Report
to the Chairman of the Hungarian Atomic Energy Commission

on the Authority's investigation of the incident at Paks Nuclear Power Plant on 10 April 2003

(Identification number of the event: 1120)

Hungarian Atomic Energy Authority

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CONTENTS

I. INTRODUCTION 3

II. FEATURES OF THE EVENT 3

II. 1 IDENTIFICATION 3
II. 2 BRIEF DESCRIPTION OF THE EVENT 3
II. 3 THE INES CLASSIFICATION OF THE EVENT 3

III. ANTECEDENTS AND EVALUATION OF THE EVENT 4

III. 1 GENERAL VIEW 4
III. 2 GENERAL VIEW OF DEPOSITION 4
III. 3 THE STAGES FOR INTRODUCING THE TECHNOLOGY 5

IV. TIMETABLE OF EVENTS 5

V. AUTHORITY PROCEDURES FROM THE BEGINNING OF THE EVENT 7

V.1 AUTHORITY ACTIONS RELATED TO THE EVENT AT THE HAEA NSD 7
V.2 OPERATION OF THE HAEA EMERGENCY RESPONSE ORGANIZATION 8

VI. SPECIFICATION OF THE CAUSES OF THE EVENT 9

VI.1 DIRECT TECHNICAL CAUSES OF THE EVENT 9
VI.2 THE TECHNICAL ROOT-CAUSE OF THE EVENT 10

VII. LEGAL, TECHNICAL, AND QUALITY-MANAGEMENT NON-COMPLIANCES 11

VII.1 LEGAL NON-COMPLIANCES 11
VII.2 TECHNICAL NON-COMPLIANCES 11
VII.3 NON-COMPLIANCES IDENTIFIED IN THE FUNCTIONING OF QUALITY MANAGEMENT 12

VIII. ANALYSIS AND EVALUATION OF THE ACTIVITIES OF THE OPERATOR 13

VIII.1 MANAGING THE CLEANING TECHNOLOGY BEFORE STARTING OPERATIONS 13
VIII.2 GENERAL EVALUATION 13
VIII.3 ACTIVITIES OF THE PERSONNEL IN THE COURSE OF THE EVENT 13
VIII.4 OTHER PERSONAL AND MANAGERIAL PROCEDURES 13

IX. NUCLEAR SAFETY, EMISSIONS AND ENVIRONMENTAL EFFECTS 14

IX.1 ENVIRONMENTAL EMISSIONS OF RADIOACTIVE MATERIAL 14
IX.2 RADIATION PROTECTION ACTIONS FOLLOWING THE EVENT 15
IX.3 SAFETY OF THE CLEANING VESSEL 15

X. ACTIONS TO BE CARRIED OUT 16

XI. EVALUATION OF THE ACTIVITIES OF THE NSD 16

XII. EVALUATION OF THE REPORT SUBMITTED BY PAKS NPP ABOUT THE EVENT 17

XIII. ABBREVIATIONS 17

I. INTRODUCTION

A serious incident happened at Unit 2 of Paks Nuclear Power Plant on 10 April 2003. In this report the main findings of the regulatory investigations are summarized for the Chairman of the Hungarian Atomic Energy Commission (HAEC). The event was investigated by an expert team of the Nuclear Safety Directorate (NSD) of the Hungarian Atomic Energy Authority (HAEA). During the investigation workers and leaders of the NPP and of the organization FRAMATOME ANP (FANP) involved during the design, preparation and application of the process or during the event itself were interviewed, in addition to which documents, video tapes and data were collected. On-site investigations based on pre-prepared plans were carried out at the NPP on 17, 24 and 29 April. Additional hearings were arranged in the framework of videoconferences to deal with questions raised during the evaluation of the interviews as well as those relating to the analyses of the NSD.

The results of the investigations were presented to the Director of the NSD and to the Director General of the HAEA in a comprehensive report. The main facts and conclusions of this comprehensive report are presented here for the Chairman of the HAEC.

II. FEATURES OF THE EVENT

II. 1 Identification

On 10 April 2003 while the assemblies were being cleaned during the course of the annual maintenance of Unit 2, severe fuel assembly damage occurred whereupon radioactivity was emitted that exceeded the value of the normal emission of a working unit.

II. 2 Brief description of the event

Annual maintenance took place at Unit 2 on 10 April 2003 according to schedule. The cleaning of the fuel assemblies was carried out in Pool 1. The inner elements of the reactor were being cleaned at the same time. The cleaning of the fuel assemblies that was taking place in the cleaning vessel was completed at 16.55 while the cleaning of the inner elements of the reactor was still in progress. The cooling of the cleaning vessel was maintained at 37°C by FANP personnel. The cooling water was circulated by a submersible pump. At 21:53, radioactive Kr-85 was detected by the detectors mounted on the cleaning equipment and the reactor`s noble gas concentration meter indicated alarm level. Co-incidentally, the dosimetric systems mounted in the ventilation stacks indicated a sudden increase in noble gas emission. The engineer on duty suspended work in the reactor hall and ordered the evacuation of the area. An emergency maintenance working group was called together to evaluate the event and to determine what steps to take. They decided that the main tasks should be to open the lid of the cleaning vessel, to investigate the vessel visually, to analyse the water covering the vessel and – if possible – to identify which assembly/assemblies was/were leaking.

The hydraulically locked cleaning vessel lid was opened at 02:15 by FANP. Suddenly an increase in the activity concentration was detected by the radiation protection monitoring system and the water level in the spent fuel pond decreased by about 7 cm. The attempt to lift up the covering lid of the vessel failed since one of the three cables broke. After the successful lifting of the lid on 16 April 2003, severe damage of the assemblies could be observed by video camera investigation.

II. 3 The INES classification of the event

The International Nuclear Event Scale (INES) 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 International Atomic Energy Agency. 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. On 11 April, classification of the event was carried out in accordance with the appropriate directive of HAEA NSD. After a long discussion the event was classified as INES Level 2 on the basis of its environmental effects. With this classification the HAEA NSD assumed a small-sized fuel leakage, with no significant fuel damage - based on the information received from the NPP. Staff at Paks NPP realised the extent of the fuel assembly damage on 16 April when the vessel lid could eventually be lifted. Based upon this new information the event was re-evaluated. The event 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.

III. ANTECEDENTS AND EVALUATION OF THE EVENT

III. 1 General view

The items investigated in this report assume greater importance if analysed as elements of a long-term trend.

The deposits that necessitated the cleaning of the fuel assemblies were first identified in 1996 in Unit 2 and this phenomenon led to a full change of fuels in the core in the middle of the 1998 campaign. A precise and detailed analysis of the causes of the deposits has not yet been completed; however, it is known that magnetite deposits are related to the decontamination work carried out earlier on Units 1-3. The reason for quickly carrying out the decontamination was because of the earlier over-long postponement of the replacement of the feed-water collectors of the steam generators.

Handling of the first event in 1998 was unique, after the exchange of all fuel assemblies of Unit 2 in 1998, the problem seemed to be solved judging from the evaluation by the NPP`s management. In the year 2000 new deposits were detected and had aggregated so much in Unit 3 by the year 2002 that it had to be shut down in February 2003 and a full fuel exchange was carried out. When the unit was restarted core asymmetry was, due to an incorrect fuel assembly emplacement, detected. Therefore, this unit has been operating at decreased power since that time. These events were followed by the incident that occurred during the cleaning of the fuel assemblies of Unit 2, and which is the subject of this report.

III. 2 General view of deposition

Deposits of magnetite on the fuel assemblies necessitated the cleaning. The emission of corrosion products from the steam generators is unavoidable and it is taken into account in the design of all NPPs. In normal conditions it is managed by filtering the feed-water and by regular changes of the fuel. In the course of steam generator decontamination, starting on Unit 2 in 1996 and carried out to an increased extent in 2000-2001 on Units 1-3, the last step, passivation, was not carried out carefully enough. Magnetite production suddenly increased causing an imbalance between magnetite production and filtration, magnetite deposits in the fuel assemblies increased and the cooling water flow-rate decreased. Consequently, the power of Units 1-3 had to be decreased; later, full refuelling became necessary in Unit 3. Finally, Paks NPP stopped the decontamination work and ordered cleaning to start.

In 2000 and 2001 Siemens KWU successfully cleaned 170 assemblies that had earlier been partially burned-out and subsequently removed from Unit 2. The cleaning was executed with a standard technology having good references and in a vessel containing seven assemblies at one time.

In 2002 Paks NPP commissioned FANP, the legal successor of Siemens KWU, to develop a vessel containing 30 assemblies and the cleaning technology for it.

In conclusion it can be stated that, due to the widely and most probably not appropriately applied steam generator decontamination, the fuel cleaning was unavoidable and that the technology selected had previously been used successfully in a 7-assembly equipment.

III. 3 The stages for introducing the technology

The 7-assembly cleaning technology was considered by the Authority as a modification of a spent fuel handling system. In the safety classification of nuclear equipment (SCNE) system the operation was assigned to SCNE Grade 3, similarly to the other fuel assembly handling and transporting equipment.

According to the Nuclear Safety Standards (NSS), for elements having SCNE Grade 3 classification, licenses issued by the internal independent unit of the licensee are needed for production, import, or installation. There was no need to license the operation of the equipment since the cleaning was to be carried out only once, after which the equipment was to be dismantled. Thus, licensing, in accordance with the relevant regulation, meant the execution of a process of modification licensing in principle.

The safety report, as a part of the licensing documentation, stated that the chemical cleaning technology can safely be applied, the cooling of the assemblies is ensured, the system is subcritical and the waste is manageable.

According to the license application, the 30-assembly system deviates from the previous one only in the capacity of the vessel and in the chemical classification of the cleaning process. Because of the late submission of the documents, Paks NPP requested that the matter be treated with urgency by the Authority. The application was examined and evaluated in accordance with the relevant regulations and internal orders by the NSD. The effects of the chemical process were emphasised in the application, in the safety measures, in the emergency measures, and during the licensing process. After checking the safety measures described in the documentation submitted, the Authority concluded that the subcriticality of the assemblies in the cleaning vessel is ensured, the cooling is sufficient during cleaning (mode C) and during the loading/unloading of the assemblies (mode A), as well as during the temporary stages (mode B) of opening/closing of the vessel lid. The measures planned for incident prevention were investigated and evaluated in the course of the licensing process.

The correctness of the grading to SCNE-3 was confirmed after a repeated review.

In conclusion, in the licensing process of both the 7- and 30- assembly systems, the NSD evaluated the documents according to SCNE Grade 3, the classification based on the safety importance of the cleaning technology and the cleaning vessel.

IV. TIMETABLE OF EVENTS

The sequence of the events and the action taken are summarized in the table below. Times are given in the first column, the second comprises a description of the event and the characteristic data.

Time	Event
10 April, Thursday	
16:00	Cleaning of the 6th set of assemblies is completed on Unit 2 but the assemblies could not be unloaded since the crane used for lifting the lid of the vessel had earlier been moved to assist cleaning of internal elements of the reactor of Unit 2.
16:40	AMDA is switched to mode B, the assemblies in the vessel are cooled with a D003 submersible pump by circulating the water of Pool 1, which contains the cleaning vessel.
19:19-19:20	Slow increase in the water level of the pressurizer holder tank of Unit 2.
21:50	Sudden increase in the count-rate of the Kr-85 detector of AMDA.
21:53	Warning signal on the noble gas detector located on the reactor platform of Unit 2; the measured value is 1700 kBq/m^3.
22:02	The dose rate is 2 mSv/h at the volume compensator tank of AMDA, and 50 μSv/h at the noble gas outlet. FRAMATOME personnel explain it by fuel rod leakage.
22:17	Noble gas concentration is 18,300 kBq/m^3 on the reactor platform of Unit 2.
22:30	Dose rate is 20 mSv/h at the volume compensator tank. Up to this time 3 noble gas outbursts with an accumulated Kr-85 count number of 100,000 were detected.
22:50	Reactor hall is evacuated on order of the dosimetry leader on duty.
23:00	Noble gas emission increases to $6*10^5$ MBq/m^3.
23:30	The engineer on duty calls together the special meeting of the Maintenance Working Group for 01:00 on 11 April.
23:45	The engineer on duty orders the ventilation of the reactor hall to be switched to full capacity
23:55	Noble gas emission increases to $1.5*10^6$ MBq/m^3.
11 April, Friday	
01:55	End of meeting of the Maintenance Working Group having reached the decisions: - to lift the lid of the cleaning vessel - to try to identify the leaking assembly/assemblies -to prepare for transfer of the leaking assembly/assemblies to the spent fuel pond - to unload assemblies from the cleaning vessel after completion of the cleaning of the reactor and continue the cleaning programme.
02:15	Immediately after opening the hydraulic lock of the cleaning vessel lid the dose rate increased significantly (6-12 mSv/h) in the vicinity of the spent fuel pond and Pool 1. Increase in the emission via the stack. Water level in the spent fuel pond decreases in a short time by about 7 cm.
02:21	Water sample taken from the spent fuel pond indicates leakage of fuel assembly/assemblies.
04:20	Unsuccessful attempt to lift the lid, one of the lifting cables breaks.
06:30	Dose rate in the middle of the surface of Pool 1 is 60 mSv/h, at the edge close to the platform stairs it is 30 mSv/h, close to the spent fuel pond it is 15 mSv/h.
07:45	The radioiodine emission accumulates to 142.6 GBq[1].
09:00	Maintenance Working Group meeting. Actions to be taken: - check position of vessel lid - compile dosimetric trends - analyse water samples radiochemically.
09:00	Dose rate at surface of Pool 1: 30 mSv/h in the middle; 15 mSv/h towards platform stairs; 0.8 mSv/h towards spent fuel pond.
12:40	Director of Safety orders partial alarming of Emergency Preparedness Unit (communication and evaluation).
13:15	The engineer on duty introduces measures regarding ventilation through the reactor hall to decrease emission.
16:00	Investigation concludes that the lid became stuck leaving a gap of about 15 cm on one side and about 2 cm on the other side. Outflow of warm water from the gap is found.
20:00	Further measures introduced by the engineer on duty to decrease emission.

[1] Emission data became available later.

20:20	Radioiodine emission in the last 4.5 hours is 38.1 GBq, the effects of emission decreasing interventions introduced at 14 o'clock is seen.
24:00	The daily noble gas emission is 160 TBq. Radioiodine emission in the last 3.7 hours is 3.9 GBq, the effects of emission decreasing interventions are clearly seen.
13 April, Sunday	
16:00	Director of Safety terminates the partial operation of the Emergency Preparedness Unit.
14 April, Monday	
afternoon	Ammonia and hydrazine are added to the water of the spent fuel pond to enhance filtering the iodine from the water.
16 April, Wednesday	
16:23	Lid of the cleaning vessel is lifted, no increase in emission.
20 o'clock	By visual (video camera) inspection, serious damage of the assemblies in the cleaning vessel is found.
22:30	Potential emergency (alert) is declared by Paks NPP, the Emergency Preparedness Unit is set into operation.
17 April, Thursday	
07:30	Maintenance Working Group meeting Actions to be taken: - preparation neutron flux and temperature measurements to ensure conditions for controlling subcriticality - ensuring cooling of the damaged assemblies: mounting new pumps, monitoring of conditions for the operating pumps - decrease of environmental emissions: coverage of Pool 1 and insertion of iodine filters into the suction-branch of the reactor hall ventilation.
18 April, Friday	
	Neutron flux and temperature monitors and an observation camera are mounted in the vicinity of the cleaning vessel in order to monitor the subcriticality and the cooling of the fuel, as well as to monitor the conditions of the vessel.
19 April, Saturday	
	Boric acid concentration in the spent fuel pond is increased to 16 g/kg to ensure subcriticality. Cooling pump of the cleaning vessel is changed for two new pumps with higher reliability. One pump is in operation, the other is a reserve that starts automatically if necessary. A plastic tent covers Pool 1 housing the cleaning vessel. Air is emitted from the tent through the operational ventilation system via filters.
20 April, Sunday	
09:00	The Director of Safety terminates work of the Emergency Preparedness Unit.
	Emission falls below the limits derived for one day.

V. AUTHORITY PROCEDURES FROM THE BEGINNING OF THE EVENT

V.1 Authority actions related to the event at the HAEA NSD

Paks NPP reported the event at 00:30 on 11 April to the NSD inspector on duty, who reacted according to the HAEA NSD rules. In this case, the first thing to be done is to collect additional information from the managers of the plant, and then to inform the leaders of the HAEA. With the knowledge of all relevant data, the NSD did not consider it necessary to take any special action but at the regular morning videoconference a detailed account was requested from the Safety Directorate of Paks NPP.

At the reconciliation meeting between Paks NPP and the NSD, the inspector on duty of the NSD concluded that, in accordance with the conditions of the incident, no interventions aimed at reducing or eliminating emissions should be licensed in advance: Paks NPP should act immediately. The NSD required additional information and started to evaluate the event; the NSD set up an ad-hoc investigatory committee.

In the framework of videoconferences, Paks NPP reported on the new developments concerning the events and the steps of action taken each day.

A principal element of the investigations involved hearings of managers and other staff of the NPP concerned with the design, preparation and application of the technology or in the event itself, as well as the collection of documents video tapes and data. HEAE NSD held on-site investigations based on pre-prepared plans on 17, 24 and 29 April. (It is mentioned here that the investigation on 17 April was not really successful since Paks NPP showed reluctance to give information.) HAEA NSD compiled a report based on the on-site investigations, the hearings, and on the data collected. The present document is a summary of that report.

NSD has continually issued resolutions aiming at the safe handling of the situation.

HAEA NSD asked its technical support organizations to analyse the main processes (criticality, cooling and flow conditions in the cleaning vessel) and also carried out analyses with its own instruments (see Chapters VI and IX).

NSD concluded on 21 April that because of the interventions that had been instigated the forthcoming actions of Paks NPP would not fall within the category of immediate incident prevention actions. Consequently, NSD restored the licensing processes.

A co-ordinated environmental radiological survey (including monitoring and evaluation) was initiated by HAEA, involving independent Hungarian organizations. In terms of providing the public with correct information, the main objectives were to obtain detailed radiological data and to provide an evaluation.

HAEA informed its partners and the supervising bodies. Early notification reports and a new INES report were prepared as part of the work of the HAEA Emergency Organization. The Director General of HAEA regularly informed the chairman of the HAEC and the secretariat for parliamentary relations of the Ministry of Economy and Transport. Regularly updated summaries were published on HAEA`s web site and a considerable number of media questions were answered.

In summary, the regulatory tasks of the HAEA NSD were continuously well performed, thanks to its well established inspection system and to the work of the experienced staff.

V.2 Operation of the HAEA Emergency Response Organization

The HAEA Emergency Response Organization was activated on 17 April on the decision of the Director General of HAEA. On the basis of the reports on the prevailing conditions and on the technological circumstances received from the Paks NPP, the HAEA Emergency Response Organization issued a press release and sent EMERCON reports to the International Atomic Energy Agency and to those countries having a bilateral agreement with Hungary on early notification. Moreover, INES classification reports were issued. In addition to written communications, oral questions of 18 newswriters and reporters were answered.

The work of the HAEA Emergency Response Organization was terminated and the normal inspection system was restored at 19:45, since no further changes in the situation were foreseen.

It can be stated that both the alarming and operation of the HAEA Emergency Response Organization were successful. One of the main conclusions of the event is that the principles and practices for providing the public with information in cases of emergency have to be revised.

VI. SPECIFICATION OF THE CAUSES OF THE EVENT

VI.1 Direct technical causes of the event

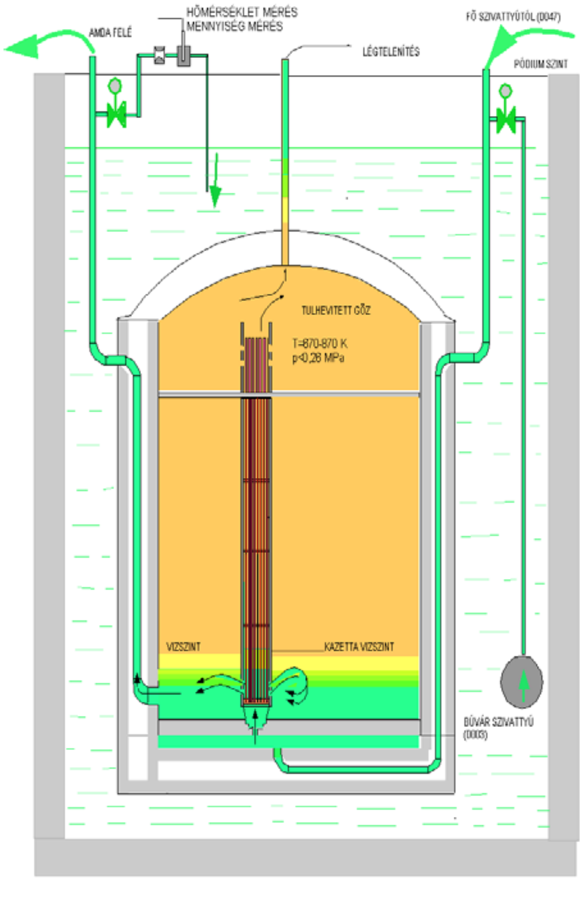
A thermodynamics and flow dynamics model taking into account every possible condition may well be able to determine the immediate causes of the event. The use of such a model became necessary since it was clear from the very beginning of the investigation that though the engineering considerations based on energy balance applied in the design proved to be basically correct, they did not reveal the failures carrying the potential danger.

Furthermore, it was obvious from the final stage that the fuel assemblies were overheated due to the remanent heat of the partially burned-out fuel elements. This became possible physically only if the flow of the cooling water along the fuel stopped and the assemblies were not covered with water. Such developments may arise in two ways:

- a significant quantity of air penetrated into the vessel,
- the production of gas took place.

Penetration of air was first assumed by the investigating committee but the information gained during the collection of data made this seem highly unlikely. Meanwhile the experts of HAEA NSD worked out a model of the internal conditions of the cleaning vessel. The available thermodynamics and flow dynamics models were utilized.

In the course of the refinement of the model an effect was revealed as a result of which the flow of the cooling water along the assemblies gradually decreased, while a by-passing flow through the small bore-holes of the assembly superficies proportionately increased. It is obvious that a decrease in the cooling water flow is coupled to an increase in the temperature. The speed of this redistribution process depends on the remanent heat production of the assemblies, on the capacities of the pump and on the number of bore-holes.



Scheme of the cleaning vessel at the phase of overheating (figure not in scale, and only one assembly shown).

Legend:

AMDA felé: to AMDA
Hőmérséklet mérés: Temperature measurement
Mennyiség mérés: Flow measurement
Légtelenítés: De-aeration
Fő szivattyútól: From main pump
Pódium szint: Platform level
Túlhevített gőz: Overheated steam
Vízszint: Water level
Kazetta vízszint: Water level in assembly
Búvárszivattyú: Submersible pump

The use of data valid for the incident showed that boiling of the cooling water commences in 2 hours and 10 minutes. This result coincides with the actual value reconstructed from the experiences of the incident. According to the model, about 1 hour after the start of boiling, a steam bubble of such a measure develops that a significant number of the assemblies are left without direct cooling. At that time the temperature of the assemblies increases by about16 °C/min if no heat removal is assumed. In reality, there existed a slight heat removal, partly via the so-called de-aeration tube and partly through the double walls of the vessel. The model that was utilized was unsuitable for determining the resultant maximum temperature. The severe damage to the assemblies was, most probably, caused by the sudden inflow of cold water when the vessel lid was opened and by the explosive production of steam.

In summary, judging from a reconstruction of the events, with the given capacity of the pump and the geometry of the vessel such an increasing by-pass flow developed through the bore-holes located on the assembly walls that the remanent heat caused the fuel assemblies to overheat.

VI.2 The technical root-cause of the event

The **presence of the bore-holes** cannot be regarded as the root-cause, since it was an **initial condition**. Basic technical causes can be found in the design and mode of operation of the vessel. According to the facts found during the investigation and to the licensing documents, the following non-compliances may well have played a role in the development of the events:

- the bottom location of the outlet of the inner vessel,
- the negligence of the bore-holes during thermohydraulic design and during design analyses,
- small cross-sectional area of the de-aeration tube,
- long-term operation in mode B,
- neglecting early opening of the lid,
- imprecise positioning of the bottom end of the assemblies (potential),
- lack of instrumentation, mainly lack of in-vessel temperature measurement, of the cleaning vessel,
- lack of continuous data acquisition (continuous data acquisition would have led to earlier failure detection),
- lack of analysis of the difference between the outlet water temperature and the near-surface pool water temperature,
- there was only a rough measurement of the pool water level, and nobody even considered that data.

The order of the events above reflects a certain order of importance. Location of the outlet **at the top** of the inner vessel would alone have prevented all the subsequent problems. Assuming that the outlet had been located **at the top** of the inner vessel, it follows that the cooling water is always led out from the hottest point, therefore simple heat balance analyses would have been satisfactory for determining whether there is adequate cooling.

Two other aspects of the main basic causes are worth a closer look: If the presence of the **bore-holes had been taken into consideration,** *a properly detailed* hydraulic analysis would have revealed that the cooling of the assemblies was inadequate; and a warming up process with positive feed-back commences.

The non-compliance of the criterion for imprecise positioning of the bottom end of the assemblies seems to be obvious but it is not proven that there were really imprecisely positioned assemblies (though neither can it be excluded). It is important, however, that in the case of such a long operation in mode B **overheating starts even without false positioning.** False positioning might simply quicken the process to some extent.

It may be stated that the location of the cooling water outlet at the bottom of the cleaning vessel should be considered as the technical root-cause of the event leading to severe fuel damage.

VII. LEGAL, TECHNICAL, AND QUALITY-MANAGEMENT NON-COMPLIANCES

In the course of the regulatory investigation the HAEA NSD analysed and evaluated the cleaning technology, the conditions for design, licensing and operation, as well as the processes for mitigation of the incident and its consequences. The revelation of the insufficiencies, deviations from the regulations, and false activities (hereafter: non-compliances) leading to the incident, was the goal of the analysis.

Non-compliances related to the activities of the operator are given in Chapter VIII, the activities of the Authority are evaluated in Chapter IX.

VII.1 Legal non-compliances

Legal non-compliance basically means any deviations from the regulations described in various volumes of the Nuclear Safety Standards (NSS) and any insufficiencies in the NSS themselves. It is important to mention that in the present state of the investigation, no full listing of the insufficiencies of the NSS is possible, instead a number of basic problems can be pointed out:

The Licensee and its commissioned partner (FANP) deviated from the NSS in the following way[2]:

- The removal of the **remanent heat** was not ensured in mode B.
- The simple heat balance calculations used to **demonstrate safe heat removal** by the constructor and the customers of the cleaning system are not appropriate.
- The philosophy of **defence in depth** was not consistently applied throughout the design of the cleaning vessel because it was assumed a priori that the development of any cooling insufficiency was excluded.
- There was no proper **instrumentation** and data acquisition.
- The protection against **single failure safety** was violated: in mode B only one pump was available.

Several insufficiencies of the NSS were also identified, their correction is the task of the NSD. No details are given in this summary, however, the full report lists all of them.

VII.2 Technical non-compliances

There are two classes of technical non-compliance: the failures arising during the planning and preparation phases, and those arising during the operation and the incident.

Main insufficiencies of planning and preparation:

- The most serious technical error committed by the designers was the **omission of any detailed thermohydraulic analysis.**
- Following the considerations based on heat balance the designers concentrated **almost exclusively on the adequacy of the cleaning process:** in other words, the possibility of insufficient cooling - stemming from a malfunction - and its consequences were neglected in the analysis.
- A **false algorithm was used to estimate the number of damaged fuel assemblies,** therefore the seriousness of the situation was underestimated.

[2] The concise report identifies all points of NSS that are violated by the factors listed here.

- The **time** between the termination of enforced flow and the **start of boiling** was erroneously determined.
- **No by-pass flow was taken into account** in the thermal safety analysis, though the bore-holes on the assemblies caused a significant decrease of cooling efficiency.
- There are basic **construction differences** between the 7-assembly vessel used earlier and the present one housing 30 assemblies. These differences were analysed only from the viewpoints of the efficiency and criteria of cleaning.
- The **loss of chemicals** used for cleaning is analysed only for small leaks, the full loss following the emergency opening of the cleaning vessel was not investigated.
- It is erroneously and groundlessly stated that the **full loss of electricity supply** has no effect on safety.
- The **incident management procedure** described in the operating manual of the AMDA system was not achievable.
- The **criterion for positioning** the assemblies is not unambiguous and not necessarily appropriate.

Non-compliances during operation[3]

- FANP personnel operated the cleaning system, **Paks NPP staff acted only as co-ordinators**.
- In mode B, only one pump remained operable, this **violates the principle of the tolerance to a single failure**.
- There were many shortcomings of **radiation protection instrumentation**.
- There were **no instructions nor documents** available for handling incidents.

VII.3 Non-compliances identified in the functioning of quality management

The technical, personnel, management and administrative non-compliances mentioned above call attention to significant problems in the functions of the quality management system. The most important problems are given below[4].

- Paks NPP has not regulated **the control of the cleaning process** appropriately.
- In activities related to the cleaning procedures **the responsibilities and terms of reference** were not prescribed for a number of important participants.
- The enforcement of the **overall responsibility of the Licensee** (Paks NPP) was not even discussed.
- During the preparation and execution of the task, the **responsible technical unit played an overwhelming role** at the expense of safety aspects.
- The operating staff, including subcontracting staff, **did not fully understand the dangers of the process.**
- Paks NPP **carried out the safety analyses before detailed plans had been completed**.
- Paks NPP endangered safety by applying the **principle of "blind" trust** towards its contractor.

In summary it can be stated that besides the construction problems described in Chapter VI, there are non-compliances that contributed to the events. Such insufficiencies are found in the areas of compliance with legal instruments, in elements of the legal instruments, in design and operation, and in the quality management system of the operator. At the same time, from the viewpoint of this investigation, the insufficiencies and errors revealed did not influence significantly the consequences of the event.

[3] The concise report identifies all points of NSS that are violated by the factors listed here.
[4] The concise report identifies all points of NSS that are violated by the factors listed here.

VIII. ANALYSIS AND EVALUATION OF THE ACTIVITIES OF THE OPERATOR

The main goal of this chapter is to analyse the role of the human factor in the event. The HAEA NSD report describes all revealed deviations and non-compliances. Here, the major findings are summarized.

VIII.1 Managing the cleaning technology before starting operations

The most important personal non-compliances are the following:

- The **team dealing with the deposits** carried out the preparations for applying the cleaning. The members of the team worked part-time on this job and without an appropriate order of procedure.
- There was no **responsible co-ordinator** of the team.
- Due to short deadlines the Safety Directorate of Paks NPP submitted, in several cases, non-compliant applications to HAEA NSD.
- Paks NPP modified the cleaning process because of former negligence. The negligence and its explanation **violate the principle of priority of safety against any other aspects,** in all uses of nuclear energy.
- In the license in principle operation in mode B was **limited in time**, this limitation was omitted from the working programme.

VIII.2 General evaluation

- Handling and prevention of the event was carried out in **a poorly arranged way.**
- Despite lack of knowledge Paks NPP did not handle the situation sufficiently conservatively, though such approaches had earlier been criticized by HAEA.

VIII.3 Activities of the personnel in the course of the event

The most important deficiencies revealed in the decision making process are:

- The Maintenance Working Group **did not work according to its own order of procedure**. Members of the Maintenance Working Group in general and some members specifically had insufficient information and were therefore not able to evaluate the situation or to formulate instructions at the beginning of the event.
- Consequently, the Maintenance Working Group **underestimated** the severity of the situation and reacted late.

About the activities of the operating staff:

- There was no clear **distribution of tasks** between the staff of Paks NPP and the staff of FANP.
- There was no unambiguous and reliable **communication channel** between the partners.
- The engineer on duty falsely **evaluated** the severity of the case. Some orders of procedure were missing that would have helped him.
- The switching on of the reactor hall ventilation was **a decision justified** on the basis of the information available that time. Nevertheless, the order to decrease maximum ventilation was issued too late.
- The operating personnel placed greater reliance on **directions from the management** in solving the problem than was justified.

VIII.4 Other personal and managerial procedures

Several factors not directly related to the event also influenced the handling of the event:

- On several occasions in the past, HAEA NSD had remarked on the insufficiencies of Paks NPP in the field of **safety culture.**
- The **ongoing changes in the organization** of Paks NPP played a negative role.
- Decisions are formally collective, **one-man responsibility** does not dominate**.**
- HAEA NSD had several times called attention to **insufficiencies revealed in the Safety Directorate** of Paks NPP. Applications were received with lack of appropriate quality

control, there was a certain lack of expertise, and the activities of the Safety Department were poorly organized.

In summary, it is obvious that – besides errors in planning, technical errors and errors in supervision – problems associated with organization and safety culture at Paks NPP have represented contributory causes of the incident.

The decision mechanism at Paks NPP that dilutes responsibility but complicates matters is to be mentioned as organizational insufficiency. In the decision making process technical aspects and points of nuclear safety may become overshadowed.

Insufficiencies, and a continuous degradation of safety culture can be detected. The attitude to safety is pushed into the background and, together with this, an exaggerated self-confidence in the management and the overwhelming enforcement of the interests of production prevailed.

Ongoing organizational and operational changes did not strengthen the commitment to nuclear safety.

IX. NUCLEAR SAFETY, EMISSIONS AND ENVIRONMENTAL EFFECTS

IX.1 Environmental emissions of radioactive material

According to preliminary data 410 TBq noble gases, 360 TBq radioiodine, and 2.5 GBq radioaerosols were emitted in the first two weeks of the incident. One half of the noble gases, predominantly Xe-133 and Kr-85m, and the great majority (95%) of the activity of the radioiodines (expressed in I-131 equivalent), were released in the first day. The time distribution of the radioaerosol emission was similar to that of the radioiodines, though the quantities were much lower.

The atmospheric emissions were monitored by continuous measurements of the NPP, samples taken regularly were analysed in laboratories.

Authority control of emissions was executed by the Lower Danube Valley Environmental Chief Inspectorate and supplemented by the measurements of the environmental authority itself. At the time of the compilation of this summary the results of the 22-23 May authority measurements and the official values of the atmospheric releases and liquid discharges were not available.

In the first hours of the incident the environmental effects of the noble gas plume were detected by the telemetric environmental monitoring station A1 located 2000 m north of the stack (downwind direction). Later no dose rate increase attributable to the incident was detected by any of the telemetric monitoring stations.

From the morning of 11 April onwards, the Environmental Laboratory of the plant monitored daily the area of the NPP and its vicinity.

Reliable information was gained on the small values of deposition by comparing the data obtained by various methods.

Measurements made by state-of-the-art mobile dose rate meters supplemented the data of the telemetric stations.

The vicinity of the plant was painstakingly and comprehensively monitored by the NPP staff. Results of the daily measurements were recorded.

The maximum individual dose for the most exposed members of the population was found to be 0.13 μSv as obtained by model calculations based on measured radiological and meteorological data. This value is equivalent to about 1 hour dose from natural background radiation.

On 14 April, the Director General of the HAEA initiated a **co-ordinated environmental monitoring programme with participation of the leading laboratories** (laboratories of the Ministry of Agriculture and Regional Development, National Research Institute for Radiobiology and Radiohygiene, State Public Health and Medical Officers' Services, National Emergency Management of the Ministry of the Interior, KFKI Atomic Energy Research Institute, National Meteorological Service). The main objective of the programme is to collect and disseminate detailed data in order to provide reliable information to the public. These results may later be utilized to verify the atmospheric and dosimetric models applied to help in decision-making in nuclear emergencies.

Activity concentrations of 0.5-500 Bq/kg(wet) were obtained from analysis of grass samples and from on-site measurement, the typical range extended from 1 to 10 Bq/kg.

The radiation burden of the population via the food-chain can be excluded because of the delay between the uptake of radiation from the soil and its manifestation in the vegetation. This is proved by the fact that no I-131 activity was found in milk samples.

Estimations carried out by sophisticated dose models confirmed the results of the dose estimates of the NPP.

According to the results of the country-wide survey the exposure of the population due to the incident was and is negligible.

IX.2 Radiation protection actions following the event

After the event, monitoring activities and instructions became more complicated than usual in the main building housing Units 1 and 2.

The use of breathing masks (first with fresh air, later with filters) was prescribed in the reactor hall, due to the contamination of the air volume. With the exceptions of the reactor hall and the hermetic space the level of contamination was insignificant.

As a result of the effective actions both the individual dose and the collective dose of the staff was kept below the authorized limit and was as low as reasonably achievable. The internal dose due to inhalation of radioactive material was also lower than the limit.

The radiation protection actions were effective and professional.

IX.3 Safety of the cleaning vessel

The safety of the cleaning vessel is to be investigated from the following aspects:

- Degradation and state of the assemblies.
- Cooling condition of the assemblies.
- Reactor-physical condition of the vessel (criticality).

The degradation of the assemblies could be estimated from the videotape records taken after the lifting of the vessel lid. Following the description given by the Paks NPP as well as the assumptions made on the processes taken place before and after the opening of the lid, with a high probability the **cold water flooding of the vessel and the explosive production of**

steam caused the breakage of the fuel assemblies. As a result, parts of the assemblies below the upper spacing plate became damaged significantly, the assembly-heads moved upwards, some of them broke.

To ensure safe cooling of the damaged assemblies Paks NPP installed four submersible pumps (reserves of each other in pairs) at the cleaning vessel. Consequently, **the problem of safe cooling of the vessel has been solved**.

The reactor-physical condition of the vessel housing the assemblies (i.e. the subcriticality of the fuel in the vessel) was analysed in several separate ways. The calculations showed that **subcriticality was well-maintained** both for normal conditions and for assumed transients.

After the incident the **boric acid concentration in the vessel was increased to 16 g/kg, ensuring subcriticality for any case**.

X. ACTIONS TO BE CARRIED OUT

Based on the non-compliances revealed during the investigation (see Chapters VII and VIII), the HAEA NSD compiled a list of actions judged to be necessary as a means of eliminating the deviations and non-compliances. Six areas are covered by the actions:

- Legal deviations
- Design deviations
- Deviations related to the operation of the system
- Decision-making and management at Paks NPP
- Organizational questions
- Safety increasing modifications

The detailed report of HAEA NSD contains the actual list of the recommended actions.

XI. EVALUATION OF THE ACTIVITIES OF THE NSD

On 30 April the Director General of HAEA set up a committee of three members independent of the NSD to investigate the licensing and supervisory regulatory actions related to the incident that took place on 10 April. The committee concluded its activities with a report, the main findings of which are as follows:

- Concerning the deposits, the NSD fulfilled its legal obligations. Based on the resolutions issued it can be stated that NSD worked with the care required to maintain the appropriate level of nuclear safety.
- Safety classification of SCNE Grade 3 of the cleaning equipment was correct from the viewpoints of the regulations and of the directives given by the International Atomic Energy Agency. However, the Authority, when accepting the classification, did not take into account the specific technical and safety-related viewpoint originating from the unique nature of the equipment. Had the HAEA NSD taken these specific aspects into account, it would have meant that supplementary documentation should have been submitted by the licensee.
- The safety classification determined the further area and rules of regulatory licensing. In the process of establishing the modification license in principle the Authority fulfilled the legal requirements. In the course of the second licensing procedure (licensing of the 30-assembly system), point 4.006 c) and d) of the NSS would have given a possibility for prescribing an operational license. However, based on the good experience gained in operating the 7-assembly cleaning, the NSD did not consider it necessary. The small insufficiencies found in the formulation of the resolutions did not influence the outcomes of the processes.
- The suitability and the possible consequences of the chemical process were emphasised in the licensing and supervisory procedures of the HAEA NSD. Only the existence of the

safety analyses related to criticality and cooling was investigated, their professional suitability was not checked.

- The supervisory activities of the NSD were carried out according to legal obligations. The radiological aspects of the cleaning system were investigated and no deviations were found. Other compliances of the operation, and the co-operation between the licensee and FRAMATOME were not supervised.

In addition to these conclusions of the committee, the examination carried out by HAEA NSD revealed that the **technical and intellectual capacities of the Authority** (including the contribution of the technical support organizations) ***enable HAEA NSD to carry out concise technical analyses of complex technical interventions, if necessary***. ***For the ongoing execution of such rigorous revisions of the analyses, however, there needs to be an increase in the Authority's resources.*** The extent and depth of the revisions of the technical analyses during the licensing procedures is not prescribed in detail neither in the Act on Atomic Energy or in its executive orders, nor in the Act on the Procedural Rules in Public Administration. After completion of the present investigation and bearing in mind the conclusion, a revision of the requirements and supervisory system concerning nuclear safety related activities seems to be reasonable. Similarly the resources of the Authority should be re-evaluated.

XII. EVALUATION OF THE REPORT SUBMITTED BY PAKS NPP ABOUT THE EVENT

During the investigation, the HAEA NSD also evaluated the report compiled by Paks NPP. This evaluation has not been completed, therefore the remarks formulated here reflect the conclusions of this time and may change later on. Further detailed comments are given in the concise report of the NSD.

In general it can be stated that Paks NPP tries to reveal in the report the causes leading to the event. Taking into account the relatively short time available for the preparation, **the report is appreciable in content and acceptable by its format.**

It is emphasized in the report that questions of **personal** responsibilities **are not discussed** since that is the target of a separate investigation. The investigation of the responsibilities of the personnel is practically restricted to the staff of FANP, therefore in this respect the report is **somewhat incomplete.**

The discussion in the report is one-sided, there is a **lack of self-criticism.**

It is stated in the concise NSD report discussing the Paks NPP report in detail that the latter should be **supplemented and, in several instances, modified** in order to comply with the formulated requirements and to fill in the gaps.

XIII. ABBREVIATIONS

AMDA	Automatic Mobile Cleaning Assembly
EMERCON	Emergency Convention (on early notification)
FANP	FRAMATOME ANP
HAEA	Hungarian Atomic Energy Authority
HAEC	Hungarian Atomic Energy Commission
INES	International Nuclear Event Scale
NPP	Nuclear Power Plant
NSD	Nuclear Safety Directorate (of HAEA)
NSS	Nuclear Safety Standards