractors were not developed, controlled and revised by the site personnel.

Additional contributing factors

Time pressures related to a prescribed fuel outage schedule, combined with over-confidence generated by previous successful fuel-cleaning operations, contributed to a weak assessment of a new design and operation, which involved fuel directly removed from the reactor following a planned shutdown.

The investigation concluded that the national authority underestimated the safety significance of the proposed designs applied for the fuel-cleaning operation, which may have resulted in a less rigorous review and assessment.

The cleaning process was successfully completed for the first five batches without experiencing any problems. However, after finishing the sixth cleaning process the fuel was not removed from the cleaning tank immediately. The reason was that the crane used for this operation was busy with other tasks. At this time, the cleaning process was at mode 'B', therefore the coolant flow rate was much lower than in mode 'C' (see Figure 3). In addition to that, the fuel assemblies had been removed from the reactor a few days before rather than one or two years prior to the cleaning, as it was with the first five batches. That meant that these assemblies had significant residual heat. Combining that with the much lower flow rate in mode 'B', the coolant was not sufficient to remove the bulk of the decay heat.

Conclusions

The fuel-cleaning incident during a planned maintenance at the nuclear power plant described above shows similarities with planned shutdown and maintenance activity failures in the oil, gas and chemical industries. The selection and recruitment of contractors played a significant role in many incidents and a lack of supervision has contributed to past chemical accidents too. The design deficiencies are not unique to this particular case either, or the change from the original design.

Analysing past events that occurred in other industries enables a wider understanding and cross-sectorial learning to others. It is also proven that events that occurred decades ago still have relevance in learning key lessons — hence the reason it is crucial to tell these stories very often to transfer the knowledge to new generation or to those professionals who are new to process safety.

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