ArevaEPRDCPEm Resource

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Subject: DRAFT Response to U.S. EPR Design Certification Application RAI No. 372, FSAR Ch. 6, Question 6.2.5-15
Attachments: RAI 372 Supplement 3 Response DRAFT.pdf

Getachew,

Attached is a draft response for RAI 372 Question 6.2.5-15 in support of a final response date of August 17, 2010. The associated FSAR markups are also enclosed in the attached file. Please let me know if the staff has questions or if the response can be sent as final.

Thanks,

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Response to

Request for Additional Information No. 372(4388, 4328, 4389), Revision 1
Supplement 3

3/09/2010

U. S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 06.02.04 - Containment Isolation System
SRP Section: 06.02.05 - Combustible Gas Control in Containment
SRP Section: 06.02.06 - Containment Leakage Testing
Application Section: 6.2

QUESTIONS for Containment and Ventilation Branch 1 (AP1000/EPR Projects) (SPCV)

Question 06.02.05-15:

In the response to RAI 69, Q 6.2.5-3, the applicant states that their response to RAI 6, Q 19-113 explains how the Combustible Gas Control System and other equipment relied upon to mitigate a beyond design basis accident meets the equipment survivability requirements of 10 CFR 50.44(c)(3).

Further, in response to RAI 6, Q19-113, the applicant states that the highest adiabatic, isochoric complete combustion (AICC) pressure and temperature resulting from the analysis of the data obtained from the 59 cases is 105.9 psi and 1634F. And, an assessment of the extended operational range with respect to a pressure spike of 105.9 psi and 1652F will be made for relevant equipment and instrumentation that needs to remain operational after a potential hydrogen combustion.

The staff review of the above response to Q 19-113 seems to indicate that the applicant only intends to address how CGCS meets the requirements of survivability at the conditions of a hydrogen burn.

10 CFR 50.44(c)(3) requires all equipment and instrumentation in containment needed to establish and maintain safe shutdown and containment structural integrity must be capable of performing their function during and after exposure to the environmental conditions created by the burning of hydrogen, in an amount equivalent to that generated from a fuel clad-coolant reaction involving 100% of the fuel cladding.

In the US EPR DCD, chapter 19.2.3.3.7.1, the applicant identifies the systems specifically designed for the environmental conditions during a severe accident in the containment, as the primary depressurization system (PDS) valves; the core melt stabilization system (CMSS); the combustible gas control system (CGCS); and severe accident hear removal system (SAHRS) equipment located in the containment.

In the US EPR DCD, chapter 19.2.4.4.5.2, the applicant lists the equipment and instrumentation in containment which must withstand the conditions expected to occur during a severe accident. This equipment is also identified in Table 19.2-2, SAHRS Design and Operating Parameters, (Containment Spray Nozzles and Passive Outflow Restrictor only), and in Table 19.2-3, Severe Accident Instrumentation and Equipment, (in containment equipment and instrumentation only).

In the US EPR DCD, chapter 19.2.3.3.7.1, the applicant states that the containment isolation valves, containment penetrations, air locks, hatches and gaskets are required to maintain their leak tightness during a severe accident.

Justify that the equipment and instrumentation, in the containment only, identified in Tables 19.2-2 and 19.2-3, will perform their severe accident function during and following a severe accident in containment at the environmental conditions created by hydrogen burning. Justify that the containment isolation valves, containment penetrations, air locks, hatches and gaskets will maintain their leak tightness during and following the environmental conditions created by hydrogen burning.

Provide the pressure and temperature conditions in containment during hydrogen burning that these instruments and components would be subject to. Identify design features, test results, or analyses which would confirm the equipment survivability.

Provide a response that addresses 10 CFR 50.44(c)(3), Equipment Survivability, including an FSAR markup for inclusion into the US EPR DCD, chapter 6.2.5.

Response to Question 06.02.05-15:

Although safety-related electrical and mechanical equipment must perform its safety-related function during design bases events, the equipment necessary for mitigating severe accident consequences must provide a reasonable level of confidence that it will function in a severe accident environment for the needed time span. This requirement is referred to as “equipment survivability” and is fundamentally different from “equipment qualification,” which is terminology used for the level of assurance provided for equipment necessary for design basis accidents. The equipment survivability assessment is performed with a practical engineering approach accompanying best-estimate accident environments.

10CFR50.44(c)(3) requires that systems and components needed to establish and maintain safe shutdown and containment structural integrity must be capable of performing their function during and after exposure to the environmental conditions created by the burning of hydrogen. Environmental conditions caused by local detonations of hydrogen must be included, unless these detonations are proven unlikely to occur. The amount of hydrogen to be considered must be equivalent to that generated from a fuel clad-coolant reaction involving 100 percent of fuel cladding surrounding the active fuel region.

The environmental conditions given in this response serve as the basis for the definition of temperature and pressure profiles to be applied to any component of systems considered necessary during a severe accident. In accordance with the requirements of 10CFR50.34, 50.44, and the guidance in SECY-93-087 and SECY 90-016, the containment integrity will be maintained during an accident that releases hydrogen generated from 100 percent fuel clad-coolant reaction accompanied by either hydrogen burning or the added pressure from post-accident inerting. Systems necessary for providing containment integrity will also perform their function under accident conditions (see 10 CFR 50.34(f)(3)(v)(A)(1)).

Severe Accident Environment with Hydrogen Burning

Over the course of a severe accident, the combustion of hydrogen generated by oxidation of zirconium in the melting reactor core leads to an increase in the pressure and temperature in the containment, even in the case of a laminar combustion, which prevails for low hydrogen concentrations. In the case of high local hydrogen concentration, turbulence can provoke flame acceleration even up to sound velocity with the possibility of a transition to detonation.

The U.S. EPR’s combustible gas control system (CGCS) is a design feature to address hydrogen generation and control. The CGCS is designed to promote hydrogen mixing in the containment atmosphere and reduce the concentration of hydrogen via 47 passive autocatalytic recombiners (PAR). A performance analysis of these hydrogen control measures was performed. This best-estimate plus uncertainty analysis incorporated several phenomenological uncertainties convolved with biases addressing regulatory expectations. The results of those studies showed that the likelihood of a fast deflagration or detonation is negligible.

Per SECY-93-087, new plant applicants should verify that the best-estimate environmental conditions (pressure and temperature) resulting from core-concrete interactions do not exceed the Factored Load Category for concrete containments for approximate 24 hours. SECY-93-

087 provides guidance for applicants to verify that the containment capability has margin to accommodate uncertainties in the environmental conditions from core-concrete interactions. These best-estimate conditions are those expected from the more likely severe accident scenarios as defined in topical report ANP-10268P-A, Revision 0, “U.S. EPR Severe Accident Evaluation Topical Report.”

Based on the more likely severe accident scenarios identified in ANP-10268P-A, Revision 0, MAAP4 calculations were prepared to derive limiting pressure and temperature load profiles resulting from hydrogen combustion during a severe accident in the U.S. EPR design. The results of this calculation are provided in this response. Figure 06.02.05-15-1 and Figure 06.02.05-15-2 present the temperature and pressure time history in the dome in case of hydrogen burning.

Testing and Severe Accident Experiments

For the mitigation of severe accidents, the Severe Accident Management Guidelines rely on both safety-related and non-safety-related systems, structures, and components (SSC). Equipment qualification (EQ) testing is performed to demonstrate that safety-related equipment will remain functional in the environment caused by the design bases event which requires its functioning. Post-accident monitoring equipment (which includes instrumentation useful for accident management in the containment) is qualified, by testing, to the design basis loss of coolant accident (LOCA) conditions. The conditions for EQ testing are assumed to rise quickly and to remain for extended periods of time (up to one year). This extended time period provides some of the margin that is useful in severe accident situations, at least for the safety-related SSCs. The containment environment for the first hour of a severe accident is not likely to exceed the EQ test levels. A best-estimate assessment shows that an adequate margin of instrument performance exists for at least 24 hours for the less severe accidents and two to three hours into even the most severe accident.

For non-safety-related SSCs utilized for severe accident mitigation, the requirement to meet reasonable assurance can be met by manufacturer testing and analysis. Data and test results obtained from type testing, industry experience, or test facilities can justify the operability and survivability of selected equipment and instrumentation. For example, the primary source for performance expectations of similar equipment in severe accident environments is EPRI NP-4354, “Large Scale Hydrogen Burn Equipment Experiments.” This information is supplemented by NUREG/CR-5334, “Severe Accident Testing of Electrical Penetration Assemblies.” The temperature in the chamber for the first program ranged from 700°F to 800°F for ten to twenty minutes during the continuous hydrogen injection tests. Although the conditions at the equipment would be less severe, the chamber conditions include the longer duration profiles indicated in this response for the more likely severe accident events. The equipment in this program was exposed to significant hydrogen burn spikes covering the stipulated temperature excursion for U.S. EPR severe accident equipment. The same equipment was exposed to and survived several events, both pre-mixed and continuous hydrogen injection, which provides confidence in its ability to survive a postulated severe accident.

These test results provide reasonable assurance if the equipment proposed uses similar materials and is of the same type and model as those tested. Thermal analysis can be performed and results verified against the test results. EPRI NP-4354 discusses two test result applications that can be used to assess equipment survivability under a wide range of calculated in-plant accident conditions. Applying the test results to demonstrate equipment survivability can either be Environmental Enveloping or Thermal analysis. EPRI NP-4354 provides further details. Results of the Industry Degraded Core Rulemaking (IDCOR) program on equipment survivability provide further assurance that selected equipment has the ability to survive and to perform its function.

Severe Accident Equipment Survivability Evaluation

Containment Isolation Valves:

In general, valves performing the containment isolation function are safety grade and will be qualified in accordance with 10CFR50.49. U.S. EPR FSAR Tier 2, Appendix 3D provides the environmental parameters applicable to the environmental conditions in specific plant building and room locations. U.S. EPR FSAR Tier 2, Figure 3D-1 and Figure 3D-2 show the typical temperature and pressure service conditions envelope inside containment used for the safety-related equipment qualification program.

During a severe accident sequence with associated hydrogen burning, temperature and pressure spikes, although of short duration, are predicted (see Figure 06.02.05-15-1 and Figure 06.02.05-15-2). These temperature and pressure excursions surpass the qualification profiles used for the qualification under 10CFR50.49. The containment isolation valves are closed early during the accident sequence prior to the predicted hydrogen burn. The valve function to close and isolate the containment is not impacted, and maintaining leak-tightness is the main criterion for a severe accident survivability evaluation.

Because the valves are isolated, the temperature spike leads to slightly elevated surface temperatures on the inside and outside of the components. The increase in surface temperature is marginal because the temperature spike is not long enough to cause significant heat transfer to the components. The increase in surface temperature is limited and is in the margin of capability for the component.

The explanation of the valve temperature spike can apply to the short-term pressure increase due to the hydrogen combustion. The pressure increase will not impact the capability of the isolation valves to maintain containment isolation and leak-tightness.

Differing types of valves, including MOVs and solenoid valves, were part of the hydrogen burn experiments performed by EPRI (see EPRI NP-4354). These valves endured several transients, which provides reasonable assurance that these components will maintain leak-tightness during and following a postulated hydrogen burn.

Containment Penetrations:

The containment penetrations, similar to the containment isolation valves described in this response, are safety grade and will be qualified under 10CFR50.49. The EPRI NP-4354 and NUREG/CR-5334 experiments included penetrations previously qualified for safety-related service in nuclear power plants. Neither test resulted in mechanical degradation that would impact the capability of the penetration to maintain leak-tightness during and following a postulated hydrogen burn.

During the NUREG/CR-5334 experiments, penetrations were subjected to simulated severe accident conditions over the course of 10 days, with temperature and pressure reaching 400°F and 75 psia, respectively. While the estimated hydrogen burn temperatures exceed 400°F for a limited time, the long-term steady temperatures are below the requirements. The electrical and mechanical penetrations maintain their leak-tightness in the event of a severe accident with hydrogen burning.

Airlocks and Hatches:

The equipment hatch and airlocks need to provide containment integrity during severe accidents with hydrogen burning. The equipment hatch has no airlock function and consists of one closure (dished cover) that is normally closed. The equipment hatch and airlocks are described in U.S. EPR FSAR, Tier 2, Section 3.8.2.1.1. The main components of the equipment hatch are the sleeve and a dished cover, including moving device and the hydraulic clamps to close the flanged joint. The cover and the sleeve are constructed of steel. The dished cover is a pressure resistant and airtight metallic piece, comprised of a dished body, a cover flange, and a sealing system. The cover flange is coupled to the wall flange by hydraulic clamps. The wall flange is welded to an intermediate sleeve, which is welded to the sleeve embedded in the inner wall of the Reactor Building. The leak tightness of the equipment hatch is verified by two concentric seals located in a groove on the cover flange. Compressible concentric seals can be pressurized in order to maintain leak tightness and provide for leakage monitoring on the inner wall flange.

The equipment hatch is classified as safety grade and will be qualified under the EQ program. This leaves the evaluation of the equipment hatch for survivability under the previously discussed severe accident conditions with hydrogen burning. The design of the equipment hatch is resistant to pressure because the additional pressure will add to the clamping force provided by the clamps. The additional force will enhance the contact of the two mating surfaces of the cover and wall flange, which increases the effectiveness of the seals. The short-term temperature excursion and long-term stable elevated temperature have a minimal impact on the leak-tightness function of the equipment hatch. The temperature spike resulting from hydrogen burning is short lived, and the heat transfer during this period to the massive steel cover will marginally increase the inner surface temperature of the cover. This increase is not significant enough to adversely impact the seal's functioning. The seals for the airlocks and the equipment hatch use an elastomer seal material, as described in U.S. EPR FSAR ,Tier 2, Section 3.8.2.6. This material maintains elasticity at elevated temperatures for extended durations and complies with the materials tested for severe accident conditions as specified in NUREG/CR 5096. Based on the design features discussed above, there is reasonable assurance that the equipment hatch will maintain its leak-tightness during the environmental conditions presented by a severe accident with accompanying hydrogen burning.

The design and materials used in the construction of the airlocks are the same as described above for the equipment hatch (see U.S. EPR FSAR, Tier 2, Section 3.8.2.1.1 and Section 3.8.2.6). Because the design features are similar, the arguments presented above for the assessment of the equipment hatch regarding leak-tightness during a severe accident are the same. Therefore, it is concluded that the design and materials used in the airlocks provide reasonable assurance that they will maintain their leak-tightness during the environmental conditions presented by a severe accident with accompanying hydrogen burning.

Equipment and Instrumentation in Containment (U.S. EPR FSAR Tier 2, Tables 19.2-2 and 19.2-3):

The main components identified in U.S. EPR FSAR Tier 2, Table 19.2-2 and Table 19.2-3 are containment spray nozzles, passive outflow restrictors, and primary depressurization system (PDS) valves. With the exception of the PDS valves, which will be electrically qualified, the components are mechanical and will be seismically qualified. The PDS valves are part of the reactor coolant system (RCS) boundary and will be qualified according to the requirements in 10CFR50.49.

The elevated environmental conditions caused by hydrogen burning during a severe accident will not affect the operability of these components. The containment spray nozzles are tangential-flow hollow cone types and are unaffected by external pressure. The temperature spike predicted because of hydrogen burning will not affect the performance of these nozzles. The passive outflow restrictors are located in the valve compartments to the left and right of the spreading room in the bottom of the containment. The restrictors are steel pipe components with no moving parts to perform their function. Both pressure and temperature increases attributed to hydrogen burning will not impact their performance. The steel of the component acts as a heat sink to the elevated temperature. Because the elevated temperature due to hydrogen burning is short lived, any increase in surface temperature is negligible. The increase in pressure will not affect the structural integrity of the component. The PDS valves will perform their function of depressurizing the RCS early in the accident sequence. Their function will not be impacted by hydrogen burning because the release of hydrogen from the degraded core is not a factor until after the depressurization. Following the depressurization, the actuator will not be required to function and the valves can fail as is.

The instrumentation identified in U.S. EPR FSAR Tier 2, Table 19.2-3 to is mostly located in either the Safeguard Buildings or the Fuel Building, and is not exposed to the elevated temperature and pressure accredited to hydrogen burning during a severe accident. Some of the instrumentation, such as core outlet temperature, RCS pressure, PDS position indication, thermocouples for the monitoring of Corium relocation in-vessel and ex-vessel, hydrogen mixing damper position indication, and delta pressure sensors are required early in the severe accident sequence, before the hydrogen burn risk. The instrumentation can fail once it has provided the required information, and the failure of the instrument can provide acceptable information to the operator. Ranges and acceptable survivability criteria will be established for each instrument on an individual basis. The instruments discussed in this section are not affected by hydrogen burning and the resulting environmental conditions.

Instrumentation that is required to function during a severe accident and considers the environments created by hydrogen burning will provide reasonable assurance that they will meet this criterion. The hydrogen monitoring system and the containment pressure sensors will have to consider elevated pressure caused by a hydrogen burn despite being located in the Fuel Building and Safeguard Buildings. Because these sensors rely on air samples and instrumentation lines open to the containment environment, elevated pressure due to hydrogen combustion and to temperature will impact the requirements for measurement range and survivability.

Other instrumentation, such as IRWST water level and thermocouples in the main coolant channel of the core catcher, are protected and shielded from hydrogen burn environments by their design and install location. The thermocouples monitoring the temperature of the main cooling channel in the basemat below the cooling structure are protected from the hydrogen burn environment by their install location. Similarly, the IRWST water level and sump delta pressure sensors are protected by the IRWST water volume. No further survivability evaluation is necessary.

General Conclusions on Equipment Survivability

The uncertainties in the equipment survivability are attributed to some uncertainties in the severe accident environments used for evaluation. The environments, in some cases, may be beyond those used in prior survivability tests and experiments. Some uncertainties may exist due to a lack of validation of analytical results by experimental data. The uncertainties do not alter the conclusions reached in the evaluation. Most of the equipment evaluated has inherent capabilities to exceed its severe environments requirements. The equipment response to the severe accident environments remains significantly below the qualification or design limits. There are sufficient margins used in qualification for design basis accidents. Similar components to those discussed in this response (such as MOVs, penetrations, and instrumentation) have been demonstrated to survive repeated hydrogen burns (based on EPRI-4354 and NUREG/CR-5334), significantly more severe than those predicted for a severe accident with hydrogen burning in the U.S. EPR.

The inherent capability of equipment to withstand severe environmental conditions, margins used in qualification tests, and prior hydrogen burn survivability experimental results provide an adequate degree of assurance that equipment will survive degraded core accidents. Steps to verify reasonable assurance will be taken during the procurement of equipment requested to function during a severe accident.

U.S. EPR FSAR Tier 2, Section 6.2.5 discusses the combustible gas control system and addresses equipment survivability. U.S. EPR FSAR Tier 2, Section 6.2.5.3.3 states that "Equipment survivability analyses, described in Section 19.2.4.4.5, consider hydrogen concentrations equivalent to that generated from a fuel clad-coolant reaction involving 100 percent of the fuel cladding surrounding the active fuel region." U.S. EPR FSAR Tier 2, Section 19.2.4.4.5.2 will be revised for consistency and will address hydrogen burning and an equipment survivability assessment.

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 19.2.4.4.5.2 will be revised as described in the response and indicated on the enclosed markup.

Figure 06.02.05-15-1—Containment Temperature (Dome) with Hydrogen Burning

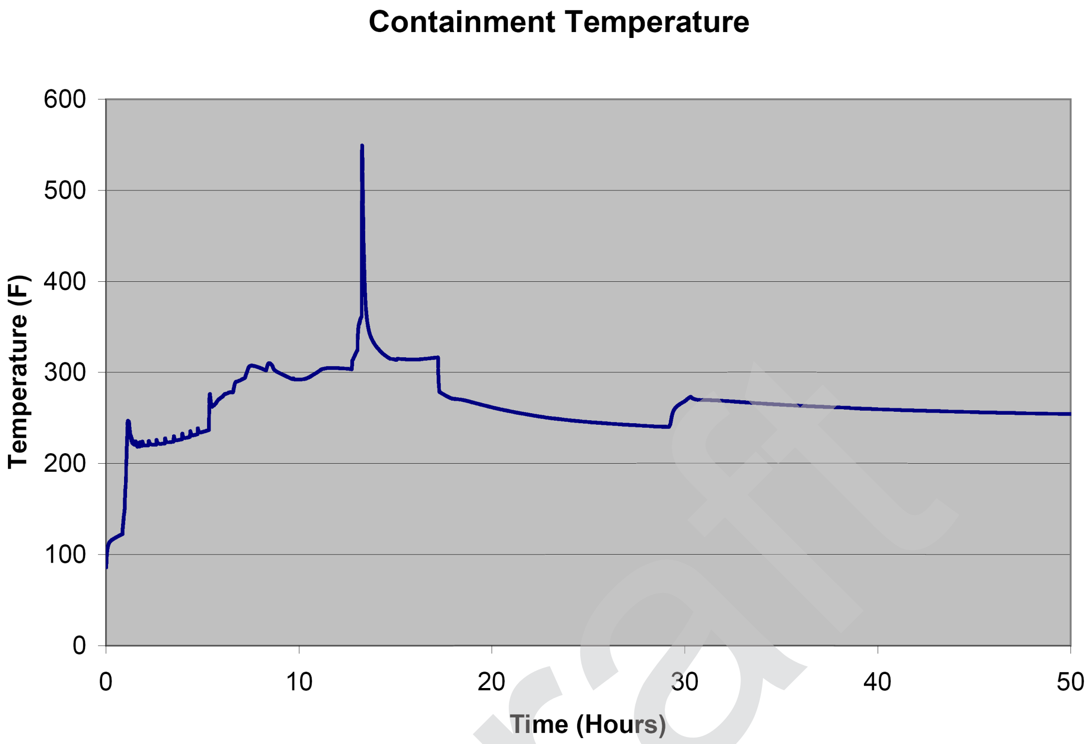
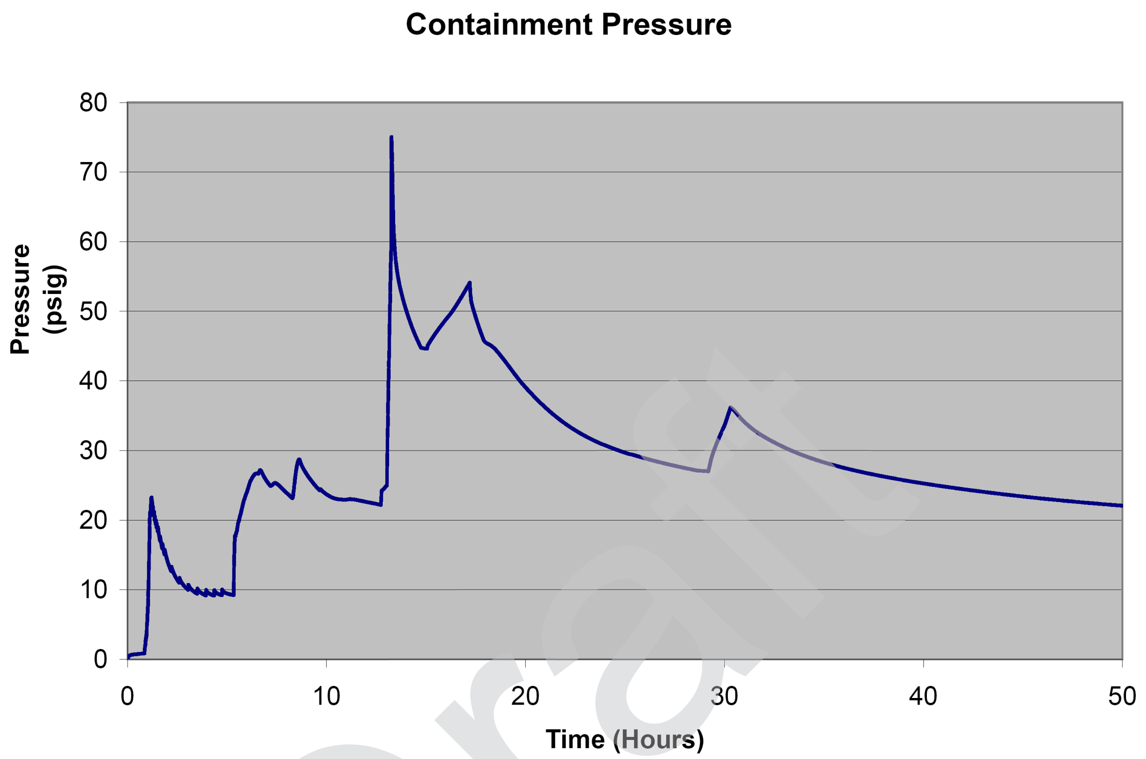


Figure 06.02.05-15-2—Containment Pressure (Dome) with Hydrogen Burning



U.S. EPR Final Safety Analysis Report Markups

19.2.3.3.7.1 Equipment and Instrumentation Necessary to Survive

Systems specifically designed for the environmental conditions anticipated during a severe accident within the RCS and the containment:

- Primary depressurization system (PDS) valves.
- Core melt stabilization system (CMSS).
- Combustible gas control system (CGCS).
- Severe accident heat removal system (SAHRS).

The PDS, CMSS, and CGCS components are located inside the containment and therefore are qualified for local ambient conditions, namely pressure, temperature, humidity and radiation. While the SAHRS is used to limit the pressure and temperature inside the containment, its main components, namely the heat exchanger and pump, are not located inside the containment. These components only need to be qualified for elevated temperature and radiation doses inside the compartments in the Safeguard Building where they are located. Containment isolation valves, containment penetrations, air-locks, hatches and gaskets, are required to maintain their leak tightness during a severe accident. This equipment is qualified for elevated pressure and temperature. Table 19.2-3—Severe Accident Instrumentation and Equipment summarizes all instrumentation and equipment necessary to monitor the severe accident progression and to allow for operator action.

19.2.3.3.7.2 Severe Accident Environmental Conditions

Environmental conditions for equipment survivability in a severe accident are quantified through the performance analysis described in Section 19.2.4.4.5. This analysis provides a realistic assessment of equipment stresses.

19.2.3.3.7.3 Basis for Acceptability

While severe accident equipment does not necessarily have to meet rigorous codes, standards, or procedures as typically specified for licensing design basis, the performance analysis given in Section 19.2.4.4.5 coupled, as necessary, with applicable equipment testing provides reasonable assurance that the equipment can perform its identified function during severe accident conditions. Of particular importance are those SSC expected to directly inform the operator of critical measures requiring operator action and those SSC expected to respond to operator action. Those SSC are included in Table 19.2-3 associated with RCS depressurization, SAHRS operation, and annulus ventilation.

For much of the early phases of a U.S. EPR severe accident, event progression is passive. Specifically, this is from the onset of the severe accident (i.e., core outlet

- Containment pressure sensors.
- H_2 Monitors.
- Hydrogen mixing dampers and position sensors, PARs, convection and rupture foils.
- IRWST water level and temperature.
- Dose rate measurement (i.e. gamma-sensitive detector).
- Severe accident sampling system.
- Thermocouples inside insulation liner to measure temperature of RPV lower head.
- Flooding valves and position sensors.
- Thermocouples in core catcher main cooling channel and steam chimney.
- Containment spray nozzles.

The time span for which the equipment is to remain operable (mission time) is also important. This is summarized in Figure 19.2-21—Course of Primary Events during a Severe Accident, which gives a schematic representation of the course of main events and maximum pressure and gas temperature during a severe accident. The graph is a composite of all 59 uncertainty analysis cases. As with Figure 19.2-20, the given values are a composite of the minimum and maximum values at the particular event times as determined from the uncertainty analysis; that is, the time development between events is not linear.

Pressure, Temperature, and Humidity within Containment

The pressure, temperature, and humidity time developments during a severe accident were evaluated from the MAAP4-based uncertainty analysis. The maximum “global” containment pressure and temperature that equipment and instrumentation may be exposed to during the progression of a severe accident are 76.9 psia and approximately 410°F, respectively. The maximum humidity inside the containment experienced by the equipment conservatively can be assumed to be 100 percent after the commencement of spraying. However, due to the existence of other gases inside containment, the steam concentration approaches a conservative value of 80 percent. Finally, the IRWST reaches a maximum temperature of 257°F. The SAHRS is conservatively designed for a maximum IRWST water temperature of 320°F.

For the relevant scenarios, which form the basis of the uncertainty analysis cases, localized hydrogen detonation and deflagration can be reliably excluded. The highest AICC pressure and temperature resulting from representative and bounding scenarios is 105 psia and 1634°F, respectively. The AICC pressure is a theoretical value that cannot be reached because actual combustion is not adiabatic, isochoric, or complete. Because best estimate, limiting pressure, and temperature resulting from hydrogen combustion during representative and bounding scenarios is 90 psia and 550°F, respectively, it is necessary to assess the equipment and instrumentation capabilities within this extended operational range.

While the equipment and instrumentation inside containment may be exposed to such pressure and temperature spikes, only equipment relied upon to establish and maintain safe shutdown and containment structural integrity must be capable of performing their functions during and after the exposure to the environmental conditions created by the burning of hydrogen per 10 CFR 50.44(c)(3).

For the mitigation of severe accidents, the Severe Accident Management Guidelines rely on safety-related and non-safety-related systems, structures, and components (SSC). Although electrical and mechanical safety-related equipment must perform their safety-related function during design bases events, the equipment necessary for mitigating the severe accident consequences is required to provide a reasonable level of confidence that it will function in a severe accident environment for the necessary time span. This requirement is referred to as “equipment survivability” and is different from “equipment qualification,” which is terminology used for the level of assurance provided for equipment necessary for design basis accidents. This implies that the equipment survivability assessment may be performed with a practical engineering approach accompanying best-estimate accident environments.

Data and test results obtained from type testing, industry experience, or test facilities can justify the operability and survivability of selected equipment and instrumentation. The primary source for performance expectations of similar equipment in severe accident environments is EPRI NP-4354 (Reference 21). This information is supplemented by NUREG/CR-5334 (Reference 22). The chamber conditions during these tests envelop those calculated for the U.S. EPR severe accident scenarios. Results of the Industry Degraded Core Rulemaking program (IDCOR) on equipment survivability provide further reassurances that selected equipment has the ability to survive and to perform its function.

The containment integrity is maintained by the containment isolation valves, equipment hatch and airlocks, containment penetrations, and the containment structure itself. A structural analysis of the reactor containment dead-weight loads, prestressing loads, and the internal pressure load due to hydrogen burning was conducted and showed that the liner is within allowable levels of strain. Containment isolation valves are closed early during the accident progression prior to RPV failure when the threat of hydrogen burning is greatest. Their function of closing is unaffected by the conditions created from burning. The performance of leak-tightness by the containment penetrations is not affected by the combustion of hydrogen. Containment isolation valves and penetrations were tested during the EPRI NP-4354

(Reference 21) and NUREG/CR-5334 (Reference 22) tests. Neither test resulted in mechanical degradation that would impact the capability of the components to maintain leak-tightness. Equipment hatch and airlocks are designed to be pressure resistant and airtight (see Section 3.8.2). The seals are embedded in grooves on the flanges and are protected from temperature spikes. The additional pressure load resulting from a spike will compress the seals and enhance contact between mating surfaces. The large metal structure will act as a heat sink over the long run . The components that provide containment isolation are classified as safety grade and are part of the U.S. EPR equipment qualification program (see Sections 3.10, 3.11, and Appendix 3D).

The main components identified in Tables 19.2-2 and 19.2-3 are the containment spray nozzles, passive outflow restrictors, and the primary depressurization system (PDS) valves. The operability of these components is not impacted by hydrogen burning during a severe accident. The containment spray nozzles are tangential-flow hollow cone types and are unaffected by external pressure. The temperature spike predicted because of hydrogen burning will not affect the performance of these nozzles. The passive outflow restrictors are located in the valve compartments adjacent to the core spreading room in the bottom of the containment. The restrictors are steel pipe components and require no moving parts to perform their function. Pressure and temperature increases attributed to hydrogen burning will not impact their performance. The steel acts as a heat sink to the elevated temperature, and the pressure will not affect the structural integrity of the component. The PDS valves will perform their function of depressurizing the RCS early in the accident sequence. Their function will not be impacted by hydrogen burning because the release of hydrogen from the degraded core is not a factor until after the depressurization. Following the depressurization, the actuator will not be required to function and the valves can fail as is.

Instrumentation identified in Table 19.2-3 is mostly located in either the Safeguard Buildings or the Fuel Building, and is not exposed to the elevated temperature and pressure attributed to hydrogen burning. Instrumentation having a mission time early in the severe accident sequence (e.g ., core outlet temperature, RCS pressure, PDS position indication, thermocouples for the monitoring of corium relocation in-vessel and ex-vessel, hydrogen mixing damper position indication, and delta pressure sensors) will not be affected by the resulting temperature and pressure spikes from hydrogen burning. Their function is performed before RPV failure and is acceptable to fail once their mission is completed. There is reasonable assurance that instrumentation that is required to function during a severe accident will survive the environments created by hydrogen burning. This instrumentation will be provided with additional protection and shielding, be protected from the environment by their installed location, or a combination of the two.

The uncertainties in the equipment survivability are primarily attributed to uncertainties in the severe accident environments used for evaluation which may be beyond those conditions used in prior survivability tests and experiments. Some uncertainties may exist due to a lack of validation of analytical results by experimental data. The uncertainties do not alter the conclusions reached in the evaluation. Most of the equipment evaluated has inherent capabilities to function under conditions that exceed the severe environment requirements. The inherent capability of equipment to withstand severe environmental conditions, margins used in qualification tests, and prior hydrogen burn survivability experimental results provide assurance that equipment will survive degraded core accidents.

~~For the relevant scenarios, which form the basis of the uncertainty analysis cases, localized hydrogen detonation and deflagration can be reliably excluded. However, because the highest AICC pressure and temperature resulting from representative and bounding scenarios is 105 psia and 1634°F, respectively, it is necessary to assess the equipment and instrumentation capabilities within this extended operational range. The AICC pressure is a purely theoretical value that cannot be reached, because actual combustion is neither adiabatic, isochoric, nor complete.~~

~~While all equipment and instrumentation inside containment may be exposed to such pressure and temperature spikes, only equipment relied upon to actively mitigate the consequences of hydrogen in the containment atmosphere is required to survive such occurrences per 10 CFR 50.44. Therefore, the hydrogen mixing dampers and PARs must be capable of surviving such short lived pressure and temperature spikes. During the recombination process, the PARs can experience localized temperatures that are well above 1832°F and must therefore be able to adapt to high temperatures. Based on the design, the PARs are not pressure retaining components and are open at the bottom and the top. Hence, the PARs are unaffected by localized pressure increase. Similar arguments can be made for the hydrogen mixing dampers and the rupture and convection foils. Because those open on pressure differential and, in the case of the convection foils on temperature differential, their operation is also not affected by localized pressure and temperature increase due to hydrogen combustion.~~

Radiation within Containment

A deterministic analysis of the direct dose radiation environment in the U.S. EPR buildings, as well as the submersion dose for accident conditions, was performed for the U.S. EPR. The analysis basis for the determination of the radiation exposure levels of severe accident equipment is a LOCA in one of the reactor coolant lines. In severe accident conditions the complete radioactive inventory of the core is released into the containment. The release rates for such a case are used to determine radioactivity concentrations for equipment survivability determinations. The analysis is based on realistic assumptions for partitioning of the fission product groups between sump water and containment atmosphere. Decay data are then used to convert these

9. Wilks, S.S., “Determination of Sample Sizes for Setting Tolerance Limits,” Ann. Math. Stat., Vol. 12, pp. 91-96, 1941.

10. EPRI TR-103413, “The MELTSPREAD-1 Computer Code for the Analysis of Transient Spreading and Cooling of High-Temperature Melts – Code Manual,” Electric Power Research Institute, December 1993.

11. Breitung, W., et al, “Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety,” NEA/CSNI-(2000) 7, October 2000.

12. Tutu, N.K., T. Ginsberg, and L. Fintrok (1988). “Low Pressure Cutoff for Melt Dispersal from Reactor Cavities,” Fourth Proceedings of Nuclear Thermal Hydraulics, 29-37.

13. Pilch, M. M., et al, “Resolution of the Direct Containment Heating Issue for All Westinghouse Plants With Large Dry Containments or Subatmospheric Containments,” NUREG/CR-6338, SAND95-2381, 1996.

14. Meyer, L., et al, “Melt Dispersion and Direct Containment Heating (DCH) Experiments in the DISCO-H Test Facility,” FZK Report FZKA 6988, ISSN 0947-8620, May 2004.

15. ANP-10290, Revision 1, “Environmental Report Standard Design Certification,” AREVA NP Inc, September 2009.

16. NEI 05-01 (Rev A), “Severe Accident Mitigation Alternatives (SAMA) Analysis, Guidance Document,” Nuclear Energy Institute, November 2005.

17. NUREG/BR-0184, “Regulatory Analysis Technical Evaluation Handbook,” U.S, Nuclear Regulatory Commission, January 1997.

18. NEI 07-13, “Methodology for Performing Aircraft Impact Assessments for New Plant Designs,” Revision 7, May 2009.

19. Letter from D. Matthews, NRC to R. Ford, AREVA NP, “Approval of AREVA NP Inc. Safeguards Protection Program and Reviewing Official, and Transmittal of Beyond Design Basis, Large Commercial Aircraft Characteristics Specified by the Commission”, December 21, 2007.

20. ANP-10296, Revision 0, “U.S. EPR Design Features that Enhance Security,” AREVA NP Inc., December 2008.

21. Achenbach, J.A., Miller, R.B., Srinivas, V., “Large-Scale Hydrogen Burn Equipment Experiments,” EPRI NP-4354, Electric Power Research Institute, 1985.

22. NUREG/CR-5334, “Severe Accident Testing of Electrical Penetration Assemblies,” SAND89-0327, November 1989.