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PHARE PH 2.02/95 Project
STUDY ON LIVE STEAM PIPE RUPTURE
EXTENDED PROJECT SUMMARY

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SUMMARY

The +14.70 m floor of the intermediate building of the WWER 440/213 units is a very sensitive area as far as high energy pipe rupture is concerned. In this area, two groups of three main steam pipes with isolation valves and common steam header as well as pipes and valves of the feedwater system and of the emergency feedwater system were originally installed without physical separation. This could lead to an unacceptable multiple pipe rupture. Moreover, in the area below +14.70 m area, there are installed electrical and I&C cabinets containing sensitive electrical equipment, related to the safety systems, which could be damaged by steam, or flooded as a consequence of this rupture. The Dukovany NPP PSA shown that the contribution of steam and/or feedwater lines break on 14.70 m level to the overall risk of the reactor core damage is very high.

In order to cope with this situation, the PHARE project PH 2.02/95 "Live steam pipe rupture" was launched. A comprehensive safety reassessment of the secondary piping located in the intermediate building, including accident analyses, layout improvements and equipment qualification were the main targets of the project. Analysis of consequences of a steam line rupture and proposals for hardware modification in the area of 14,70 m floor of the intermediate building in order to enhance the global safety of this type of NPPs were the main anticipated outputs of this project.

The methodologies and approaches, based on recognised international practices and IAEA guides was applied in the project implementation together with powerful computer software to perform detailed safety related calculations.

A pilot plant for this project was selected NPP Dukovany in Czech Republic; Hungary and Slovak Republic, operating analogical plants, were co-beneficiaries of this project.

A Consortium Framatome – Siemens – GEC Alstom Velan was contracted for this project. Framatome was leader of the Consortium and was responsible for organisation and general management of the project. Leadership of the project tasks was shared between all three members of Consortium: Framatome and Siemens, having extensive experience in the design and performance analysis of the nuclear island of the NPPs, were responsible for steam and feedwater lines part of the project. GEC Alstom Velan, designer and supplier of main steam isolation valves for some WWER440/213 plants, was responsible for this part of the project.

Local sub contractor, Nuclear Research Institute Řež, took the responsibility for providing input data, performing selected calculations and reviews and together with some other supporting organisations (e.g. VUJE, Trnava) dealt with qualification of equipment.

Project commenced in November 1997 and was completed in February 1999. The project was performed according to the terms of reference and Work Plan and the project aims and objectives, defined in the Terms of Reference, were fulfilled.

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INTRODUCTION

The +14.70 m floor of the intermediate building of the WWER 440/213 units is a very sensitive area, since two groups of three live steam pipes with isolation valves and common steam header as well as pipes and valves of the feedwater system and of the emergency feedwater system are installed here without physical separation. This could lead to an unacceptable multiple pipe rupture.

Steam line break without closing of the fast acting main steam line isolation valves leads to rapid depressurization of the secondary system and consequently to a large and rapid cooldown of the primary system. This causes the thermal stresses in the reactors vessel wall and can lead (especially in the case of low wall temperature and high primary pressure) to brittle fracture of the vessel material. In this case, the integrity of the reactor pressure vessel may be endangered.

Another significant risk is that due to cooldown of the primary coolant, the reactivity contribution of the moderator increases. At the same time, the coolant volume decreases and consequently the primary coolant pressure also decreases. For this reason, the reactor power rises and boiling margin in the core drops in such a way, that the acceptance criterion for departure nuclear boiling radio may be violated.

In addition to the above mentioned, in the area below +14.70m floor, sensitive electrical equipment, related to the safety systems, is installed, which could be damaged as a consequence of this rupture.

Considering the above mentioned risks, the Dukovany NPP arranged, besides others, for performing additional main stream line break calculations for the pipes located in the 14.70 m intermediate building floor area. The analysis confirmed that the contribution of steam and/or feedwater lines break on 14.70 m level to the overall risk of the reactor core damage is very large.

Considering safety importance of this problems and high related risk, the European Commission decided to open the PHARE project and grant the contract aimed in completion of already started work and facilitated a new detailed safety reassessment of the secondary piping located in the intermediate building, including accident analyses, layout improvements and equipment qualification.

1 OBJECTIVES

The overall objective of this project was to contribute to increasing safety of operation of WWER-440/213 nuclear power plants trough safety reassessment of the secondary steam piping located in the intermediate building of the WWER-440 NPP.

The specific objective of this project was to:

- Analyse the consequences of a steam line rupture occurring in the +14,70 m area of the intermediate building of WWER-440/213 nuclear power plants and more generally inventory of all possible sources of accident (pipe rupture) aggravation in the same area;
- Propose the hardware modifications list that helps to enhance the global plant safety, but also harmoniously integrates into the current configuration, i.e. without transferring the initial problem to heave design bases reconsideration of neighbouring equipment and/or structures;
- Provide appropriate and sufficient information to the beneficiary for enabling him to put the case forward to the local Safety Authorities and launch the modifications on the basis of the project output.

The project was designed in such a way that a model for calculations was selected Dukovany NPP, and the results were made available also for co-beneficiaries, Hungary and Slovak Republic, operating analogical plants.

It should be noted that qualification of main steam isolation valves within this project concerns only their mechanical ability to close during the accident. The other aspects concerning the qualification of their electrical support systems to accidental environmental conditions were considered in parallel projects PH 2.03/94 and PH 2.03/95.

2 IMPLEMENTATION

2.1 Distribution of responsibilities

PHARE project PH 2.02/95 on 95 "Live steam pipe rupture" was started on 4 November 1997 after signing the contract No. 97 – 0605. The tasks were performed according the Terms of Reference and Work Plan and project was completed on 4 April 1999.

Framatome was responsible for project leadership as well as participated in the definition of the main layout options and in the review of the overall arrangement obtained at the end of the project implementation. Framatome was also responsible for steam generator relief and safety valves qualification.

Siemens was in charge of the accident analyses and electric equipment qualification assessment.

GEC Alstom Velan was in charge of main safety isolation valves qualification assessment.

The final version of the technical project report was submitted by the contractor and distributed in April 1999. The report consists of three volumes.

2.2 Scope of work and work description

Organization of project in nine closely related tasks (one of them with two additional subtasks) was proposed in the project work plan:

- Task 1: Project start up, management and quality assurance;

- Task 2: Loss of 3 (or 2) steam generators: accident analysis;
- Task 3: Layout provisions against aggravation of initial main secondary pipe (main steam and feedwater) rupture;
- Task 4: Rerouting of emergency feedwater system;
- Task 5: Impact of pipe rupture to equipment and structures;
- Task 6: Civil work resistance and floor leak tightness;
- Task 7: Mains steam isolation valves qualification assessment;
- Task 7a: Steam generator relief and safety valve qualification assessment;
- Task 7b: Qualification assessment of electric equipment subject to internal hazard;
- Task 8: Project consolidation;
- Task 9: Applicability to Bohunice and Paks NPP.

In the first phase (Task 1) the Quality assurance programme was prepared for entire project and project schedule and work plan elaborated, based on preliminary inventory of safety weaknesses or non-conformances to be solved.

The second phase – project implementation (Tasks 2-7b) was performed in three closely related packages: accident analysis (Task 2), layout studies (Tasks 3-6) and qualification assessments (Tasks 7, 7a and 7b).

The final phase – project consolidation (Task 8) was aimed in validation and safety assessment of enhanced design and improvement proposals and estimation of their contribution to the safety upgrading.

Subsequently (Task 9), the evaluation of applicability of project results for Bohunice and Paks NPP was performed.

3 PRESENTATION OF PROJECT RESULTS

Considering close relationship of selected project activities, some work plan tasks were merged during the project implementation and presentation of the results, to reflect fully the established project objectives. Three principal sets of project results are discussed below:

- Reviews of calculations;
- Qualification of electric and electro-mechanical components;
- Proposal of modifications and improvements.

3.1 Reviews of calculations

3.1.1 Introduction

Steam line break without closing of the fast acting main steam line isolation valves leads t rapid depressurization of the secondary circuit and subsequently to a large and rapid cool down of the primary system. The thermal stresses in the wall of reactor pressure vessel are unavoidable consequence of this situation and in unfavourable conditions can lead to brittle fracture of the vessel material and potential loss of the reactor pressure vessel integrity.

Another consequence of this situation is that due to cool down of the primary coolant the reactivity contribution of the moderator increases. The primary coolant volume and pressure decrease. For these reasons the rector power rises and boiling margin in the reactor core drops in such a way that the acceptance criterion departure nuclear boiling ration nay be violated.

Several main steam line break calculations shown that break in one steam line does not lead to unacceptable consequences from the point of view of reactor overcooling and loss of reactor power control. However, a potential risk of multiple parallel steam lines break in the 14,70 m area of the intermediate building of WWER-440/213 requires more detailed safety analysis, including evaluation of potential needs for modifications and /or special measures against aggravation of and initial one main steam pipe rupture.

Therefore, the review of thermal hydraulic calculations, fluid mixing calculations and pressure thermal hydraulic calculations was performed within the Task 2 of this project.

3.1.2 Thermal hydraulic calculations review

Four of already performed 25 analyses were selected for this review:

- Pressurized thermal shock oriented main steam line break analysis from zero power;
- Pressurized thermal shock oriented main steam line break analysis from full power;
- Departure nuclear boiling ratio oriented main steam line break analysis;
- Calculation oriented on long-term cooling.

The analyses were based on input data provided by NRI Řež, Czech Republic and Siemens experience gained from other WWER-440/213 plants. The thermal hydraulic code, used for calculations was RELAPS5/MOD3.1.

Basic conclusions from the review are:

- The pressurized thermal shock following main steam line break in the case of full power can lead to more adverse situation as in the case of transient from zero power;
- Performed departure nuclear boiling ratio analysis was found conservative. It was shown that main steam line break accident is not a vital problem for WWER440/213with respect to fuel loading. The reactor is not endangered, even in the case of six steam generator affected;
- The relevant acceptance criteria of the long term cooling analysis are not violated even in the case of very conservative assumptions – total loss of secondary systems;
- Computer codes and input model used for calculations were found to be adequate and the results of thermal hydraulic analyses were confirmed to be correct.

3.1.3 Review of fluid mixing calculation

The review dealt with the fluid temperature and reactor pressure vessel wall-to luid heat transfer coefficient distribution in the downcomer.

Main steam header break under full power, acting signal “main steam header break” and failure of valves closing on all steam lines were assumed. High pressure safety injection start after the break and emergency core cooling water injection for about 2700 s into cold leg 5, leading to a cold water plume in the downcomer below this cold leg was considered.

KWU-MIX code was used to review the calculations made by NRI Řež, Czech Republic using CATHARE code.

It was shown, that the main steam header break causes natural circulation in all loops, and both calculations indicated an intensive mixing of emergency core cooling system water, injected into the leg 5 with hot water, flowing out from the steam generator.

Analogically, good overall agreement of both calculations results was found also for distributions of fluids temperature and reactor pressure vessel wall-to–fluid heat transfer coefficient in downcomer.

3.1.4 Pressure thermal hydraulic calculation review

The stress field calculations performed by NRI Řež, Czech Republic and Siemens shown slightly different results. NRI used more simplified input therefore their results were more conservative but fully confirmed by more precise calculation of Siemens.

For the pressurized thermal shock transient following main steam line break in the case of zero power, the calculated maximum value of T_{ka} calculated by NRI is 95.6 °C and by Siemens109.6 °C. Since the last calculations were performed using more advanced code, the results of Siemens calculations were proposed for consideration by the safety authority.

3.2 Electro-mechanical components qualification

3.2.1 Introduction

Steam generator safety valves (SGSV), which can be challenged in saturated or slightly subcooled water flow conditions must be able to reclose at the pressure not too far below their set pressure.

Steam generator relief valves (SGRV) should be operable down to a steam generator pressure close to atmospheric and qualified to operate with water steam mixture flow and saturated water flow.

However, at most plants, the construction of safety and relief valves does not allow to realize the decay heat removal via steam release to atmosphere at low pressure, in case of closure of the main steam isolation valves. This represents a limitation of the cooldown capability, in particular, the feed and bleed operation in the secondary circuit is not possible at low pressure.

Therefore the subject of work (planned mostly under the Task 7a) was to assess the operability of both valves for two phases and saturated water flows in their expected operating range.

3.2.2 Steam generator safety valve qualification assessment

In the case of accident with primary to secondary circuit leakage (steam generator tubes damage or primary collector lid fit up) the steam generator safety valves (SGSV) should work properly with any of steam, steam-water mixture, saturated water and subcooled water media. Relevant qualification has to be preformed.

Framatome background and methodology was used for qualification of SGSV type SIZ 1508, installed at Dukovany NPP. As a result of the tests it has been concluded that he design of the type 1508 SGSV allow correct operation in the two phase and saturated water flow with some potential constraints:

- Primary to secondary circuit leakage transient can consist of a succession of opening and closing cycles at low frequency , which is only acceptable for a short period;
- If the discharged water flow stream is subcooled, the frequency of SGSV oscillations will be greater than in steam and can lead to steam/guides galling;
- In regard with the above-mentioned transients, the support of the valves is recommended to be checked to prevent excessive acceleration of the upper structure if the safety valve.

The overall conclusion was, that the (theoretical) qualification for water–steam and water operation of the SGSV is possible with the exemption of subcooled water discharge during a long period.

3.2.3 Steam generator relief valve qualification assessment

Analogically to SGSV, Steam generator relief valves (SGRV) should be also qualified for water discharge operations during primary to secondary circuit leakage accident.

Theoretical assessment of the operability of Russian provenience SGRV of type 936-150/250 ES3 in water shown that they should not be any principal difference in their operation in steam or water. In the period of project implementation Framatome performed the experimental test of SGRV together with related steam dump station to atmosphere at the EDF loop facility. The results fully confirmed the theoretical assessment and the SGRV can be operated in saturated steam, saturated water and saturated steam-water mixture.

3.3 Electric and I&C equipment qualification

3.3.1 Introduction

In the event of break on a main steam line or on a feedwater line, electrical equipment might be flooded due to the untightness of the floor of the intermediate building or damaged because of resulting ambient conditions. Requalification or replacement of safety related electric equipment was therefore proposed (planned Task 7b). The aim was to assess practicability to arrange for changes in safety related electric equipment located in concerned area.

3.3.2 Electric and I&C equipment qualification assessment

Siemens reviewed NRI specifications and methodology used in Nuclear Power Plant Research Institute, Trnava, Slovak Republic and proposed several improvements and upgrade in tests methodology, in particular in stipulation of threshold values and loads to be applied.

3.4 Proposed modifications and their efficiency

Three basic directions in proposed modification of main steam lines and feedwater lines were followed in this project:

- Provisions and modifications against secondary high energy piping break;
- Rerouting the emergency feedwater system;
- Main steam isolation valves upgrading.

They correspond to works performed within the tasks 3, 5 and 6 and the principal achievements, in each direction are described below.

3.4.1 Provisions and modifications against secondary high energy piping break

3.4.1.1 Introduction

Following dynamic effects are assumed after high energy pipes (with pressure over 2 MPa and temperature higher than 100°C) rupture:

- Pipe whip due to reaction forces;
- Jet impingement due to thrust forces of the liquid/steam mixture discharged through the break.

Whipping or jet impingement due to the break of high energy pipe should not aggravate the initial accident (pipe break) or damage any safety related equipment designed to cope with the initial accident. Dynamic effects should not hinder reactor shut down and keeping it in the safe shutdown conditions.

However, the considered zone, situated at 14.70 m and underneath of intermediate building is particularly vulnerable due to accumulation of several, vital for NPP operation, equipment (main steam lines, feedwater lines, emergency feedwater piping, steam generator valves etc.). Therefore it is necessary to analyze the layout provisions against aggravation of initial pipe break (planned Task 3), assess a potential risk of consequences of the main steam line break and determine the number of steam generators, which may be affected by the initial break (planned Task 5 and 6). At the same time it should be evaluated, whether it would be reasonable to consider rerouting of critical pipes and/or upgrade the critical components (planned Task 4).

3.4.1.2 Identification of locations of postulated breaks

The aim of the work was to perform the safety analysis and dynamic calculations, defining the worst equipment failure resulting from the secondary steam pipe line break, identify the safety related components, which have to be protected against mechanical and hydraulic effect of pipe break and evaluate whether proposed improvement measures are sufficient from the point of view of safety. The last activity covered also civil work resistance and floor leak tightness in the critical zone of intermediate building.

Calculation of the locations of postulated breaks of steam piping as well as feedwater piping systems on 14.70 m level was performed by NRI Řež. The postulated break points were used in follow up calculations as well as in proposal of modifications.

Generally speaking, earthquake was found as one of the most critical loading for the considered pipes. Critical points were found to be located at the connections between main steam and feedwater lines with smaller diameter auxiliary lines.

In order to decrease the number of ruptures and to solve some design problems (mainly related to seismic loads) some limited modifications of the supports of pipes and equipment were proposed – they are described later in this document. In the course of calculation, some modifications in calculation model were also proposed, corresponding better to real conditions.

3.4.1.3 Potential improvements

Modifications of pipes and equipment supporting and restraints inside the intermediate building were the main proposed improvements.

Modification of supporting is aimed in decreasing the number of postulated pipe break locations and also in decreasing the loadings from normal operation as well as seismicity. The main modifications are as follows:

- Replace the design based fixed points located on the steam and feedwater headers by guiding support;
- Change the design of the non-hermetic penetrations of the steam lines from steam generators No. 2 and 5 into the wall between the reactor hall and intermediate building;
- Install additional damper on feedwater or steam branches lines (the pipe branches connected with steam and/or feedwater headers).

Following modeling of the behavior of the circuit affected by the pipe break, several restraints inside the intermediate building were proposed. They were considered, in particular, in the area of penetrations to hermetic zone (anchoring the limiter on strong embedded part of the hermetic penetration), in the set of potential intermediate break points (installation of 5 additional restraints) and on the main feedwater lines heads (installation of two additional restraints, each for three fixed points with high risk of break).

3.4.2 Rerouting the emergency feedweater system

3.4.2.1 Introduction

In the original design of WWER 440/213, the emergency feedwater system (EFWS) components (pumps, valves, piping) are not protected against common failures such as big fire, flooding, earthquake. Additionally, the piping can be affected by the steam and feedwater pipe breaks. Loss of feedwater supply constrains decay heat removal with potential subsequent fuel element damage.

To avoid the consequences of common failures, the new routing of the system was proposed within the Task 4 of this project.

3.4.2.2 Proposal for rerouting the EFWS system

In the preparatory phase, the safety criteria were developed, providing a basis for follow up study of EFWS rerouting. Both internal (e.g., fire, turbine missiles, heavy load drop, flooding, high energy piping break) and external (e.g., freezing, seismic protection of the system as well as neighboring technological equipment and civil constructions) hazards were considered.

As the main result of the performed study reinstallation of the piping in two separated areas inside the floor +22,50 m was proposed. Existing hermetic zone penetrations should be connected with new piping via short vertical spools between the level +22.50 and +14.70 m. Additional improvements related to rerouting of EFWS were also proposed, in particular in seismic and fire protection. Operational characteristic of active components (pumps) should be also re-evaluated considering increased length of the circuit.

3.4.3 Main steam isolation valves upgrading

3.4.3.1 Introduction

Air operated gate valves are installed at Dukovany NPP to fulfill the function of quick closing the main steam lines. They are of nominal diameters of 18" and 20", 600 Lbs rating, classified in safety class II according the ASME code. The original main steam isolation valves (MSIV) have been designed to properly close during accidental conditions, however they do not cope with fast closure in the case of steam line breaks.

The aim of upgrade of the valves (as defined in the planned Task 7) was to provide for capability to close under severe blow down conditions. To assure this objective, the new design was proposed to limit the stress level in the main technical parts of the valve, as the guiding rods and the seats surfaces.

3.4.3.2 Main re-designed parts

The main MSIV parts, considered for redesign were:

- Wedge;
- Guiding rods; and
- Seats.

Covering of all main parts of the MSIV with hard facing alloy was proposed to decrease the surface detrition.

Using of full length guides (to eliminate the guide damage), reduction of internal diameter on the wedge seating (to increase the contact surface between the wedge and seat in order to reduce the stress level on the hard facing alloy) and better finishing of internal surfaces were the main results of optimization study of wedge design.

Increasing the weld beads at the guiding rods and increasing of the section of the guiding rods were proposed based on optimization study.

Besides the above-mentioned covering the seats with hard facing material, more precise (smooth) finishing of the seat edges was the main result of the optimization study.

Optimization of wedges and guiding rods design shown that upgraded MSIV is able to perform emergency closing function under blow down conditions.

As a part of the optimization work, in situ inspection procedure to define the main technical requirements for MSIV upgrade, welding procedure to improve the welds on the guiding rods and also valve qualification procedure were proposed.

4 PROJECT CONCLUSIONS AND ACHIEVEMENTS

Comparing the achievements, as described in the preceding chapter, with objectives and work plan of this project it can be concluded that the overall objective as well as the specific objectives of the project were achieved. The main results, structured according project tasks, can be summarized in following conclusions:

- The accident analyses demonstrated that the loss of three steam generators is acceptable and the loss of six steam generators would be acceptable, provided that feed and bleed means are available (Task 2);
- Review of available stress analyses, to postulate ruptures on steam and feedwater circuits outside the hermetic zone, confirmed stress analyses conformance with international rules and standards. Seismic upgrading of the circuits was identified as the main issue for the future improvement (Task 3);
- Review of proposed rerouting of the emergency feedwater system, using Framatome criteria and requirements, confirmed acceptability of the proposal. Attention should be paid to neighbouring equipment sensitive to seismic stability (Task 4);
- Installation of additional restraints was proposed, necessary to limit the consequences of whip effects, induced by the previously selected break points at the terminal ends located inside the intermediate building. Optimization of restraints for selected intermediate break points, identified by dynamic calculations was also proposed (Task 5);

- Analyses of consequences of whip effects on the civil structures at the floor +14.70m led to definition of new anchorages on the main steel beams of the intermediate building (Task 6);
- Calculation, justification and detailed description of the main steam isolation valves upgrading was provided in order to qualify them for operation in case of a steam generator depressurization after main steam line break (Task 7);
- Preparatory work and qualification criteria were identified and qualification assessment was performed for existing steam generators safety valves and relief valves. The valves can be theoretically qualified for water and water-steam operation with the exemption for subcooled water discharge flow occurring during a long time (Task 7a);
- Methods, guidance and criteria for qualification of relevant I&C systems were proposed to facilitate qualification process (Task 7b);
- All proposed improvements were evaluated as a complex and safety substantiation report was prepared in order to assist the beneficiary in preparation of safety case for the regulatory body (Task 8);
- Applicability of project results for analogical NPPs Paks (Hungary) and Jaslovske Bohunice (Slovak Republic) was evaluated (Task 9).

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