Integrated Safety Assessment Program for KRSKO Modernization Project

Lecturer
Lesson V II2D_1

Workshop Information

IAEA Workshop

City, Country
XX - XX Month, Year
Integrated Safety Assessment Program

- Justification for SGR
- KRSKO Modernization Project Scope
- Analysis for SGR and Power Uprate
- Licensing Process
- Startup Program
- Integrated (PSA) Safety Assessment Program
Integrated Safety Assessment Program

JUSTIFICATION FOR SGR
Reasons And Goals of SG Replacement

1. PRELIMINARY EXPLANATION
2. REASONS FOR SG REPLACEMENT
3. GOALS OF SGR
4. CONSEQUENCES AS A RESULT OF NON-EXECUTION OR DELAYS
1. Preliminary Explanation

1. SGs were the major obstacle to stable economic and safe plant operation.

2. NEK management proposal to replace SGs in year ‘92 was supported by the managing board and the government in year ‘95.

3. All nuclear power plants in the world having their SGs of a similar design as NEK have already replaced them.
2. Reasons for SGR

1. SG tube degradation process:
   - require high maintenance costs
   - imperil further stable and safe plant operation
   - require power reduction after Outage ‘98 already

2. Maintenance costs and lower energy production exceed SGR cost

3. Only direct maintenance costs (app. 70 m DEM) in recent 5 years have exceeded the value of 2 new SGs (app. 50 m DEM)

4. Power operation after year 2003 is questionable
Plan of Net Electrical Output According to Different Scenarios

Plan of Net Electrical Output

Year

Plan of Net Electrical Output

Plan of Net Electrical Output

v GWh

v GWh

v GWh

Scenarij (A)  Scenarij (B)  Scenarij (C)
SG Plugging and Power Reduction per Years

Percent of SG Plugging and Power Reduction per Year

- Predvideno čepljenje
- Dejansko čepljenje
- Moč

Year:
- 1983
- 1988
- 1993
- 1998
- 2003

%:
- 0
- 20
- 40
- 60
- 80
- 100
- 120
3. **Goals of SGR**

1. Ensure plant operation over the plant’s anticipated life, year 2023

2. Sustain plant power operation and increase plant availability to a level of 85%

3. Increase of 1 TWh per year in total annual production (25%)

4. Reduce operational costs per kilowatt of energy produced
Cost Price Trend of Electrical Power per Scenarios

Krško NPP Cost Price Trend

v SIT na kWh

Year

Scenarij (A)  Scenarij (B)  Scenarij (C)
4. Consequences as a Result of Non-execution or Delays

1. At least 2% reduction of power and plant operation already after Outage ‘98

2. Increasing maintenance expenses and lower power production to an extent of ~ 70 m DEM/year

3. Plant shutdown before year 2005 due to:
   1. Unstable plant operation and nuclear safety issues
   2. Economically unjustifiable plant operation

4. Ecological consequences
Economic Effects

- Increase of Direct Expenses for Inspection and Maintenance of SGs in year 2000 (inspection, sleeving, plugging ~ 16 m DEM)
- Reduced Electrical Power Production due to:
  - longer outage - 20 days ~ 0.34 TWh
  - power reduction appr. 7.5% ~ 0.3 TWh
  - non-acceptance of power increase - 6.5% ~ 0.26 TWh

Total Electrical Power not being Produced - 0.9 TWh

0.9 TWh x 6 pf = 54 m DEM

- Direct and Indirect Expenses - 70 m DEM
Environmental Issues

- SGs and especially SG tubes contribute to the integrity of the primary system and prevent radioactive releases into environment.
- Current SG tubes are subject to numerous tube degradations (stress corrosion cracking).
- In spite of maintenance activities the risk of radioactive releases into environment cannot be avoided.
- Few longer shutdowns due to tube leaks and eventual one or two radioactive releases into environment lead to immediate and probably permanent shutdown of the Krško NPP.
Regulatory Restrictions

- Krško NPP was permitted to operate with 18% plugging level.
- To continue plant operation after Outage ‘98 the Krško NPP expected to get a permit from the SNSA for plant operation up to 24% of SG plugging level.
- In year 2000 SG plugging level was expected to exceed 24% therefore new analyses will have to be performed, 3-4 m $ worth.
- The increased risk and reduced safety margin may cause the SNSA and authorized institutions not to permit plant operation with the plugging level exceeding 24%.
Integrated Safety Assessment Program

KRSKO MODERNIZATION
PROJECT SCOPE
Scope of Krško SG Replacement and Power Increase Project

- Supply of 2 steam generators
- Replacement activities and associated modifications for replacement and power increase
- Analysis necessary for SG replacement and power increase + ICCM and RTDBE modifications
- Supply and installation of plant specific simulator
- Other activities
Supply of Two Steam Generators

– RSG thermal power 1000
– Full functional and physical integration
– Main features
  • Design (FWinlet, TSP, AVB …)
  • Materials (I - 690 TT …)
  • Manufacturing process (Tube expansion …)
– Documentation (Design, Manufacturing, Test reports …)
– Transportation
SG Replacement and Associated Modifications

- One major contractor
- No major modifications
- Equipment hatch is large enough
- Polar crane modifications
- Two-cut method/RC piping
- Testing
- Major project goals:
  - Quality
  - Schedule
  - Radiation Dose Reduction
  - Waste Reduction
Analysis for Replacement and Power Increase

- Safety Analysis
  - Operating window determination
  - Verification of new operating conditions
  - Remaining USAR analysis
- Plant operation verification
  - Mechanical review/analysis
  - System verification
- Snubber reduction
  - SG snubber reduction
  - Piping snubber reduction
    - Rerouting piping
    - Class 1 piping
- ICCM
Plant Specific Full Scope Simulator

- Meet the requirements of regulatory body
- Full scale replica of the Krško NPP MCR
- Fully dynamic real-time simulation consistent with ANSI/ANS 3.5 standard
- Plant local panels included
- Linkage with SG replacement project
Other Activities

- Building for old SG’s
- Simulator building
- Cooling towers
- Transportation of new SG’s
Integrated Safety Assessment Program

ANALYSIS FOR SGR AND POWER UPRATE
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

- Introduction
- Scope of analysis
- Safety analyses
- Mechanical analysis
- Plant maneuverability verification
- Conclusions
RSG “Software” Activities

Support to Hardware itself’ (i.e., RSG)
- Inputs to RSG Stress Report

(Plant Analysis and Licensing)

Impact of RSG on the rest of NSSS “Compatibility Studies” WHY?
- New primary operating parameters
  Operating Window)
  AND
- Increased SG size
  (primary side water volume ▲, secondary side water mass ▲, SG weight ▲, Center of Gravity Height ▲)
- Different SG Hydraulic characteristics

Impact on Original/
Current Licensing Analyses and
Design Basis Documentation
Standard Uprating Program Methodology

Ground Rules and Criteria:

– No impact on plant design basis
– Review to encompass only what is effected by uprating
– Review conducted using codes, standards, criteria applicable to current plant SPECIFIC OPERATING LICENSE
– Analytical techniques:
  • Updated techniques used if reanalysis is necessary for uprating
  • No reanalysis if not affected by uprating or previously performed at uprated power
What Have Utilities Considered As Priorities With RSG Programs

- Upgrade analysis to current technology
- Increase electrical output via uprating
- Incorporate fuel enhancements/optimization
- Increased NSSS component fatigue analysis for PLEX considerations
- Enhance operating flexibility
- Maintain common licensing basis for sister units
- Incorporate surveillance/maintenance improvements
- Minimize regulatory risk
- Utilize synergy to optimize cost accounting
Historical Background Of Feasibility Evaluations

- Uprating “Feasibility Study” in 1991. In fact, evaluations only without analysis concluded 2000 MWt feasible, but the following may be necessary:
  - Fuel upgrading with IFMS
  - B.E.analysis with W COBRA TRAC for LB LOCA
- Accordingly, first uprating proposal in 1994
- In frame of fuel and RSG discussions closer look given at DNB conclusion, no major fuel upgrade necessary
- Following NEK’s RFQ, feasibility of using BASH for LB LOCA was determined (enabling a base scope minimizing changes and costs)
- Estimate of system changes was refined
- As a result, proposed analyses program included little methodology changes to existing licensing basis
Feasibility study conclusions

- Up to 5% power uprate without modifications
- Power uprate above 5% - require some modifications - depends on new SG performance
- 6.3% - recommended based on feasibility study - from 1882 to 2000 MWt
Three basic NPP Krsko requirements:

- Safety margins shall be maintained
- Operation margins shall be maintained (plant maneuverability shall not be decreased (step load, ramp load reduction,….))
- Thermal power increase to 2000
Main Changes to Licensing Basis

- Uprating
- Operating window
- Revised thermal design procedure (RTDP)
- NOTRUMP SB LOCA
- Mass and energy release calculations
- Shutdown margin calculations
- Decay heat, ANS 1979 + 2 ⇔ (except ANS71 + 20% for Appendix K)
- R.G. 1.70 Rev. 3 for accident reanalyses
- NAOH tank removal in containment spray
- Minimized boron concentration in BIT
- Thimble plug removal
Plant Safety improvements:

- New SG (improved material - 690TT, upper feed, state of the art design)
- Fuel improvements (ZIRLO, annular axial blanket)
- Simplified FW system (upper feed - no split flow any more)
- Other small modification (safety AFW control valve trim replacement, non-safety - BD, CY, SD, HD, SAT removal - TSP basket instalation)
Whole Chapter 15 and 6 analyses will be repeated - NO EVALUATION (NPP Krško UPR specification reviewed by AI and SNSA - comments included)

− New methods and codes (all presented to SNSA before contract signature)
**Phased Program of Analyses**

- Establishment of new operating conditions
- Verification of new operating conditions
- Possible uprating driven modifications
- Complete program of analyses and documentation
  - Accident analyses
  - Design transients
  - Mechanical review
  - System evaluations
  - Control system setpoints
  - Documentation
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

SCOPE OF ANALYSIS - Continued

**Phase 1**

NSSS New Operating Conditions
- POWER
- FDH (Tavg)

- DNB
- FUEL
- Plant Maneuverability
- Turbine Limitations

**Phase 2**

Verification of new Operating Conditions
- Limiting Accidents Analysis: DNB, LOCA
- Overpressure Protection
- Containment Integrity

**Phase 3**

Remaining Safety Analyses

**Phase 4**

Plant Operating Justification
- Mechanical Review - Analysis
- System Verification
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SCOPE OF ANALYSIS - Phase 1

Establishment of new operating conditions

- Introduction of Operating Window (OW) Approach
- Reactor Thermal Power Uprate (6.3%)
- Primary coolant flow determination
  - calculated/adjusted BEF (2.8% adjustment factor)
  - MMF (0.5% hydraulic SG changeout)
  - TDF (3.0%)
- Fuel Rod Limit
  - max. T_{\text{HOT}} (fuel cladding corrosion analysis)
  - F_{N,\text{H}} = 1.62 was assumed
Establishment of new operating conditions - cont.

- T&H core design (Plant specific uncertainty analysis, Minimum DNBR (SAL) with RTDP +WRB-1 correlation)
- Optimization of plant operation ($F_{NOH} = f(T_{AVG})$; protection dynamic compensation; margin to OTDP trip in normal operation)
- Turbine limit (min. $T_{HOT} = f(SG$ outlet press) vs. th. power)
- Additional Analyses Inputs: RSG and UPR Modifications
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

SCOPE OF ANALYSIS - Phase 2

- Cycle 17 operating point
- Fuel clad temp. corrosion limit
- Turbine limit

Tavg (st. C)

307.4st.C
305.7st.C
305.0st.C
301.7st.C

Primary flow - SGTP (%)

0%
5%
Verification of new operating conditions

- Program of limiting analyses to cover OW
- RVP T&H analysis (rod drop time measurement)
- Critical Analyses:
  - DNB analyses
  - Limiting LOCA Analyses
  - Decay Heat Removal
  - Overpressure Protection
  - Containment Integrity
Margin to DNB Analysis

- Verify adequate margin to DNB SAL:
  - RWAP, CLOF Analyses (Limiting Operating Points)
  - OPDT/OTDT trip setpoints
  - Core Protection Diagram
    - (margins to PCT, DNBR, Hot leg boiling)
  - Dynamic Compensation (Lead_Lag on ΔT and TAVG)

- Criteria
  - ANSI Condition II
    - (DNB > SAL; peak pressure < 110% design limit;
      Assumptions
    - RTDP(MMF); DNB@const. p, t; $F_N \Delta H = 1.65$; conservative reactivity feedback
Margins to LOCA Analysis

- Criteria: 10CFR50.46 (adequacy of ECCS DHR)
  - PCT<1204degC, Zr reaction<17%; H2>1%
- Assumptions: 10CFR50, Appendix K
  - Decay Heat ANSI Standard 1971+20%
- LB LOCA: chopped cosine, skewed to the top/bottom (BASH/LOCBART methodology)
- SB LOCA: skewed to the top + RCP trip verification (NOTRUMP code methodology)
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

SCOPE OF ANALYSIS - Phase 2

DHR Analysis

– Verification of adequate AFW sizing
  • LONF (ANS Condition II)
  • FLB (ANS Condition IV - adopted WEE criteria that no bulk boiling occurs in the primary coolant system following a feedline rupture)

Overpressure Protection

– Limiting accidents (secondary/primary peak pressure < 110% design)
  • loss of external electrical load
  • turbine trip
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

SCOPE OF ANALYSIS - Phase 2

Containment Integrity Analysis

SRP6.2.1.1A, NUREG 0588 Appendix B

Spectrum of MSLBs

- Pth 102%, 70%, 30%, 0%
- Large/small double ended rupture
- With/without water entrainment
- Single failures considered (DG, MSIV, AFW)

Spectrum of LOCAs

- Multiple break sizes and locations (DEHL, DECL, DEPS)
- Minimum and maximum SI
- Single failures considered (DG, CI, RCFC)
Remaining Safety Analyses

- Increase/Decrease in Reactor Coolant Flow/Inventory
- Reactivity and Power Distribution Anomalies
- ATWS
- Increase/Decrease in Heat Removal
- Subcompartment Pressurization
- Radiological Consequences
System verification:

Goals:

– Compare functional requirement (taken into account in the safety analyses) to the installed capacity.

– Propose modifications if any.

– Plant Maneuvrability
  
  • Load Step Changes
  • Load Ramp Changes
System Verification

- Setpoint study
- Safety injection system
- Auxiliary feedwater system
- Safety valves
- Pressurizer relief and spray valves
- Steam generator relief valves
- Residual heat removal system
- Containment spray system flow capabilities
- Chemical and volume control system
- Reactor make-up water system
- Spent fuel pit cooling system
- Component cooling system
System Verification (Continued)

- Steam dump system
- Essential service water system
- Ventilation and air conditioning systems
- Turbine-generator system evaluation
- NSSS instrumentation recalibration
- Extraction steam system
- Turbine closed cycle cooling system
- Electrical system analysis work
- BOP instrumentation and controls
- BOP thermal/hydraulic analyses
- BOP piping
Possible Uprating Driven System Modifications

- Feedwater control valves
- Other modifications to condensate and feedwater system
  - Condensate pump suction butterfly valves
  - New condensate bypass line
  - Operation with 3 feedwater and/or condensate pumps
- Drain valves
- Condensate storage tank for operational flexibility
- Condenser/circulating water system
  - Additional cooling tower cells with fans
  - Additional cooling tower pump
  - Additional load center
  - Possibly additional 110 KV to 6.3 KV transformer
- Steam generator safety valves
- Steam dump control Tref lead/lag
Mechanical Review

- System inputs
  - Design transients specification
  - Hydraulic forcing functions
  - Gamma heating calculation
  - Fast neutron fluence

- Primary components verification
  - Stress and fatigue reconciliation to DTS
  - Pipe break loads reconciliation
  - Seismic loads reconciliation
  - Heatup and cooldown curves
  - SG supports deadweight analysis
RCL and connected Class 1 piping analysis (structural analysis):

- RCL model updated with new SG (Siemens seven mass points model)
- RCL model coupled with CNT interior structure for seismic analysis
- RCL Dynamic analysis
  - Seismic Time history analysis
  - LOCA analysis (due to LBB only 6” break
  - Static analysis (deadweight, thermal)
- Class 1 piping analysis
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

SCOPE OF ANALYSIS - Phase 4

**RCL Analysis Results:**
- Interface data for RSG and SGR (In structure response spectra, displacements, loads)
- Inputs for pipe stress and fatigue analysis (completed)
- Inputs for LBB analysis (RCS)

**LBB analysis**
- RCL LBB
- LBB for Auxiliary lines class 1 > 6”

**ALL criteria per SRP meet - LB LOCA dynamic effect can be removed from NEK design bases**
Interfaces With RSG

RSG ↔ SW  RSG data for analyses

SW ↔ RSG  Formulation of data formers modelling of RSG in loop model Benchmark GEN and LOFTRAN

SW ↔ RSG  Design transients for RSG SG Nozzle loads in structure response spectra

INTERFACES WITH SIMULATOR

SW ↔ SIM  Data base for simulator

OVERALL PROGRAM WILL BE SELFSTANDING
Component Evaluation Process

COLLECT INPUT
✓

PERFORM EVALUATION / ANALYSES
✓

DOCUMENT ENGINEERING RESULTS
✓

PREPARE SAFETY EVALUATION
Equipment Design Considerations

- Reactor vessel
- Reactor vessel internals
- Control rod drive mechanisms
- Pressurizer
- Reactor coolant pumps
- Reactor coolant piping
- Primary equipment supports
- Reactor coolant loop branch nozzles
- Auxiliary Class 1 piping
Input Required For Component Revaluation

- Power capability parameters
- Design transients
- Loca hydraulic forcing functions
- Reactor coolant piping loads
- Heat generation rates
- Fluence
- E-specs
- Stress reports
- Use of original ASME code edition
Process for Performing Evaluations/analyses of Components

- Review existing E-spec. requirements and stress reports
- Determine effects to revised input on E-spec. requirements
- Assess effect of revised input on stress report
- Perform necessary effort to demonstrate continued compliance
  - Most limiting to least limiting
  - Existing analyses bounding
  - Generic analyses bounding
  - Reanalyses necessary
- If continued compliance not demonstrated
  - Modify requirements
  - Modify hardware / operations
RC components verification

- Rx vessel (CRDM, reactor vessel internals, new heatup and cooldown limiting curves)
- RCP
- PRZ

Inputs

- RCL loop analysis
- Revised Design Transient Specification

Results:

- Addendums to E-specifications Stress reports (per ASME)
**Documentation**

- Work reports
  - Model validation
  - Optimization analyses
  - Verification analyses
  - DNB, LOCA, SLB, HEATUP, Overpressure
  - Safety analyses
  - Plant operating justification
- Safety analysis handbook
- Summary report
- USAR
- Technical Specifications
- Component safety evaluation checklist
- Setpoint study and PLS
- Startup tests
- Plant documentation
Safety Analysis and Assessment of Steam Generator Replacement and Power Uprate Presentation

Documentation to be submitted to AI and SNSA

- Work Reports (for each set of analysis)
- Summary Report
- USAR Revision (RG 1.70 Rev.3)
- PLS
- Technical Specifications
- Plant Startup Test Program Procedures
- Documents Update / Addenda (E-specifications, Stress reports,..)
- Independent Evaluation Report for each work report prepared by Authorized Institution(s)
TRAINING COURSE ON SAFETY ASSESSMENT OF NPP TO ASSIST DECISION MAKING
Integrated Safety Assessment Program

ANALYSIS FOR SGR AND POWER UPRATE

LICENSING PROCESS
Licensing Aspects of the Project

- Nuclear safety related licensing
  - Compatibility of new SG’s with plant, new SG installations and power increase will be covered by safety analysis subproject
  - Results will be received and evaluated by authorized institutions
  - Regulatory body will in parallel process review and evaluate all reports and analysis
  - License amendment is expected to be issued at the end of the whole process
  - Additional licensing process is initiated for design, manufacturing and testing of new SG’s
  - Additional review and evaluation will be conducted for SG replacement activities and associated modifications as part of regulatory body and authorized institutions activities during each outage
  - Specific license is expected to be issued for old SG building
Licensing Aspects of the Project (Cont.)

– Civil construction licensing process

• Civil construction licensing process is initiated for the new buildings

• Civil construction licensing process will be necessary for modifications on transportation route and for transportation itself
PSA Analysis of Plant Safety Before and After Modernization

- Integrated assessment of plant safety based on PSA model
- Results indicate that safety status of the plant is enhanced after modernization project completion compared to the current status
Simplified Flow Path for Licensing Process

1. Project Announcement to Regulatory Body
2. Application for formal initiation of licensing process with project description and specification submittal
3. Step by step review of project documentation and safety analysis from Authorized Institution and regulatory body
4. Incorporation and resolution of comments from review process and approval/acceptance of reports
5. Formal application for approval of proposed changes and associated safety analysis/evaluations
6. Final regulatory body review and approval of project and safety analysis
7. Implementation
Startup Program
After SGR And Power Increase
Startup Program After SGR And Power Increase

Contents of the Presentation

- Introduction
- Startup program definition
- Licensing aspects
- Startup procedure validation - advantage of having plant specific simulator
- Test results - lessons learned
- Conclusions
Startup Program After SGR And Power Increase

Introduction

- The following approach was adopted:
  - Regular plant startup test program should be used as a starting point - expand it with additional or modified tests required due to modernization project
  - Prepare and conduct all the warranty tests as a part of startup program
- Bases, starting point for Startup program due to modernization:
  - USAR Chapter 14
  - WCAP 7905 (RG 1.68 as a reference)
  - ADP 1.1.233
Startup Program After SGR And Power Increase
Startup Program Definition

- Integral Cycle 17
- Startup program
- SMI, OSP

- GOP, SOP

- SU Program SSR-NEK-10.2

- Construction Tests
Each of the modernization projects defined its scope of startup testing:

- RSG (warranty tests only - total 3 tests)
- SGR (total of 21 tests)
- UPR (total 10 tests)

Integration of all three together done by UPR (to avoid SU procedure overlap or missing) - documented in separate work report (SSR-NEK-10.2)

Integral plant startup for Cycle 17 prepared based on program SSR-NEK-10.2 and existing “normal” plant startup program (SUP-16.020)
Startup Program After SGR And Power Increase
Licensing Aspects

- No licensing requirements in US for testing after SGR and UPR (reference legislation)
- SNSA involved in the process of Startup program evolution (comments, questions, meetings)
- Final Work report on Startup program due to Modernization project - SSR-NEK-10.2 submitted to SNSA together with all the SUP procedures and AI positive FIER (Final Independent Evaluation Report)
- SNSA issued licensing amendment according to which all the SUP results with analyses had to be provided to SNSA this will be the bases for permanent approval of new rated thermal power
- NEK prepared SU Test program report - SNSA is reviewing it
Startup Program After SGR And Power Increase

Startup Procedure Validation

- Markup of the procedures provided by the subcontractor
- For each of the SU procedure plant engineer/specialist assigned to assure that procedure will be finalized with all require plant details and specifics - Same individuals assigned as test leaders
- Key plant startup procedures validated on the simulator
- All procedures that required plant operator’s action during at power operation, had been validated and trained with operations control room crew on the plant specific simulator
- Number of procedure enhancements implemented
- Load swing - example; positive aspects - contribution of Simulator use in this process.
Startup Program After SGR And Power Increase

Startup Procedure Validation

LOAD SWING TEST
Feedwater flow (t/h)

- Simulator data
- Plant data
Startup Program After SGR And Power Increase

Test Results - Lessons Learned

- RSG - Warranty tests well within acceptance criteria (SG level stability, SG thermal performance and Moisture carryover)

- UPR tests completed (primary flow verification, FW flow control verification, verification of proper setpoint adjustments, SD response verification, SF/FF cross-calibration, load swing,..) - due to final SUP adjustment - PLS rev.15 issued

- RSG - all tests completed including RCS support gap adjustment/verification) - some minor nonconformances identified (in process of resolving last two items)
Open and clear technical communication *between the plant, regulatory body and its technical support organizations* is necessary to define SUP since there is no licensing requirements.

Tests have to be limited to the ones that are necessary - tests such as large load reduction tests, etc. should be avoided since they can be justified by adequate analysis.

Communication and coordination of activities is key to success in performance of such startup program (on operational level).
Startup Program After SGR And Power Increase

Conclusions

- All the tests successfully completed among them the most important are:
  - the primary flow above the one assumed in the safety analysis
  - successful FW control verification and adjustment as well as load swing test - verification of plant maneuverability
  - moisture carryover very low and thermal performance above the warranted limit - assurance for long term operability

- All above bases for SNSA to issue licensing amendment for permanent NPP Krško operation at 2000 MWt
Integrated Safety Assessment Approach to Evaluate Plant Changes (Plant Modernization)
NEK IPE/IPEEE PSA Model Evolution

Phases

- NEK PSA Model ‘Evolution’ Phases
  
  - **Phase I**
    - Baseline W GRAFT/WLINK NEK PSA Model (Baseline ‘freez date’- December 31, 1992), with implemented IPERS Level 1 Comments/Recommendations
  
  - **Phase II**
    - Transfer to Risk Spectrum Professional PSA software
    - Implementation of IPERS Comments/Recommendations
    - Optimisation of the overall model structure to RS capabilities and features
    - Integration of the NEK Internal/External - Level 1/Level 2 PSA model (Model “NEK16B”)

IAEA Training Course on Safety Assessment of NPPs Assist Decision Making
NEK IPE/IPEEE PSA Model Evolution Phases (Cont.)

– NEK PSA Model ‘Evolution’ Phases (cont.)

• Phase III

  ❖ NEK PSA Model Update (Model “NEK98”; new ‘freeze date’ - end of OUTAGE 1999; May, 1999)

• Phase IV

  ❖ NEK PSA Model Modernisation Project Evaluation (Model “NEK2000”)
Methods and Approaches
ISA of NPP Krško Modernisation Program

- ISA implemented into two stages:
  - **Stage 1** - (addresses all plant modifications implemented since 1992 and up to Outage 1999 - documented in ESD TR 05/99)
  - **Stage 2** - (include steam generator replacement and power up-rate, as well as other modifications planned to be implemented during Cycle 16 and in Outage 2000 - documented in ESD TR 05/99)
Methods and Approaches
ISA of NPP Krško Modernisation Program

- Large number of input items for both stages (1391 stage 1 and 225 for stage 2)
- Existing SE&SS database used as a stating point (initial screening - guideline developed)
- Screening results - evaluation of safety impact - Categories:
  - **PSA impact (PSA)** - plant change may influence any aspect of the PSA process and which can be quantified directly or through the use of expert judgement
  - **Qualitative assessment (QA)** - plant change made to systems/equipment and assumptions that are relevant to safety but cannot be modelled in the Krško PSA
Methods and Approaches
ISA of NPP Krško Modernisation Program

- Screening results - evaluation of safety impact - Categories - continued:

  • **General plant improvement (GPI)** - categorised items are related to systems or plant hardware that are not safety relevant, but ultimately may contribute to safe operation

  • **Qualitative consideration (QC)** - included changes in the procedures and training that cannot be addressed in PSA quantitatively but are safety significant

  • **Qualitative safety impact (QSI)** - includes changes in safety-related documentation (USAR, TS and others) which can have safety benefits but can not be quantified or further assessment is not needed

  • **Radiological Protection (RP)** - includes modifications relating to improvement in the radiological protection at the plant

  • **Safety Culture (SC)** - groups modifications that have been introduced to improve the safety culture of the plant
## Methods and Approaches - Phase 1 Screening

### ISA of NPP Krško Modernisation Program

### Screening results - Stage 1

<table>
<thead>
<tr>
<th>Screening category</th>
<th>Category</th>
<th>No of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PSA impact</td>
<td>PSA</td>
<td>144</td>
</tr>
<tr>
<td>2 Qualitative assessment</td>
<td>QA</td>
<td>74</td>
</tr>
<tr>
<td>3 General plant improvement</td>
<td>GPI</td>
<td>171</td>
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<tr>
<td>4 Qualitative consideration</td>
<td>QC</td>
<td>111</td>
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<tr>
<td>5 Qualitative safety impact</td>
<td>QSI</td>
<td>94</td>
</tr>
<tr>
<td>6 Radiological protection</td>
<td>RP</td>
<td>35</td>
</tr>
<tr>
<td>7 Safety culture</td>
<td>SC</td>
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## Methods and Approaches - Phase 1 Screening

### ISA of NPP Krško Modernisation Program

### Screening results - Stage 2

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<th>No of items</th>
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<tr>
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Methods and Approaches - Phase 2, 3 and 4
ISA of NPP Krško Modernisation Program

– **Phase 2 activity** - detailed evaluation of the items with potential PSA impact:
  • Stage 1 - 144 items
  • Stage 2 - 24 items
– **Phase 3 activity** - Implementation of PSA model changes
  • Stage 1 - NEK98 model
  • Stage 2 - NEK2000 model
– **Phase 4 activity** - Quantification of PSA Level 1 and Level 2, interpretation of results, sensitivity analysis and documentation
Modifications Important to Safety
Stage 1 - 1992 - 1999

Modification implemented:

– AMSAC
– BIT CB reduction
– HL recirculation switchover time
– Replacement of 125 Class 1E batteries
– four hours control gas supply to AF and MS valves
– New inverters
– FPAP - modification - CB-3A
– ESW new filters
– EOP changes
– PSA parameter update - plant “experience”
Modifications Important to Safety - **Stage 2**

1. **FPAP - Stage 2** (AB-9, SW, CB-1)

Modification includes:

- **AB-9** - Install area sprinkler system and one-hour wrap (nine critical cables),
- **SW** - Install sprinkler system over SW motors, install one-hour heat shield between pumps and three-hour wrap (three power cables)
- **CB-1** - Double fusing of control circuits for separation and add circuits to shutdown panels (minimal list)

Quantified safety influence: Large reduction in fire CDF - **87%** (from 9.78E-5 to 1.25E-5)
Modifications Important to Safety - **Stage 2**

2. **RCS - New SG - S&F Design**

Modification includes:

- **Installation of new SGs** (cutting, decontamination, fit-up and clamping, welding, NDE, installation of new platforms, new SG insulation, ..)

Quantified safety influence:

Large reduction in CDF - **19.7%** on IEs (CDF from 5.34 E-5/ry to 4.29E-5 after SGR)
Modifications Important to Safety - **Stage 2**

3. Secondary Side Modifications

- FW piping & pump impellers (cutting “upper” line, elimination of connection between AF and FW, ...)
- FW protection (water hammer protection removal)
- FW control valves replacement, FW control changes (all parts except valve body - FCV 551A(552B) for startup up to 20% power, above FCV551(552), additional MS, FW Flow transmitters (3-3-3), median select control
- HD pipe replacement (segment between FWRHEX2 and HDT)
- CY piping (on CY suction)
- BD (pipe and protection against water hammer-inside SG cubicle)
Modifications important to safety - **Stage 2**

3. **Secondary side modifications** - continued

- AFW control valve trim modification and time delay for MD PMP trip (turbine isolation vlv closure) increase from 10 to 15 sec (two position trim (Cv=33 and Cv=60 allowing AF PMPs degradation up to 10%);)

- SD control (new lead/lag card on Tref - significantly faster SD response on loss of load initiating signal)

**Quantified safety influence:**

Additional reduction in CDF - 1.7% on IEs (CDF from 4.29E-5/ry to 4.20E-5 after SGR)
Modifications Important to Safety - **Stage 2**

4. **SAT (NaOH) Removal**

- Containment spray additive (NaOH tank removal) - based on WCAP-14455 and plant specific analysis (for long term pH sump control TTT installation in four baskets - TS change,.);

- Operation problem with NaOH tank will be eliminated

- Implemented in two phases

Quantified safety influence:

Decrease of CI FT frequency - effect on Level 2 - no sensitivity done within ISA scope.
Modifications Important to Safety - **Stage 2**

5. **ESW Screenwash Strainers (old) Modif.**

- Screen wash strainers removal (not needed after strainers installation on main ESW lines)

Quantified safety influence:
Decrease of SW FT frequency - effect on Level 1 - no sensitivity done within ISA scope
Modifications Important to Safety - Stage 2

6. Power uprate for 6.3%

- Parameters with potential impact on PSA - screening process results documented in SSR-NEK-19.0
- Potentially affected accident analysis repeated and results re-assessed - effort documented in NEK ESD TR 04/99
- Conclusion: power uprate do not change “success criteria” defined in IPE/IPEEE (contribution of positive effect of new SG and other modification)

Quantified safety influence:

No observable influence within available PSA methodology/tools
7. LTOP Modification

- LTOP protection accomplished through RHR suction relief valves - valve(s) replacement - passive protection
- RHR suction valve auto-closure removal

Quantified safety influence:
Large positive effect on shutdown PSA - evaluation not included in ISA
**Modifications important to safety - Stage 2**

**8. Wet cavity modification**

- Simple modification - removal of sump - cavity check valve on 4” pipe
- Extensive analysis done by WEE to prove that this design change have no adverse - negative effects on DBA

Quantified safety influence:
Large positive effect on Level 2 - MCCI prevented in many accident sequences - shift in small to very small RC (increase in very small RC from 26.7% to 31.5% and decrease small RC from 68.9% to 64.2%)
Modifications important to safety - Stage 2
9. EOP modification - Rev.8

- Major reason for modification - ICCM installation
- More reliable information available to MCR operators (two ICCM trains - RVLIS)
- Procedures easier to handle - lower subcooling required due to large decrease in core TC measurement uncertainty, procedure improvement due to RVLIS

Quantified safety influence:
Positive effect on CDF - no particular sensitivity on this model change done within ISA scope
Modifications Important to Safety - Stage 2
10. Plant Specific FSS

- Improved training on risk significant operators errors (for example ES-1.3 - establish cold and hot leg recirculation, establish secondary heat sink, initialization off F&B on time,..)

- Reduction by a factor 2 on HEP (expected benefit) and 5 (upper bound) for those critical tasks (first 100 events ranked by a fractional contribution factor)

Quantified safety influence:
CDF reduction (internal events) of \(-15\%\) for expected HEP reduction and \(-23\%\) for upper bound HEP reduction
Modifications Important to Safety - Stage 2

11. LBB Application - SRP

- Dynamic effect of LB LOCA can be eliminated from design bases per GDC#4 (1988) if plant has “proper” piping;
- Taking credit of LBB unnecessary restrictions - supports can be removed - lower probability for impact (supported by IN92-86) avoiding situations in which stress in pipes above the ones taking into account during design
- LB LOCA frequency reduced from 5E-4/ry to 8E-6/ry - (see EPRI NP-5854, figure 4, WCAP-14572)

Quantified safety influence:
CDF reduction (internal events) of -7%
Modifications Important to Safety - **Stage 2**
Other Mod. (Categorized as AQ or GPI)

- Fuel improvement (ZIRLO, top removable nozzle,..) - QA
- CY suction piping replacement - QA
- CW system traveling screen heaters replacement - GPI
- Acquisition of PIS phase II signals - GPI
- ..........

**Quantified safety influence:**
Positive effect on overall safety - not directly seen through PSA model (QA, GPI, QC, QSI)
PSA Results and Their Interpretation

Overview

– Level 1 results- consideration of CDF
– Level 2 results - consideration of release categories (RC) frequencies
– Re-considerations of plant vulnerabilities identified in IPE and risk sensitivity
PSA Level 1 Results

- Significant reduction in Internal Initiating Events (IIE) CDF

  
  "NEK98"   "NEK2000"   (1992 - "NEK16B")
  5.34E-05 /ry  4.20E-05 /ry  (5.44E-05 /ry)

  - IIE CDF reduces by 21% with respect to 1998 (23% reduction from 1992 estimation)

- Large reduction in total NEK CDF

  
  "NEK98"   "NEK2000"   (1992 - "NEK16B")
  2.20E-04 /ry  1.28E-04 /ry  (2.30E-04 /ry)

  - Total NEK CDF reduces by 42% with respect to 1998 (44% reduction from 1992 estimation)
  - Redistribution occurs among the contributing initiator categories to total NEK CDF. Internal fire category is not dominating contributor any more.
PSA Level 1 Results - continued

IIE CDF Profile

- LOOP
- SBO
- Med LOCA
- SGTR
- Tr. with MFW
- Large LOCA
- Small LOCA
- Trans. w/o MFW
- Interfacing LOCA
- Loss of ESW
- Loss of IA
- Loss of CGW
- Others

Graph legend:
- "NEK98"
- "NEK2000"
PSA Level 1 Results - continued

Total NEK CDF Profile

<table>
<thead>
<tr>
<th>Category</th>
<th>1992 - &quot;NEK16B&quot;</th>
<th>&quot;NEK98&quot;</th>
<th>&quot;NEK2000&quot;</th>
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<tr>
<td>Other External Events</td>
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<td>1.26E-05</td>
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<tr>
<td>Internal Events</td>
<td>5.44E-05</td>
<td>5.34E-05</td>
<td>4.20E-05</td>
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</table>

Total 2.30E-04 /ry  2.20E-04 /ry  1.28E-04 /ry

IAEA Training Course on Safety Assessment of NPPs Assist Decision Making
PSA Level 2 Results

RC Frequency Profile for IIE

Frequency (/ry)

0,000E+00 5,000E-06 1,000E-05 1,500E-05 2,000E-05 2,500E-05

NEK98, TR-05/99

6.07E-07 1.58E-05 1.42E-07 1.24E-05 8.92E-06 3.45E-06 1.57E-06 1.35E-08 2.32E-08 2.90E-08 5.58E-06 1.54E-06

NEK2000

4.37E-07 2.11E-05 1.98E-07 6.11E-06 3.85E-06 4.81E-06 7.47E-07 1.05E-08 1.87E-08 1.08E-08 2.66E-06 2.81E-07
PSA Level 2 Results - continued

- RC Frequency Profile for Overall IE Spectrum

<table>
<thead>
<tr>
<th>Event Type</th>
<th>NEK98</th>
<th>NEK2000</th>
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<tr>
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<td>Seismic Events</td>
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Very Small Releases

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<tr>
<td>Frequency (f/yr)</td>
<td>1.22E-05</td>
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<td>Seismic Events</td>
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<tr>
<td>Internal Events</td>
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Small Releases

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<tr>
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<tr>
<td>Frequency (f/yr)</td>
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Large

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Plant Vulnerabilities and Risk Sensitivity

Re-consideration of plant vulnerabilities

- Vulnerabilities identified by NEK IPE: Op. errors related to switchover to CL recirc. following MLOCA, SGTR followed by op. errors, interfacing LOCA, transients followed by loss of AFW
- Installment of new SGR basically eliminates SGTR concerns. Use of plant-specific simulator would reduce the likelihood of errors associated with risk-important operator actions. Secondary side MFW / AFW re-configurations reduce the risk associated with loss of AFW upon transient.
- Plant vulnerabilities are reduced.

Re-consideration of plant risk sensitivities

- Sensitivity analyses did not identify any new components or aspects to which the plant is additionally sensitive following the modifications.

No undue risk impact from plant operating practices was identified.
PSA Results and Their Interpretation

- To conclude:
  - Total NEK CDF is reduced significantly.
  - Redistribution occurs among the initiator categories contributing to NEK CDF. Seismic events are dominating contributor, followed by internal events.
  - In RC frequency profile, shift toward smaller releases is observed.
  - Plant vulnerabilities are reduced.
  - No relevant changes observed in risk sensitivity.
  - No undue risk impact identified from operating practices.
Integrated Safety Assessment Program

CONCLUSIONS
Conclusions

KEY ISSUES FOR PROJECT SUCCESS

– Early involvement in the design and planning phases of the project by the key plant organizations and personnel

– Teamwork and open communication established early and continuously throughout the project between the diverse organisations inside NEK and the contractors
Conclusions (Cont.)

KEY ISSUES FOR PROJECT SUCCESS

- Implementations of lessons learned from past SGR’s by both NEK and main contractors
- Commitment to safety and ALARA
- Use of experienced contractors and subcontractors
Conclusions (Cont.)

KEY ISSUES FOR PROJECT SUCCESS

– Management support from within the participating companies
– The everybody’s goal to complete the project in a
  • safe
  • quality and
  • efficient manner
Conclusions (Cont.)

PROJECT RESULTS AND BENEFITS

- Plant safety improvements
- Ecology (reduced emissions from fossil fueled plants)
- Energy (Increased power production by ~ 1 TWh)
- Economy (Long term reliable operation with ~ 8 year investment return with very competitive price)