KKM TRACG LOCA

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ABSTRACT

Best estimate codes and methodologies provide excellent opportunities to model and analyze real plant response. TRACG is a GE Hitachi Nuclear Energy Company (GEH) proprietary version of the Transient Reactor Analysis Code (TRAC). It is a best-estimate code for analysis of boiling water reactor (BWR) transients, based on a multi-dimensional two-fluid model for the reactor thermal-hydraulics, and a three-dimensional neutron kinetics model for the reactor core. TRACG has an extensive qualification history against separate effects test data, component performance tests, integral system effects tests and plant data. NRC reviewed and approved in detail the qualification record covering BWR/2s through BWR/6s, ABWR, and ESBWR designs. TRACG code was used to evaluate loss of coolant accident (LOCA) response for the Mühleberg Nuclear Power Plant (KKM). The analysis was performed to support operation up to the current licensed thermal power (CLTP) with GNF2 fuel design. The analysis was performed using the TRACG-LOCA methodology (Reference 1), which inherently assumes the use of the PRIME methodology for thermal mechanical considerations (Reference 2).

This LOCA analysis was performed in accordance with Nuclear Regulatory Commission (NRC) and Swiss Federal Nuclear Safety Inspectorate (ENSI) requirements and demonstrates conformance with the emergency core cooling system (ECCS) acceptance criteria described in 10CFR50.46. The objective of the LOCA analysis is to provide assurance that the most limiting break size, location, power/flow point, and ECCS single failure combination have been considered.

Thanks to the best estimate model and application, the models and basis established in this analysis form the foundation for the next step for the plant capability analysis to determine the robustness and capability of the plant.

KEYWORDS
TRACG LOCA, KKM, best estimate, MAPLHGR, PCT

1. INTRODUCTION

The evaluation described in the paper was performed to update the results of the loss-of-coolant accident (LOCA) analysis for the Kernkraftwerk Mühleberg (KKM) Nuclear Power Station with the best estimate LOCA methodology. The analysis was performed to support operation up to the current licensed thermal power (CLTP) with GNF2 fuel design. The analysis was performed using the TRACG-LOCA methodology (Reference 1), which inherently assumes the use of the PRIME methodology for thermal mechanical considerations, Reference 2.

This LOCA analysis is provided in accordance with Nuclear Regulatory Commission (NRC) and Swiss Federal Nuclear Safety Inspectorate (ENSI) requirements and demonstrates conformance with the emergency core cooling system (ECCS) acceptance criteria described in Reference 6. The objective of the LOCA analysis contained herein is to provide assurance that the most limiting break size, location, power/flow point, and ECCS single failure combination has been considered, and that all acceptance criteria are met.

A detailed description of the LOCA models for TRACG is contained in Reference 3 with a detailed description of the application methodology given in Reference 1. The qualification basis for TRACG is provided in Reference 4. This methodology is used in the present analysis for KKM to calculate an exposure-dependent maximum average planar linear heat generation rate (MAPLHGR) curve that will yield licensing basis LOCA results that meet the regulatory criteria. This study is intended to update the LOCA analysis basis for KKM to reflect a best-estimate plus uncertainty methodology using the TRACG-LOCA methodology, Reference 1.

2. OVERVIEW OF THE TRACG-LOCA APPLICATION METHODOLOGY

Enhancing the methods used for loss of coolant accident (LOCA) analyses helps ensure nuclear reactors operate safely and with high performance. In the past, analytical tools for LOCA assessments contained substantial conservatisms aimed at overcoming the limited understanding of the complex physical phenomena associated with a LOCA and the resulting physical model uncertainties, as well as the limitations in numerical analysis methods and restrictions in computational resources. Regulatory requirements impose additional conservatisms to increase assurance of public safety. In the U.S., these conservative modeling requirements were encoded in 10 CFR 50.46 and Appendix K. The best-estimate LOCA analysis methodologies, built on the knowledge gained from the continuing LOCA research and technology development, present an alternative to the traditional Appendix K methods. GEH has developed and is currently in the process of licensing in the U.S. a realistic methodology for ECCS performance evaluation based on TRACG (References 1, 4, and 5). The TRACG code represents the state of the art for BWR thermal hydraulic analysis, uses improved physical models and uncertainty analysis capabilities, and implements many numerical advancements beyond the legacy computational tools. The proprietary TRACG computer code is one of the most advanced thermal-hydraulic system codes available for BWR safety analysis. It has been extensively validated and used for other types of analyses including anticipated operational occurrences (AOOs), stability, and anticipated transients without scram (ATWS) events. It has also been used for licensing of the ESBWR.

The ECCS performance during a postulated LOCA event is evaluated to demonstrate compliance with the regulatory acceptance criteria. In the U.S. these criteria are defined in 10CFR50.46 (Reference 6). The TRACG-LOCA methodology is a best-estimate plus uncertainties technique that differs from the traditional Appendix K methods. It is based on a nominal analysis together with a quantification of the uncertainties in the analysis following the guidelines of the Regulatory Guide 1.157 (Reference 7). The methodology together with its licensing application in the U.S. is structured following the Code Scaling, Applicability, and Uncertainty (CSAU) Evaluation Methodology approach. The CSAU (Reference 8), a

study chartered by the U.S. NRC, is the first example of best-estimate method application to ECCS evaluation analysis. Additional guidance and principal criteria for such applications are provided by the U.S. NRC in Regulatory Guide 1.157. GEH has adhered to the principles provided in this guidance and continues to develop and maintain the TRACG code per Regulatory Guide 1.203 (Reference 9).
The CSAU approach is organized under three main elements. The first element addresses the requirements and capabilities, while the second element deals with assessment and ranging of parameters. The third element of CSAU is related to addressing the uncertainties. All the physical phenomena involved in the analysis are evaluated and ranked according to their impact on critical results in the Phenomena Identification and Ranking Table (PIRT) process. Model biases and uncertainties for the LOCA application of TRACG are assessed for each of the high and medium-ranked phenomena. The TRACG-LOCA methodology addresses all of the potential uncertainties and eliminates the excess conservatism while ensuring a bounding approach. The model uncertainties are evaluated by comparing code predictions to available and applicable data. The individual model uncertainty assessments are typically performed on the basis of comparisons between separate effects test data and TRACG calculations performed with the best estimate version of the code or with individual correlations used by the code. The biases and uncertainties indicated by the data comparisons are used to establish probability density functions (PDFs) for PIRT multipliers on TRACG parameters and correlations. The biases are compensated by appropriate choice of the mean value of the PIRT multiplier. The uncertainties are accommodated by choosing PDFs to represent the standard deviation of the data comparisons. The code uncertainties for BWR ECCS LOCA predictions are assessed by direct comparisons with integral tests. TRACG has been extensively qualified against separate effects tests, component performance data, integral system effects tests, and operating BWR plant data. These studies have established the fundamental accuracy of the models and correlations used by the code. Conservative values are used for some plant parameters particularly if they are not included in the uncertainty analysis. An example of one of these parameters used in the KKM TRACG-LOCA analysis is the core spray flow limitation for some of the hot bundles imposed to address uncertainties in the spray distribution across the core. For channels in which a core spray downflow limitation is imposed the limitation is based on the two standard deviation lower bound value of the minimum spray flow seen in testing of the CS system.

Using this best-estimate plus uncertainty technique, more favorable LOCA acceptance criteria results are obtained. These improvements are basically achieved by eliminating the excess conservatism that is not mandatory when a best-estimate method is used and the uncertainties are explicitly accounted for. In realistic calculations, there are no mandatory restrictions for models that can be used, as long as adequate validation and justification is provided. Among the other features that differentiate the realistic methodology from the traditional Appendix K methods are the use of best-estimate models for sources of heat, break flow characteristics, and heat transfer models.

The uncertainty quantification, an essential part of best-estimate methods, is achieved by well-established statistical techniques. The quantification of the uncertainties in the LOCA application is accomplished in two stages. In the first stage, a number of runs are carried out by randomly sampling the uncertainty contributors from their respective distribution functions for all the high and medium ranked PIRT parameters. The probability densities for the uncertainty parameters are developed as part of the methodology by rigorously evaluating the code capability against the experimental results and, in some cases, from the known possible ranges of plant operating conditions. In the second stage, the run results are examined to determine the PCT and oxidation results for compliance with the 10 CFR 50.46 criteria. The distribution of the PCT results is checked for normality. If the normality of the distribution can be established, then the one-sided upper tolerance limit for PCT is calculated with high confidence from the standard deviation and the mean value. If the normality cannot be deduced from the computed results, then the upper tolerance limit for PCT is determined by relying on non-parametric (i.e. distribution-free) order statistics. In this method, the number of samples (i.e. computer runs) is determined by the confidence level and coverage desired for the final results. This is given by the well-known order statistics method based on the Wilks formula. Using 59 runs, the upper tolerance limit is determined from the highest value of the figure of merit. The non-parametric order statistics is already in use both in the U.S. and in Europe. The same statistical technique is also used in minimum critical power ratio (MCPR) calculations for AOO applications using GEH's NRC-approved TRACG-AOO methodology.

The TRACG-LOCA application methodology entails a number of elements that provide a structured process to the analysis. The KKM TRACG-LOCA application includes the following major aspects:

- Identification of plant-specific parameters of interest that could have an important impact on the LOCA results; The key analysis parameters are confirmed with plant engineering to accurately reflect the plant operating conditions, ECCS initiation and operating parameters, and the subsystems available for each possible single-failure scenario. The major design inputs also include:
    - Analyzed operating conditions
    - Relevant ECCS information (flow rates, initiation signals, delays, etc.)
    - Vessel and piping geometry information
    - The core spray flow to the hot bundle; core spray timing
    - Base fuel design to be used for the analysis
    - Recirculation pump data
    - Specific regulatory requirements
    - Break information (location, areas) and break boundary condition information

- PIRT assessment documentation: The PIRT as detailed in Section 5 of NEDE-33005P (Reference 1) and the uncertainties specified in the same document are applicable. The generic PIRT assessments in NEDE-33005P are reviewed for applicability to KKM. The PIRT parameter matrix is generated for statistical calculations.

- The basedeck generation provides the plant-specific input applicable to KKM-specific configuration. For the best-estimate analysis, the model is prepared as accurately as possible, and using bounding inputs whenever necessary.
    - Vessel volumes, consistent with plant design data
    - Recirculation loop, modeling break sizes consistent with plant design data
    - Core spray flows and radial distribution using applicable conservatism
    - A bundle component consistent with GNF2 bundles used in KKM
    - Control set-points
    - ECCS initiation logic
    - Heat balance

- The basedeck verification is performed to confirm that inputs are consistent with the geometry, plant operating condition, and ECC system inputs described above..
    - Bundle component and power distribution in the bundle
    - The performed calculations and modeling are consistent with the methodology
    - Comparison with any applicable plant transient data (e.g., Reference 3)
    - Break flows and vessel volumes; depressurization timing
    - The core sprays flows
    - Confirmation of sequence of events and response

- Break spectrum analysis: A break spectrum is generated considering various locations and sizes of breaks, as described in this paper.

- The limiting break size is defined based on the break spectrum above and the uncertainty calculations will be done for the limiting break size. Additional statistical calculations are performed for other potentially limiting break sizes and locations as needed. The PIRT parameters are selected for each statistical assessment based on the event being analyzed (e.g. large recirculation line break, core spray line break).

- Compliance with the acceptance criteria is assessed based on the results of the statistical evaluations. The results of the statistical evaluation and the compliance evaluation form the licensing basis for the plant.

- MAPLHGR Generation: Based on the licensing basis evaluations, the MAPLHGR limits are established to ensure that the acceptance criteria would be met with a high degree of confidence.

3. LOCA ANALYSIS REQUIREMENTS

3.1. ECCS Acceptance Criteria

The following acceptance criteria are applied to the results of this evaluation as given in 10CFR50.46 in the U.S. ENSI has adopted 10CFR50.46 acceptance criteria for application in Switzerland:

1. Peak cladding temperature: The calculated maximum fuel element cladding temperature shall not exceed 2200°F (1204 °C).

2. Maximum cladding oxidation: The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation. Total oxidation means the total thickness of cladding metal that would be locally converted to oxide if all the oxygen absorbed by and reacted with the cladding locally were converted to stoichiometric zirconium dioxide. If cladding rupture is calculated to occur, the inside surfaces of the cladding shall be included in the oxidation, beginning at the calculated time of rupture.

3. Maximum hydrogen generation: The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel were to react.

4. Coolable geometry: Calculated changes in core geometry shall be such that the core remains amenable to cooling.

5. Long-term cooling: After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

3.2. ECCS Failure Considerations

For the KKM LOCA analysis, there is a requirement to assume that one ECC system will fail to perform its function after an event. This single failure is termed the “N-1” criterion. The single failures considered and remaining systems available are shown in Table I. The most limiting single failure, break location, and break size will be identified.

Table I Single Failure Evaluation

Assumed Single Failure	Remaining Systems
CS	2 RCIC + 1 CS + 2 ALPS + ADS
ADS (1 valve)	2 RCIC + 2 CS + 2 ALPS + ADS (N-1 valves)
RCIC	1 RCIC + 2 CS + 2 ALPS + ADS

3.3. Break Locations

Several break possibilities are considered in the KKM TRACG-LOCA analysis. The break locations considered in this analysis include the following:

- Recirculation suction and discharge line (a spectrum of break sizes up to and including the double-ended guillotine break)
- Feedwater line
- Steamline (inside containment)
- Steamline (outside containment)
- Core spray line (a spectrum of break sizes up to and including the double-ended guillotine break)

4. KKM TRACG MODEL

The TRACG model presented in this paper is based on the specific configuration of KKM. The level of detail and nodalization of the model are consistent or more detailed than the generic inputs used for the demonstration analyses presented in Reference 1. Key features of the model are given below:

- The vessel component is divided into 22 axial levels and 4 radial rings.
- The 240 physical fuel bundles are represented by 29 channel components based on the GNF2 fuel design..
- Hot channels are modeled to capture LOCA behavior for different axial power shapes (top-, mid-, and bottom-peaked axial power shapes) at different exposures (low, medium, and high exposure). The power shapes used in the analyses are illustrated in Figure 1. Two of the hot channels (one top-peaked and one bottom-peaked) have a liquid downflow limitation imposed at the top of the channels. This downflow limitation (1 gallon per minute) is the two sigma lower bound of the minimum spray flow to a channel determined from core spray tests for KKM.
- There are two recirculation loops represented by multiple pipe, tee, valve, and pump components.
- The 12 jet pumps are represented by two symmetric, hydraulically-scaled jet pump components.
- The steam separators are modeled with three representative separator components
- The 4 physical steam lines leaving the vessel are modeled as two steam lines. One represents a single steam line and the other represents three lumped lines. Associated with these steam lines are the inboard and outboard MSIVs, modeled with valve components. Also associated with the steam lines are the SRVs, modeled as two valves connected to pressure boundary condition components. The open area fraction of the SRVs is determined by the TRACG control system where the opening and closing setpoints of each physical valve can be specified.
- A flow boundary condition connected to the steam line upstream of the SRVs is used to model RCIC turbine steam extraction.
- The feedwater lines are represented by a single lumped line. A flow boundary condition is connected to the feedwater line model to model the RCIC liquid injection. The mass flow rate and enthalpy for the feedwater and RCIC system is provided through the TRACG control system.
- The modeled steam lines include models to represent the TCV and TBV. The model considers a single turbine rather than explicitly modeling the dual-turbine arrangement at KKM. This is acceptable for vessel isolation scenarios including the LOFW event given that the steam line losses and lengths are

conserved in the model. The control and protection range indicated vessel levels are calculated by TRACG control system logic based on the differential pressure between the flow boundary condition components.

- The control rod guide tubes are modeled by three pipe components (one for each radial ring in the core region).

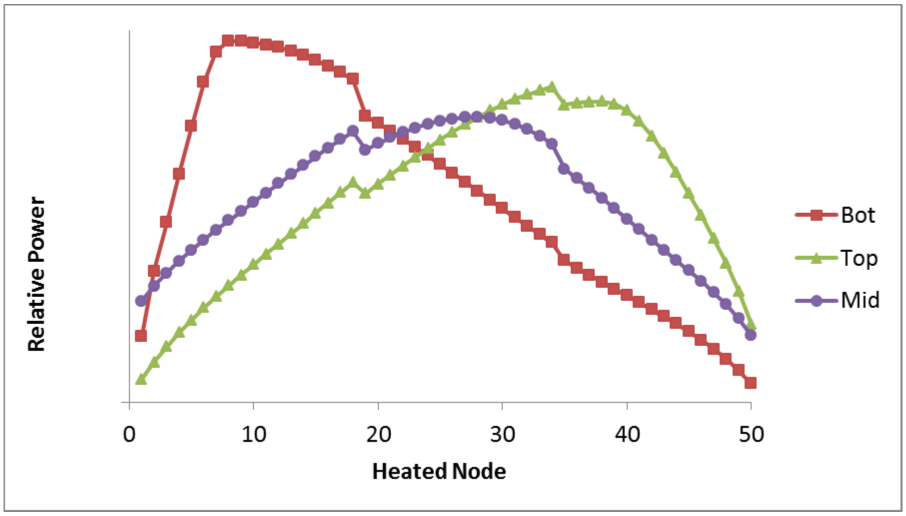

Figure 1. Representative Hot Channel Axial Power Shapes

5. ANALYSIS ASSUMPTIONS AND INPUTS

5.1. Analysis Assumptions

In addition to the major modeling assumptions listed in Reference 3 analysis, the following major analysis assumptions were used for the KKM TRACG LOCA analysis:

- If more than one initiating signal exists for a safety function or system the second signal is used as specified by ENSI A01 guidance. For example, the CS system initiates on high drywell pressure or low water level. In all TRACG analyses presented herein the CS system will not initiate until both signals have been met.
- Loss of Offsite Power (LOOP) is assumed at the most unfavorable time.
- As described in Reference 3, ANS 5-1/1979 is used for decay heat calculations. In this analysis the decay heat group powers are initialized for each channel group based on the exposure of that channel group. Therefore, every channel group modeled contributes to the overall decay heat based on the specified exposure of that group.
- The break boundary condition is assumed to be steam at atmospheric pressure (no credit is taken for increased drywell pressure expected in a LOCA scenario).
- The drywell is not physically modeled. Instead the time to high drywell pressure is calculated based on break area in a bounding, conservative way as documented in Reference 1.
- A full core of GNF2 fuel is assumed.
- No credit is taken for injection flow from CS or ALPS until the injection valves are fully open.
- The recirculation line breaks are modeled as split breaks all the way up to 200% of the pipe flow area. The double-ended guillotine break is modeled by opening two breaks (each equal to 100% of the pipe flow area) and closing off the main flow area of the pipe of interest so that the two sides of the pipe no longer communicate.

- A single component within the ECCS network fails coincident with the LOCA (single failure assumption). For a break that is located in the ECC system injection path, the single failure is assumed for the ECC in the division with the intact flow path piping.
- For CS or ALPS injection into the broken CS line, it is assumed that no injection flow reaches the vessel regardless of the size of the break.
- In the CSLB, which assumes a CS single failure, all of the injection through the CS spargers is allocated conservatively to ring 3 (core periphery) due to very limited available spray flow (from a single ALPS system).

5.2. Inputs

5.2.1. Reactor System Description

KKM is a BWR/4-type jet pump plant with 240 fuel bundles. For this analysis the reactor is considered to have a rated core thermal output of 1097 MWt, which is the CLTP. All relevant off-rated power/flow conditions were considered in the evaluation to determine the most limiting point on the operating map. The plant operating options considered in the TRACG-LOCA analyses are Extended Load Line Limit Analysis (ELLLA), Increased Core Flow (ICF), Single Loop Operation (SLO), and Final Feedwater Temperature Reduction (FFWTR).

5.2.2. ECCS Description

The primary Emergency Core Cooling System (ECCS) network at KKM consists of two independent core spray (CS) systems and an automatic depressurization system (ADS). The power for operation of the ECC systems is normally received from regular off-site AC power sources. Consistent with ENSI guidelines a loss of external power (LOEP; or Loss of Offsite Power: LOOP) is considered at the most challenging time in the licensing basis LOCA analysis for KKM.

KKM also has a special independent system for the removal of decay heat (SUSAN) which was originally designed to provide reactor water inventory makeup in special event conditions such as an earthquake, airplane crash, flood, lightning strike, or influence by a third party. It was also designed to provide core cooling following a CS line break and to provide long-term post-LOCA containment cooling. In this analysis the CS line break is considered in the licensing basis LOCA evaluation and the SUSAN system is credited for all break locations in the TRACG-LOCA analysis described herein. For the LOCA analysis the SUSAN system is comprised of two independent reactor core isolation cooling (RCIC) systems, two independent alternate low pressure spray (ALPS) systems, and two independent diesel generators.

6. RESULTS

6.1. Nominal Break Spectrum Results.

In performing the nominal break spectrum analysis, all of the break locations discussed in Section 3.3, all operating conditions and single failure considerations discussed in Section 5.2 were considered. The results provided here are the bounding results after all that consideration. Non-recirculation line breaks except for the core spray line break are not as challenging as the recirculation line breaks mainly due to elevation of the break with respect to the core. Details of the core spray line breaks are given below in Section 6.1.3.

A range of break sizes were analyzed for the recirculation line (both suction and discharge sides of the recirculation pump). The nominal break spectrum for the recirculation line was performed for a core spray single failure as well as a single failure of an ADS valve. Figure 2 shows the nominal PCT for a range of break sizes analyzed for the recirculation line and core spray line. The points in the figure represent the PCT for the limiting scenario for that break size; the combination of the limiting location on the recirculation line (typically the suction line) and the limiting single failure (ADS valve or RCIC failure on small break end and CS pump failure on large break end) for each break size. The nominal core spray line break spectrum is shown assuming the limiting failure of 1 CS pump.

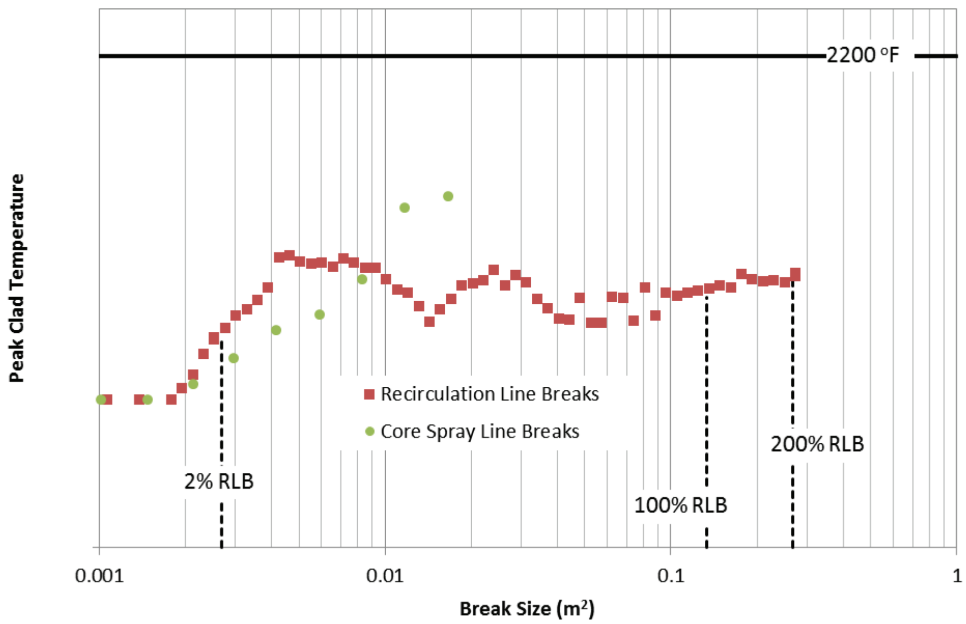

Figure 2. Nominal Break Spectrum for Recirculation and Core Spray Line Breaks

The following subsections describe the system behavior for a few selected nominal breaks.

6.1.1. Large Recirculation Line Breaks

Recirculation suction line breaks larger than about 25% of pipe cross-sectional area are considered large breaks because breaks of this size and greater cause early boiling transition and an associated first peak PCT. The limiting single failure for breaks of this size is a core spray system. A large recirculation line break, such as the double-ended guillotine break, is characterized by a rapid drop in core flow rate. Because of this drop in flow rate, nucleate boiling can no longer be sustained at the clad surface, resulting in boiling transition. The subsequent heatup is driven by the stored energy and the fission energy in the fuel and the significantly lower heat transfer rate across the cladding. The vessel pressure is also dropping rapidly at this time as inventory is lost out of the break. The depressurization is large enough that within the first few seconds pressure decreases below the saturation value and the liquid in the lower plenum flashes. The resulting two-phase mixture passes through the core and provides enough cooling to quench the heatup resulting from the early boiling transition that leads to the first peak PCT. Subsequent heatup occurs when enough inventory has exited the vessel through the break to begin to uncover the fuel. In the double ended guillotine break (DEGB) of the suction line the secondary heatup starts at about 30 seconds. The remaining CS pump (assuming a CS single failure) begins injecting at approximately 45 seconds. This is followed by both ALPS pumps injecting starting about 15 seconds later. RCIC injection begins at approximately 65 seconds and injects for a brief period (about 20 seconds) when the vessel pressure decreases below the minimum injection pressure and the RCIC turbine cannot extract enough energy to pump liquid back into the vessel. The low pressure ECCS injection immediately has a positive impact on the core heatup rate. However, the heatup is not fully terminated until there has been enough ECCS make-up water to refill the vessel above the bottom of active fuel. The quench direction is therefore from the bottom of the channel up as the vessel is refilled.

6.1.2. Small Recirculation Line Breaks

All recirculation suction line breaks smaller than about 25% of pipe cross-sectional area are classified as small breaks for this evaluation. The initial decrease in core flow for these breaks is not significant enough to cause early boiling transition. Therefore, small breaks do not have a first peak PCT as it is traditionally defined and described in Section 6.1.1. In the TRACG analyses for virtually all of the breaks in this category the failure of an ADS valve is the most limiting single failure because the break area is too small to contribute significantly to vessel depressurization. Break sizes smaller than 2% were also analyzed assuming the single failure of a RCIC pump because the capacity of the two RCIC pumps begins to be comparable to the initial break flows for very small breaks. The limiting nominal break on the recirculation line is a suction line break of about 3% of pipe cross-sectional area with an ADS valve single failure. This break is characterized by steady inventory loss out of the break that results in a drop in the downcomer level to the level 1. The level drop is relatively slow compared to the large break scenario and steam cooling from the covered portion of the core is able to cool the uncovered portion for a much longer period of time after the initiation of the break. After the MSIVs are closed on level 2 the vessel pressure increases even while the liquid level is dropping. At about 1 ½ minute in to the event two RCIC systems turn on. The relatively cold RCIC injection through the feedwater spargers condenses steam and turns around the pressure increase before SRV setpoints are reached. At about 3 minutes the ADS timer delay has expired and operable ADS valves are opened. At this point the dome pressure is still near operating pressure. The ADS valves opening causes a flashing of the liquid in the core and lower plenum, which results in temporary cooling followed by the core becoming almost completely voided when the flashing ends. The break uncovery happens shortly after ADS initiation. After this point, the RCIC liquid injection is of little consequence beyond the initial impact of preventing SRV actuation because the pressure is already low and the RCIC flow is injected into the downcomer, where it goes directly out of the break. The core begins to heatup shortly after break uncovery when the steam surge from ADS subsides. The ADS valve single failure is more severe at this break size because the additional time it takes the two remaining ADS valves to depressurize the vessel allows for a longer heatup time prior to low pressure injection. The PCT quickly turns around after the CS and ALPS systems begin to inject. This is initially due to steam cooling from feedwater flashing and initial spray flow followed by reflooding the core from the bottom. However, the heatup time is enough to produce a PCT beyond the initial operating temperature.

6.1.3. Core Spray Line Breaks

The core spray line double-ended guillotine break is the most challenging break in the entire nominal spectrum, including the recirculation line break spectrum. The limiting single failure in the event of a core spray line break is the core spray pump failure in the intact line. The limiting operating condition for the limiting CS line break is at the minimum licensed feedwater temperature (FFWTR).

In a CS line break, with CS single failure and FFWTR condition, the injection into the broken loop goes directly out through the break and is assumed completely unavailable in the analysis. This leaves a single ALPS pump injecting into the intact loop as well as two RCIC pumps available for reflooding the vessel. The core spray line is relatively small, but the break draws inventory from inside the core shroud. The elevation of the lower CS sparger is less than 0.50 m above the top of active fuel. This means that the break flow is a low quality mixture until the level is just above the level 1 setpoint. The level drop in a predominantly liquid break of this size is still quite rapid. The pressure stays approximately constant after

MSIV closure until about 50 seconds into the event (liquid breaks of this size and smaller are ineffective at depressurizing the vessel until the break uncovers). At this point the water level has dropped enough to uncover the break elevation. The inventory loss rate starts decreasing dramatically at this point. The pressure begins to decrease as a result of the switch from a primarily liquid to a primarily steam break (Figure 3).

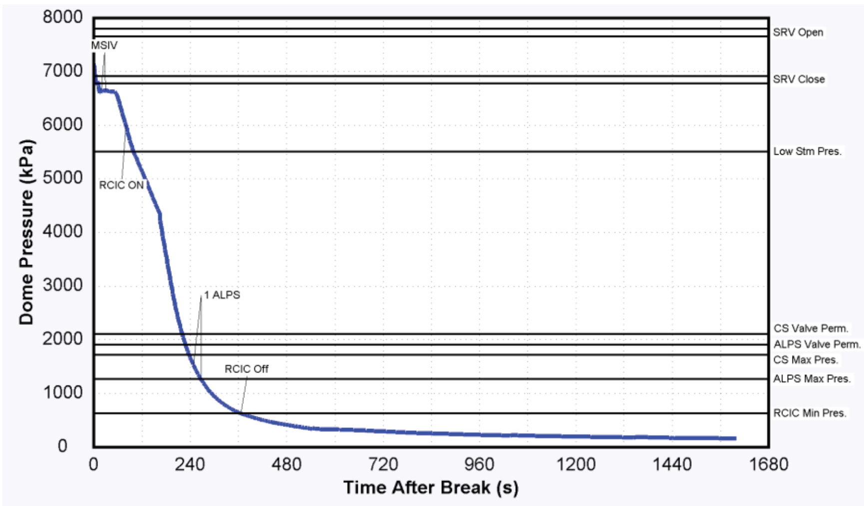

Figure 3. Dome Pressure, CSLB (DEGB, FFWTR)

Both RCIC systems begin injecting at about 80 seconds. The uncovery of the break and subsequent depressurization causes flashing in the liquid and a swell in the two-phase level. The ADS initiation sequence is triggered when the downcomer water level briefly drops below level 1 prior to RCIC injection. The valves open after the ADS timer delay is expired. Opening the ADS valves results in a significant increase in the average void fraction in the core. The level initially increases due to void-driven level swell, but eventually decreases as more inventory is lost through the SRVs and the break. The level ultimately drops to a point where enough fuel is exposed to produce a fuel heatup. The single available ALPS pump begins injecting at approximately 4 ½ minutes in to the event. The core average void fraction begins to gradually decrease after ALPS injection (Figure 4).

The inventory addition from ALPS is not evident in the sensed downcomer level, which shows a drop in level after the flashing from the ADS depressurization settles out. This is because ALPS injects inside the shroud and only RCIC is injecting to the downcomer. Once the vessel pressure decreases to the minimum operating pressure for RCIC, the RCIC operation terminates.

The RPV pressure eventually drops below the saturation pressure of the liquid in the feedwater line. Immediately following this, the inventory in the feedwater line starts flashing, which pushes that inventory into the vessel. This additional inventory provides enough cooling to halt the PCT heatup temporarily. Once the flashing subsides though, fuel continues to heat up briefly until ultimately the peak PCT is reached. The heatup duration is extended because of the limited makeup capacity that 1 ALPS pump provides relative to the continued loss of inventory through the break and the ADS valves. The cladding temperature decreases as the single available ALPS pump refloods the vessel enough to establish a two phase level such that the steam generated in the lower portion of the core is able to effectively cool the exposed portion.

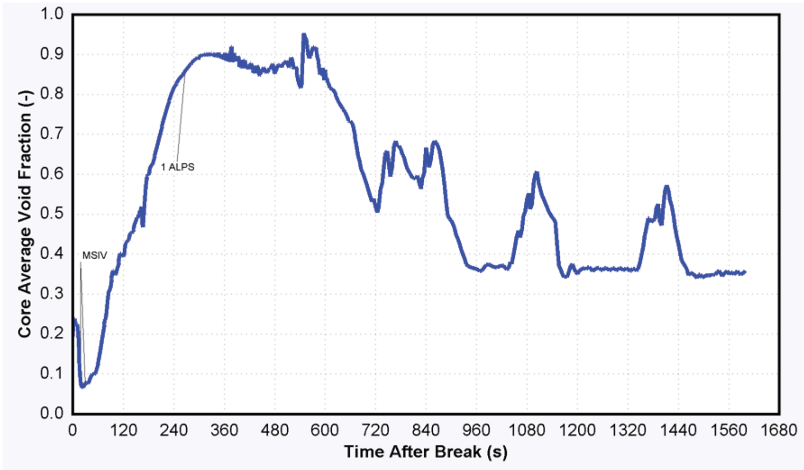

Figure 4. Core Average Void Fraction, CSLB (DEGB, FFWTR)

The duration of the heatup, thanks to limited ECCS availability, is long enough that the PCT for the double ended guillotine break of a core spray line is significantly higher than those of the recirculation line breaks (Figure 2).

Furthermore, the nominal CS line break spectrum (CS single failure at FFWTR condition) in Figure 2 shows that the PCT increases as the break size increases. The most limiting break is the double ended guillotine break of the CS line and there are no limiting smaller break sizes such as those seen on the recirculation line because the significant heatup occurs when the vessel is already at low pressure. The PCT is determined by the duration of the heatup time; i.e. how quickly the single available ALPS pump can reflood the vessel. This results in the largest possible break size being the most limiting.

6.2. Statistical Results for the Limiting Case

The TRACG-LOCA application licensing topical report (LTR), Reference 1, and Section 2 describe in detail the statistical process used for determining licensing basis results. The significant phenomena considered in the statistical evaluation are selected using the phenomenon identification and ranking table (PIRT) selection process. This is a process in which phenomena are ranked based on relative importance to LOCA transient applications. All phenomena that have a medium or high ranking are treated in the statistical evaluation. The treated phenomena each have an assumed statistical distribution based on data from relevant tests as described in Reference 1. This application uses PIRTs whose rankings were specially considered for KKM, considering the plant’s design, ECCS configuration, and regulatory requirements.

The input value for each PIRT parameter treated is randomly sampled from its distribution for each of the 59 trials (not counting the nominal case) that make up the Monte Carlo statistical evaluation process at a given break size and location. For the distributions of critical output parameters of interest (i.e. PCT and oxidation) the process described in Reference 1 is used to calculate an upper tolerance limit with high confidence.

The nominal break spectrum described in Section 6.1 is used to determine which points are analyzed with the statistical (CSAU) evaluations. The statistical evaluation was performed for the limiting scenarios identified in the nominal break spectrum; DEGB of the recirculation suction line (CS single failure), the limiting small break of the suction line (ADS single failure), the limiting intermediate break of the suction line break (ADS single failure), and the CS line DEGB (CS single failure, FFWTR). These points represent the largest break size and location in the recirculation line, the most limiting nominal break size for the entire recirculation line, a limiting intermediate size recirculation line break, and the most limiting overall pipe break considering off-rated conditions, respectively.

After statistically evaluating all potential limiting scenarios amongst the nominal break spectrum results, the double ended guillotine break of the core spray line with CS single failure at FFWTR condition emerged as the licensing case. Table II provides a summary of the licensing results.

Table II Licensing Basis Results

Criteria	**TRACG-LOCA Analysis Result**	**Acceptance Criteria**
Licensing Basis PCT	< 1710°F	<2200°F
Maximum ECR	<4%	<17%
Core-Wide Metal Water Reaction Rate (Hydrogen Generation)	<0.1%	<1%

7. CONCLUSIONS

A revised LOCA analysis for the KKM plant has been conducted using TRACG methodology. The results obtained using the realistic calculations indicate that the plant meets the Swiss regulatory requirements and would maintain adequate safety margin in case of a LOCA. The detailed analysis using realistic inputs and models provides a better understanding of event progression particularly for different break size/location and single failure assumption combinations. In this particular analysis, a non-recirculation line break is shown to be more limiting than a typical double-ended guillotine break of the recirculation line. As realistic calculations provide a more favorable PCT response in large-break LOCA cases compared to conservative approach, the combination of assumed available systems and the uncertainty treatment resulted in core spray line break with FFWTR condition as the licensing case. Overall lower PCT results from the best-estimate plus uncertainties analysis also provides a greater operational margin because of improved MAPLHGR limits.

NOMENCLATURE

ADS	Automatic Depressurization System
ALPS	Alternate Low Pressure Spray
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CRD	Control Rod Drive
CS	Core Spray
CSAU	Code Scaling Applicability and Uncertainty
DEGB	Double Ended Guillotine Break
ECCS	Emergency Core Cooling System
ECR	Equivalent Cladding Reacted
ENSI	Swiss Federal Nuclear Safety Inspectorate
FFWTR	Final Feedwater Temperature Reduction
KKM	Kernkraftwerk Mühleberg
LOCA	Loss of Coolant Accident

LOEP	Loss of External Power
LOFW	Loss of Feedwater
LOOP	Loss of Offsite Power
MAPLHGR	Maximum Average Planar Linear Heat Generation Rate
MSIV	Main Steam Isolation Valve
NRC	Nuclear Regulatory Commission
PIRT	Phenomenon Identification and Ranking Table
PRV	Pressure Relief Valve
RCIC	Reactor Core Isolation Cooling
RPV	Reactor Pressure Vessel
SRV	Safety/Relief Valve
SUSAN	Spezielles Unabhängiges System zur Abführung der Nachzerfallswärme (Special Independent System for Removal of Decay Heat)
TBV	Turbine Bypass Valve
TCV	Turbine Control Valve
TRACG	Transient Reactor Analysis Code

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