INCREASING THE LEAK-TIGHTNESS OF HERMETIC ZONE AND OTHER IMPORTANT COMPONENTS IN NPPS

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1 Increasing the leak-tightness of hermetic zone in VVER 440 NPPs

1.1 Function of the hermetic zone

The hermetic zone is a system of hermetic compartments at a given reactor unit with its external boundary being under operation hermetically isolated from the external atmosphere. The hermetic boundary is the last barrier preventing leakage of radioactive products to the environment.

The purpose of the hermetic zone and its localising systems is to minimise potential radioactive leakages in long-term and to mitigate consequences of LOCAs (Loss-of-Coolant Accident) on the environment.

The hermetic boundary consists of a reinforced concrete structure dimensioned to withstand the DBA (Design Basis Accident) and of technological components such as:

- liner (stainless steel liner 3mm, carbon steel liner 4mm – V 230; 4mm and 6mm – V 213),
- hermetic doors,
- hermetic hatches,
- technological penetrations, and
- other technological components penetrating through the hermetic boundary.

The efficiency of localisation depends on a successful implementation of their functions by all localisation components and systems. The decisive factors are the leak-tightness and strength of the hermetic boundary and its components.

Technical safety of a NPP is directly proportional to the integrity of hermetic compartments and their hermetic boundary that forms the so-called third barrier for radioactive fission products on their way out from the hermetic compartments and houses the reactor coolant (primary) circuit. Speaking about integrity of the hermetic compartments, we mean their strength and leak-tightness.

1.1.1 Leak-tightness of the hermetic zone

In pre-operational conditions, the hermetic zone undergoes a number of tests that are needed to verify the reliable function of the hermetic boundary (in compliance with the technical design, technical specifications, operating instructions, safety report as well as limits and conditions stipulated by the Slovak Nuclear Regulatory Authority (ÚJD SR)).

The purpose of operational periodical integrated leakage rate tests (ILRT) is to determine the actual leak-tightness of the external hermetic boundary at an overpressure corresponding to the design pressure anticipated under LOCA conditions.

During reactor refuelling outages, the following operational tests are performed:

- local leak tests of individual hermetic components prior to and after repairs,
- individual tests of rooms,
- follow-up ILRT (performed at both overpressure and underpressure) with the purpose to detect leaks arisen during the process of operation,
- periodical ILRT performed each year at the end of the refuelling outage,
- pre-operational ILRT – 1st main ILRT with the purpose to determine the leakage rate and to verify the strength of the hermetic zone.

During the follow-up ILRT, by means of calculational methods, the leakage rate is determined anticipated during a LOCA type DBA.

The test may be performed in two stages:

- at an overpressure of 20 kPa (V-230) or 50 kPa (V-213), with the purpose to detect leaks on the hermetic boundary from outside; the test consists in pressurising the hermetic zone to a test overpressure and in such a way a pressure difference is formed compared to the external atmosphere,
- at an underpressure of about – 5 kPa, with the purpose to detect leaks on the hermetic boundary from inside; the test consists in vacuuming the hermetic zone.

1.1.2 Strength of the hermetic zone

Under normal conditions, it is expected that strength testing is performed always prior to starting up a new reactor unit and later on during operation after each substantial intervention into the hermetic boundary after a previous approval from the Regulatory Authorities.

Under the test overpressure, the external hermetic boundary is adequately tested not only for its leak-tightness but also for its strength.

Strains are measured by means of resistance strain gauges applied to the external and internal surfaces of the structure. Deflections are measured by optoelectric sensors or displacement sensors.

The purpose of the operational strength test is

- to verify the efficiency of performed resealing works and the static resistance of the civil structure under the test overpressure (measured strains and deflections of walls and ceiling slabs shall correspond to calculated values);
- to verify the static resistance of all hermetic boundary components inclusive of the isolation valves;
- to detect leaks on the hermetic boundary at a substantially higher pressure difference.

1.2 Methods for leak repair

The methods used depend on the location and type of detected leaks.

The most common methods are welding, application of sealing compounds, pastes and foams.

Leak detection and repairs on the hermetic boundary (except for common resealing works) are expensive since in most cases the leaks in question are hidden leaks on the hermetic liner covered by concrete.

In case of such hidden leaks, a higher level of leak detection and repair is needed than those commonly used which shall be accompanied with methods able not only to detect leaks themselves but, in addition, to detect the direction of leak propagation.

1.2.1 Injection of epoxide resins

This is the case when the cracks in reinforced concrete civil structures or spaces between the liner and concrete are filled with injection materials (epoxide resins) injected under pressure using special injection pumps. The following materials are used:

- double-component epoxide resin, and
- epoxide resin paste (sealing compound to seal the cracks) made by SIKA, Switzerland.

The injection materials are applied into the cracks sufficiently large to enable insertion of a wire with a minimum thickness of 0.3 to 0.5 mm. Then a PVC tube is slid on the wire enabling thus to fill the crack with the injection material.

1.2.2 Injection of polyurethane materials

The largest locations with secondary leaks need repairs using injection materials able to provide for leak-tightness of reinforced concrete walls. These are particularly locations with leaks inaccessible for common injection using epoxide resins.

Polyurethane injection materials meet these criteria and may be used for leak-tight applications to concrete structures. Approximately 35 seconds after the application, polyurethane materials expand.

1.3 Results obtained in the field of resealing works

VÚEZ holds qualification certificates to perform resealing works in the hermetic compartments/containment of VVER 440 and VVER 1000 NPPs in Slovakia, the Czech Republic and Hungary pursuant to legislation and regulations valid in the aforementioned countries. In case of such activities to be performed in Bulgaria (Kozloduy NPP), it will be necessary to obtain approval of relevant Bulgarian Regulatory Authorities.

1.3.1 Jaslovské Bohunice V-1 NPP (Slovak Republic)

The most extensive works were performed at the Jaslovské Bohunice V-1 NPP Units 1 and 2 since these are not only the oldest operating reactor units in Slovakia but also the technical status of their hermetic zone was very unsatisfactory at that time.

After a detailed analysis of the technical documentation on the hermetic zone and hermetic boundary components, it was decided to start the resealing works in 1990.

All the repair and resealing works were performed by qualified VÚEZ workers who participated also in leak detection and ILRT performance.

The leakage rate prior to the initiation of resealing works (r. 1990) was:

- Unit 1 - 5039%/24 h extrapolated to an overpressure of 80 kPa,
- Unit 2 - 7173%/24 h extrapolated to an overpressure of 80 kPa.

The leakage rate before the completion of the Gradual Reconstruction at the V-1 NPP (in 2000) was 54.57%/24 h and 42.14%/24 h at Units 1 and 2, respectively (see Fig 1).

1.3.2 Jaslovské Bohunice V-2 NPP (Slovak Republic)

The resealing works were initiated by VÚEZ in 1996.

The leakage rate prior to the initiation of resealing works was 16.37%/24 h and 15.32%/24 h at Units 3 and 4, respectively, extrapolated to an overpressure of 150 kPa.

The leakage rate in 2000 was 7.47%/24 h and 9.92 %/24 h at Units 3 and 4, respectively (see Fig 2).

The most common methods for leak repair used at these units were as follows:

- repair of hidden leaks by removal of cover concrete and subsequent welding (using the technology of water jet and electromechanical equipment),
- repair of hidden leaks by injection,
- implementation of structural changes of the hermetic liner in locations with leaking structural components (elimination of hidden leaks under the concrete and prevention of pressurised air spreading under the non-hermetic liner towards the hidden leaks).

1.3.3 Dukovany NPP (Czech Republic)

Resealing works at Unit 1 were initiated by VÚEZ in 1997.

The leakage rate from the hermetic compartments prior to the initiation of resealing works was 12.46%/24 h and 10.246%/24 h at Units 1 and 3, respectively, extrapolated to an overpressure of 150 kPa.

The leakage rate from the hermetic compartments in 2000 was 9.68%/24 h and 9.815%/24 h at Units 1 and 3, respectively (see Fig 3).

1.3.4 Mochovce NPP (Slovak Republic)

To leak testing at this NPP, a great attention was already devoted during the process of construction. From 1997 to 1999, VÚEZ performed more than 1000 local leak tests at each Mochovce reactor unit as well as several follow-up tests aimed at leak detection.

The pre-operational ILRT at Unit 1 was conducted in March 1998 with the leakage rate measured of 2.03%/24 h and at Unit 2 it was performed in August 1999 with the leakage rate measured of 1.88% /24 h.

The periodical ILRT at Unit 2 was performed in 1999 and the resultant leakage rate measured was 1.838% /24 h and at Unit 1 in 2001 and the leakage rate measured was 1.565% /24 h.

This means that the technical status of hermetic compartments at both of these reactor units is very good. The limiting condition for the leakage rate from hermetic compartments at these reactor units is 5%/24 h (stipulated by ÚJD SR).

1.3.5 Paks NPP (Hungary)

In 2000, VÚEZ performed ILRT accompanied with leak detection at the Paks NPP Unit 1. The leakage rate obtained was 10.9%/24 h.

Based on the summarising list of detected leaks, a program for leak repair on structural nodes of the hermetic boundary was proposed.

At present, a contract is being prepared for resealing works to be performed in 2001 after a repeated ILRT.

1.3.6 Temelín NPP - VVER 1000 MW (Czech Republic)

In the Temelín NPP, VÚEZ participated in the process of construction by the supervision over containment erection works and performance of first local tests. Later on, a programme for ILRT was prepared and the test was performed with good results (Unit 1: 0.0395%/24 h, Unit 2: 0.0726%/24 h).

The limiting condition for the leakage rate from the containment is 0.4%/24 h (stipulated by SÚJB – Czech Nuclear Regulatory Authority).

1.4 Conclusion

Good results of resealing works are documented by the reduction in leakage rates from hermetic compartments at individual NPP reactor units.

The objective of resealing works is to further increase the leak-tightness of the hermetic zone and to improve thus the technical and radiation safety of the localisation system of the concerned reactor unit as a whole.

Part of the works is performed repeatedly each year. These are periodical resealing works concentrating mainly on local and individual leak tests of hatches, doors, penetrations and vent systems.

With the support of ÚJD SR and IAEA, VÚEZ extends its activities by the preparation and implementation of the ageing management programme for the containment reinforced concrete structure. Monitoring of containment ageing and possible repairs finally will contribute to increasing the NPP safety.

In the future, increasing the leak-tightness of the hermetic boundary will be extended by the qualification and re-qualification of hermetic boundary components according to internationally recognised requirements.

Figure 1: Effectiveness of leaktightness enhancement at NPPs
Air leakage rate from the Bohunice V1 NPP hermetic compartments - Unit 1 and 2 (from the year 1993)
Extrapolated to 80 kPa

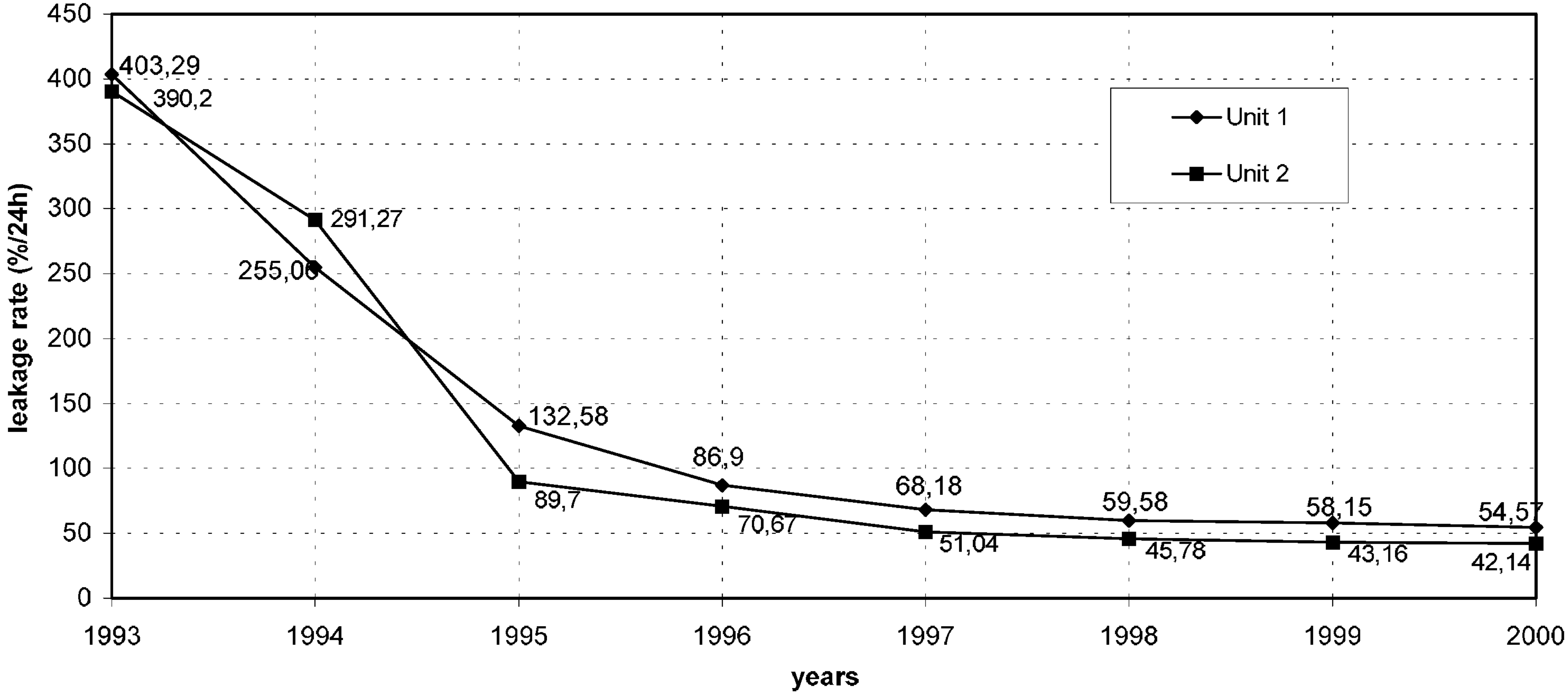


Figure 2: Effectiveness of leaktightness enhancement at NPPs
Air leakage rate from the Bohunice V2 NPP hermetic compartments - Unit 3 and 4 (from the year 1989)
Extrapolated to 150 kPa

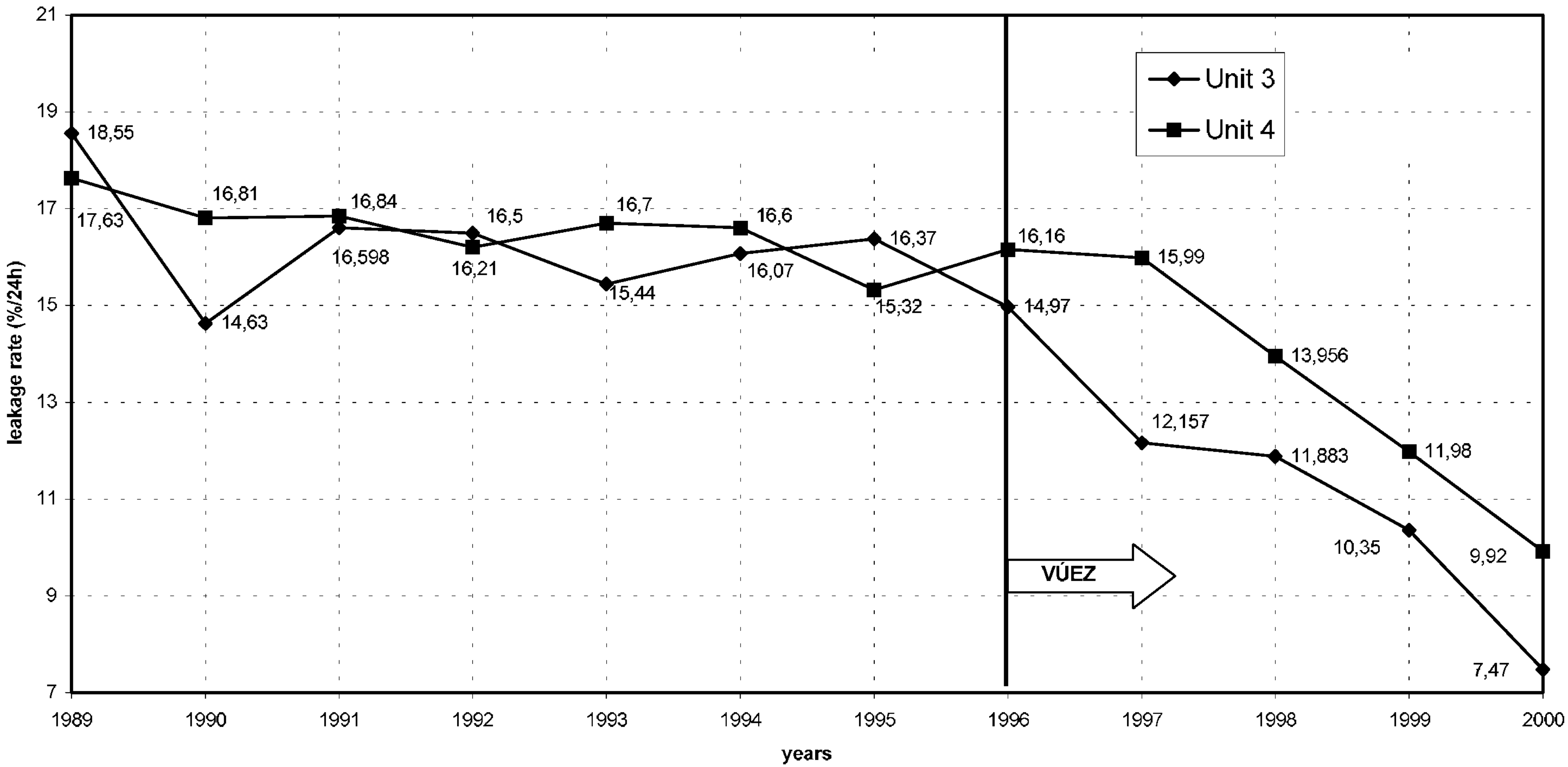
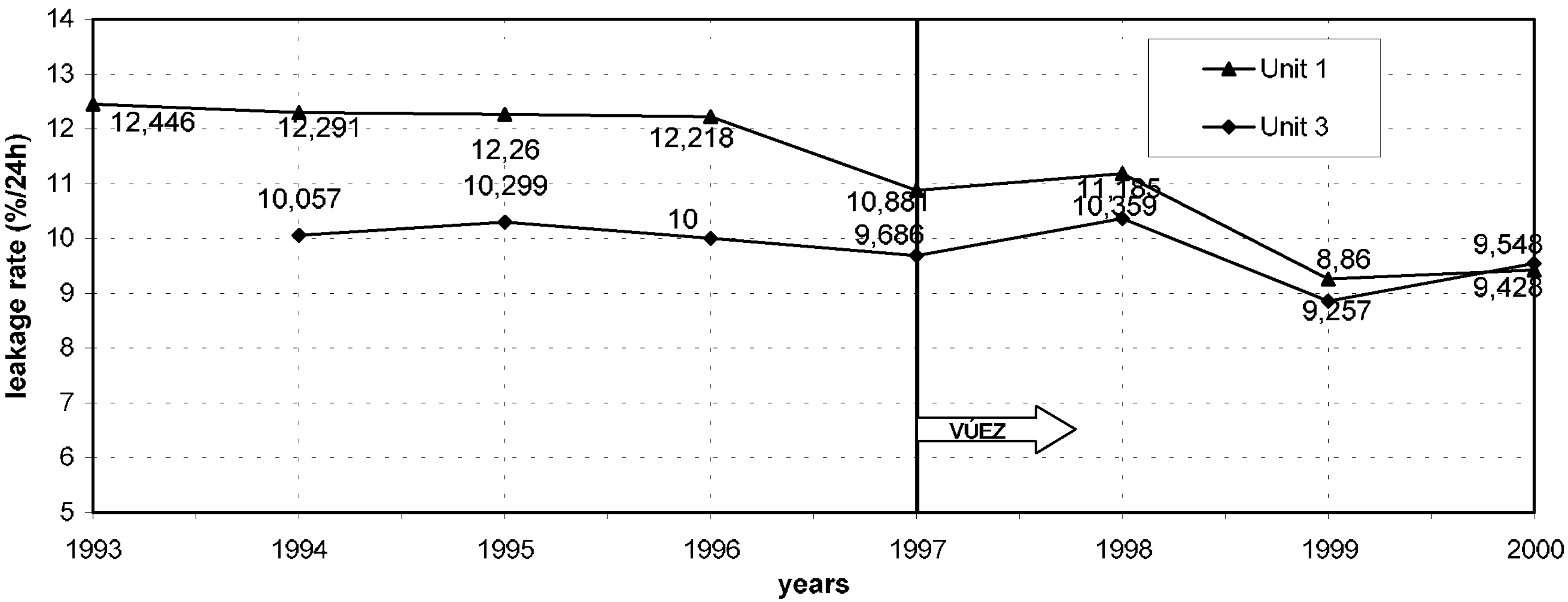


Figure 3: Effectiveness of leaktightness enhancement at NPPs
Air leakage rate from the Dukovany NPP hermetic compartments - Unit 1 and 3 (from the year 1993)
Extrapolated to 150 kPa



2 Resealing of weld joints in pools and tanks in the Jaslovské Bohunice V-1 NPP

In order to extend the lifetime and to enhance the leak-tightness and safety of classified equipment, a requirement for resealing weld joints in classified pools and tanks in the Jaslovské Bohunice V-1 NPP was imposed.

Resealing involved the following items:

- emergency water storage tank (EWST) – 800 m^3 tank,
- refuelling pool,
- spent fuel storage pool.

In pools and tanks, only resealing of weld joints was performed. Liner plates of these items are homogeneous, without any visual changes observed and leakages resulted from leaks in weld joints. In spite of this, the tanks and pools are permanently monitored and possible leakages of liquid media are evaluated.

To reseal weld joints, several approaches were proposed:

- new lining of the whole item (as a result a double lining would be obtained),
- overlapping of weld joints with stainless steel strips,
- resealing of weld joints by application sealing materials (coats).

After the evaluation of proposed approaches, the application of sealing materials to weld joints was selected. To prepare the technical documentation and to perform supervision during the application, VÚEZ was selected by the operating organisation.

First it was necessary to verify sealing materials for their suitability for this purpose. For verification, materials made by CHESTERTON were pre-selected.

These are double-component polymeric ceramic composites based on epoxide resins reinforced with ceramic mixtures providing for the resistance to leakages, chemical impacts, corrosion and erosion. After application, a smooth surface resistant to abrasion may be obtained.

To verify the pre-selected sealing materials, a test programme was prepared by VÚEZ and submitted to ÚJD SR for approval. Based on the programme, sealing materials were exposed to the following load impacts:

- irradiation in Co chamber,
- immersion in the spent fuel pool (special container),
- application to the wall of the refuelling pool (universal nest),
- exposition to boric acid solution,
- exposition to decontamination solutions and decontamination procedures including thermal loads and jet abrasion,
- immersion in boiling boric acid solution for different time periods obtaining thus conditions of thermal loads anticipated under a LOCA-type DBA.

Test results obtained were evaluated and compared to values obtained with reference samples and with samples exposed to irradiation, spray and decontamination solutions, jet abrasion, long-term radiation loads and high temperatures.

The sealing materials selected show the parameters specified by the manufacture, meet the requirements specified by the NPP and were approved by the ÚJD SR for application in NPPs.

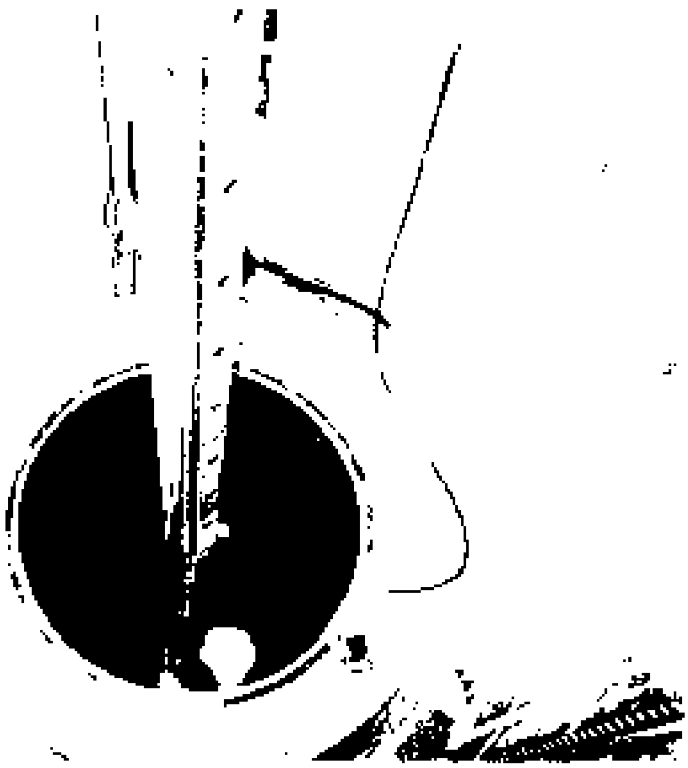
The sealing materials were applied to refuelling pools at the V-1 NPP Units 1 and 2 and EWST (800 m^3) at the V-1 NPP Unit 2. These materials were used to reseal all the weld joints on the walls of these tanks and pools (both continuous and spot welds). They were applied in several layers; between layers 2 and 3, a glass grating was inserted to reinforce the sealing material.

By resealing of weld joints with ceramic composites, it is expected that requirements imposed upon the leak-tightness will be met for the next 12 years.

Since the sealing materials application, refuelling pools and EWST in the Jaslovské Bohunice V-1 NPP are continuously monitored for leakages. Two monitoring points have been created in the refuelling pools and 10 in EWST and the leakages are monitored and registered daily.

Up to now, no leakages of liquid media have been monitored. As a result, it is concluded that the resealing was successful and sealing materials selected are suitable for the given purpose.

A detail view of resealing the refuelling pool bottom
(numbering of resealed welds can be seen)



A global view of the resealed refuelling pool

3 Innovation of the seal of reactor pit protective hood (kolpak)

The reactor pit protective hood is located on the hermetic boundary and therefore shall provide for its leak-tightness. Together with its mating flange and sealing node, it prevents steam and gas leakages from the reactor to the reactor hall and protects the reactor from falling objects. The protective hood closes the refuelling pool from above and together they form a hermetic compartment.

This item ranks among classified equipment pursuant to relevant Slovak regulations.

The protective hood with its mating flange is sealed with a simple rubber seal with a diameter of 32 mm placed in a groove in the mating flange. The rubber seal together with the mentioned equipment form a flange joint individual leak testing of which is impossible.

That was why a requirement was imposed by the operating organisation to specify and propose a new seal able to withstand the conditions in NPPs and to resist loads under normal operation as well as under DBA; furthermore, the seal design shall enable individual testing after potential repairs.

In addition to this flange joint, it was necessary to solve the leak-tightness of the node which is formed by a removable segment of the mating flange (the so-called small sector of the mating flange) and the flange of the protective hood.

The segment hermetically isolates the space under the protective hood (part of the hermetic zone) from other non-hermetic compartments and seals in three planes:

- between the segment and the mating flange,
- between the segment and the flat flange of the transport channel,
- between the segment and the protective hood.

For all mentioned joints, several types of sealing materials from six manufacturers were pre-selected.

Based on the test programme, the pre-selected materials were tested in VÚEZ to verify their:

- design,
- manufacturing technology,
- modification technology,
- installation technology,
- design and modification enabling individual leak testing,
- capability to resist conditions and environment in NPPs,
- capability to meet the requirements for nuclear and technical safety imposed upon equipment in the nuclear industry.

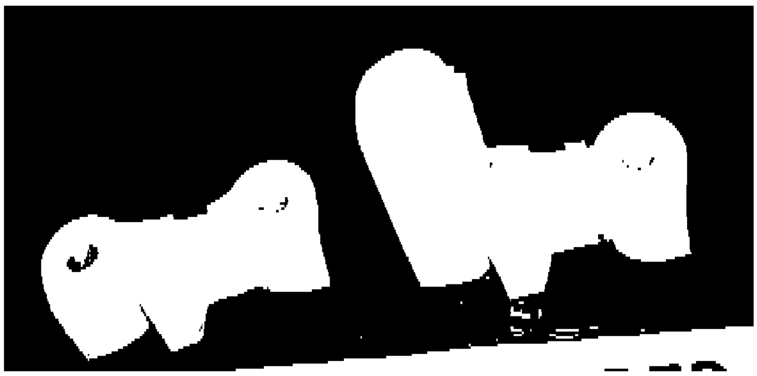
To enable proper design of the seal, the flatness of mating surfaces of the protective hood and mating flange was measured. The flatness was measured in two circles of the sealing surfaces of the protective hood and the mating flange. Based on flatness measurements, thickness of the new seal was proposed.

Pre-selected sealing materials were tested and, as a result, the most suitable was finally chosen.

After material selection, the shape of the seal was proposed and nozzles for the production of appropriate seal profiles were manufactured. The seal profiles were connected to form one whole, the final seal. This seal was exposed to tensile and pressure tests to verify the strength of the glue joint. The tensile and pressure tests simulated the loads from the protective hood and the tightening moment of the screws and loads anticipated under accident conditions (temperature up to 130°C).

The proposed new seal successfully passed all the necessary tests and, as a result, was approved by ÚJD SR. Based on the approval, a change design was prepared and the seal under the protective hood at Unit 3 in the Jaslovské Bohunice V-2 NPP will be replaced in 2001. At the other units, the replacements are expected to be performed gradually during refuelling outages.

Test equipment in test laboratory of VIPOTEST, s.r.o., Púchov
Tests of sealing material produced by RUBENA, a.s., Náchod



New seal of the protective hood that passed all the tests
and was proposed to be used for the seal reconstruction at the V-2 NPP Unit 2

4 SMÚ-V system

4.1 *Purpose*

SMÚ-V system has been implemented in the Jaslovské Bohunice V-1 NPP (VVER 440 - V230).
It is designed to monitor leakages from the NPP primary circuit. It is based on monitoring the trends in absolute humidity in the SG compartment where the primary circuit is located. Physically, the system principle issues from the properties of the material used for individual technological parts of the primary circuit. Material properties exclude the so-called guillotine effect when an immediate break of individual parts occurs. In principle, material defects appear after some time – usually after several hours.

SMÚ-V system is designed so to signal water leakages amounting to 4 l per minute. This corresponds to international criteria for LBB (leak-before-break) detection systems.

4.2 *Principle of operation*

Water leakage in its steam phase is detected through humidity and temperature measurements in the monitored compartments. At each reactor unit, 20 sensors are installed. The system continuously measures and evaluates atmosphere parameters in the vicinity of the main circulation lines, in the pressuriser relief tank room, at intake openings of vent systems and under the reactor cap. At the same time, automatic corrections to the impacts of the environment are performed. Based on mentioned parameters, the system evaluates leakage value and its location. The measured parameters are continuously processed by an intelligent measuring system able to generate optical and acoustic signals of exceeding the limiting conditions; at the same time it controls and evaluates physical testing of sensors and measuring circuits.

The data measured are loaded into a database and hourly and daily averages are calculated. These averages form a basis for comparison of currently measured data and subsequent evaluation of alarms. Alarm signals derived from absolute humidity changes are led parallelly to the operating diagnostic room and the relevant main control room.

4.3 *Sensor testing*

As sensors are located in non-accessible compartments, in addition to data measurements, physical verification of their function is performed in such a way that a thermal wave is generated in the vicinity of sensors and the response of sensors to the increased temperature and reduced relative humidity is measured. The thermal wave is generated by means of a test head provided with a Peltier cell located on the sensor body. In SMÚ-V system, only one sensor is tested at a time to avoid the impacts on absolute humidity measurements. Measurements of tested sensor parameters are taken each 5 seconds. The process of testing for one sensor takes 20 minutes and the generated thermal wave represents a harmonic function.

4.4 Backup of measured data

SMÚ-V system has been installed at Units 1 and 2 in the Jaslovské Bohunice V-1 NPP. The system of Unit 1 measures and evaluates also data from Unit 2 and vice versa. Similarly, power feed to the sensors is backed up and the function of power feed is always taken over by the system which is under operation. In addition, the evaluation programme monitors the operation of the computer, evaluates the data on the supply voltage of sensors, availability of the printer etc. Measured data on average relative humidity and absolute humidity, and data on the environment are stored during one campaign and their visualisation is possible.

4.5 Protection of sensors and system corrections to the environment

Since the sensors are located directly in the radioactive environment during the whole campaign, some of their properties are changed during such a long time. The impacts of radioactive radiation are manifested first of all by the reduction of electric capacity of the part of the sensor designed for relative humidity measurements. The results from testing by means of the thermal wave are used to calculate the so-called correction constants that is applied to obtain thus as precise measurements as possible. After the campaign, the sensors are always calibrated in compliance with relevant metrological regulations.

Another way of protection bears relation to the sensors design: during their manufacture the sensors are provided with protective lead cells. Distribution of sensors throughout the SG compartment is also performed so to minimise the impacts of radioactivity.

The system assures the correction of output parameters to the changes of atmospheric humidity, changes of cooling water temperature in vent system coolers and changes of configuration of vent system coolers.

4.6 SMÚ-V system control

SMÚ-V system provides the operator with all measured data in both numerical and graphical forms. The operator may choose between temperature, relative or absolute humidity showing the measurements taken during the past hour, day or month. Furthermore, also all the data measured during one campaign are available arranged according to date and time. Another part of the programme provides for signalling the emergency conditions to the main control room. Printing of measured data is possible in both numerical and graphical form. Programme may be controlled by the keyboard or mouse.

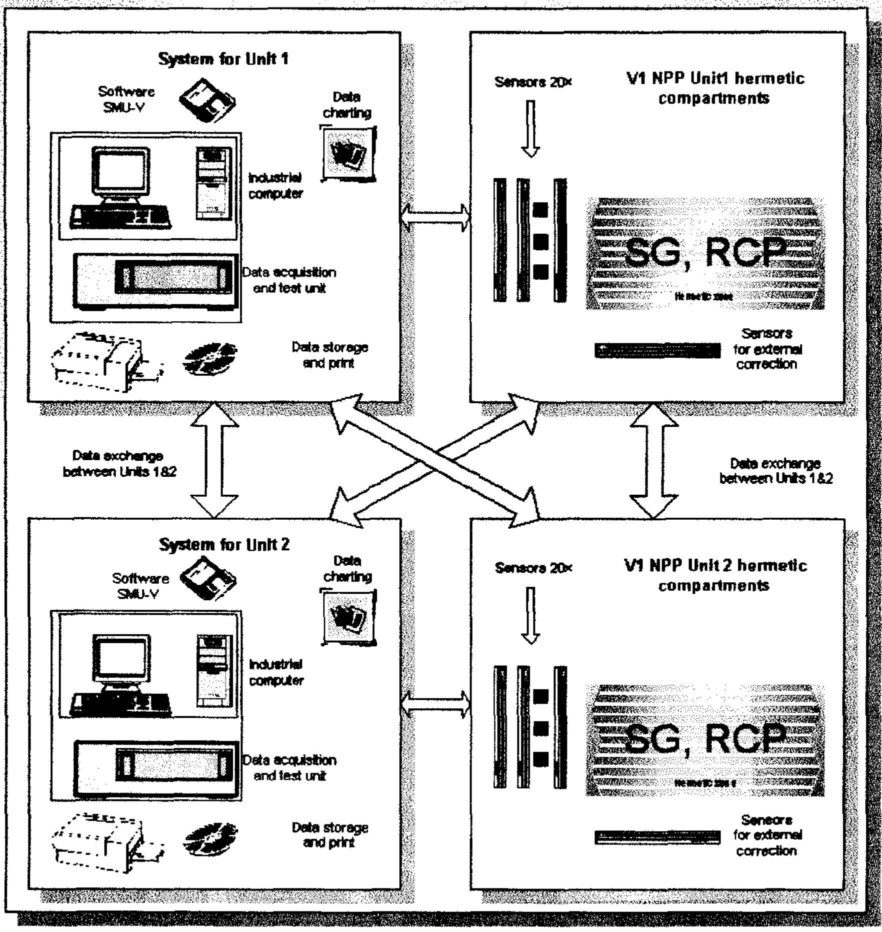
4.7 Practical experience from SMÚ-V system operation

SMÚ-V system has been operated in the Jaslovské Bohunice V-1 NPP since 1993. During this period, several leakages in the SG compartment have been detected by the system, none of them being a dangerous leakage from the primary circuit. Various leakages of cooling water from vent system coolers and the like were detected.

Alongside with another two independent systems designed for detection of leakages, SMÚ-V system is an efficient tool enabling to diagnose leakages.

The figure bellow shows a principal scheme of SMÚ-V system operation.

Leakage monitoring based on the principle of humidity in the Jaslovské Bohunice V1 NPP



Properties:
- measurement of 40 signals - humidity a temperature
- physical testing of sensors (by a thermal wave)
- graphic presentation of results
- data filing for the whole campaign
- visualisation of alarm conditions
- correction for external impacts and sensor ageing
- long-term experience, 5-year operation in the Jaslovské Bohunice V1 NPP