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Calculation Of Environmental Conditions in NEK Intermediate Building Following HELB

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ABSTRACT

The purpose of Equipment Qualification (EQ) in nuclear power plants is to ensure the capability of safety related equipment to perform its function on demand under postulated service conditions, including harsh accident environment (e.g. Loss of Coolant Accident - LOCA, High Energy Line Break - HELB). The determination of the EQ conditions and zones is one of the basic steps in the frame of the overall EQ project. The EQ parameters (temperature, pressure, relative humidity, chemical spray, submergence, radiation) should be defined for all locations of the plant containing equipment important to safety.

This paper presents the calculation of thermohydraulic environmental parameters (pressure and temperature) inside Intermediate Building (IB) of Krško NPP after the postulated HELB. The RELAP5/mod2 computer code was used for the determination of HELB mass and energy release and computer code GOTHIC was used to calculate pressure and temperature profiles inside NPP Krško IB.

INTRODUCTION

One of the basic steps in the process of equipment qualification is the determination of EQ parameters for both normal and accident conditions. The typical EQ parameters that have to be addressed are:

- *temperature,*
- *pressure,*
- *relative humidity,*
- *chemical spray,*
- *submergence,*
- *radiation,*
- *vibration and seismic motion*

EQ parameters should be defined for all areas where the electrical equipment, which must function during and following DBA (LOCA, HELB) in harsh environment and which safety function is important for accident mitigation or which failure can prevent operation of safety-related equipment, and post-accident instrumentation required for post-accident monitoring, is located.

To demonstrate equipment performance during the accident a harsh environment conditions must be defined. A harsh environment is the environment where a significant increase above the normal plant environmental conditions during and following Design Basis Accident (DBA) or High Energy Line Break (HELB) occurs. Harsh environmental parameters are limiting for environmental qualification of electrical equipment. Accidents producing harsh environmental conditions involve pipe break in the reactor coolant system or other plant process systems. However, other accidents can produce harsh environments: e.g., rod ejection, radioactive waste processing system failures.

Pressure and temperature are EQ parameters of primary importance in this analysis. RELAP5/mod2 computer code was used to define mass and energy releases resulting from pipe breaks with the conservative assumptions maximising the release of mass and energy to the environment and minimising the transfer of energy and cooling to the environment. The assumptions result in the conservative temperature, pressure and steam conditions used for equipment qualification. According to those results, a calculation of environmental parameters (temperature, pressure), in the various locations of the NPP Krško IB, was performed using GOTHIC computer code. The results of such calculations are temperature and pressure envelopes for all transients in specified location.

On the basis of NEK USAR, Plant Layout Drawings, Plant Systems Descriptions, Master Equipment Component List (MECL) and walkdown the safety related equipment was identified and located and, depending on the location where the HELB can occur, four limiting accidents were identified and calculated for Intermediate Building (IB):

- ***Main Steam Line Break (MSLB)***
- ***Main Feedwater Line Break (MFLB)***
- ***Steam Generator Blowdown Break (SGBDB)***
- ***Auxiliary Feedwater Pump Turbine Steam Supply Line Break (AFPTLB)***

It should be noted that Auxiliary Feedwater Line Break (AFWLB) is covered by MFLB because main feedwater is conducted through the auxiliary feedwater line and the break can occur in the same location as MFLB. A separate mass and energy release was calculated with RELAP5/mod2 computer code for each transient, assuming the systems operating on maximum operating parameters and the break to the atmosphere, what maximises the releases. Additionally, the MSLB case was analysed also with USAR data. To determine IB pressure and temperature response GOTHIC calculation was performed for each postulated HELB.

IB MODEL AND CALCULATION ASSUMPTIONS

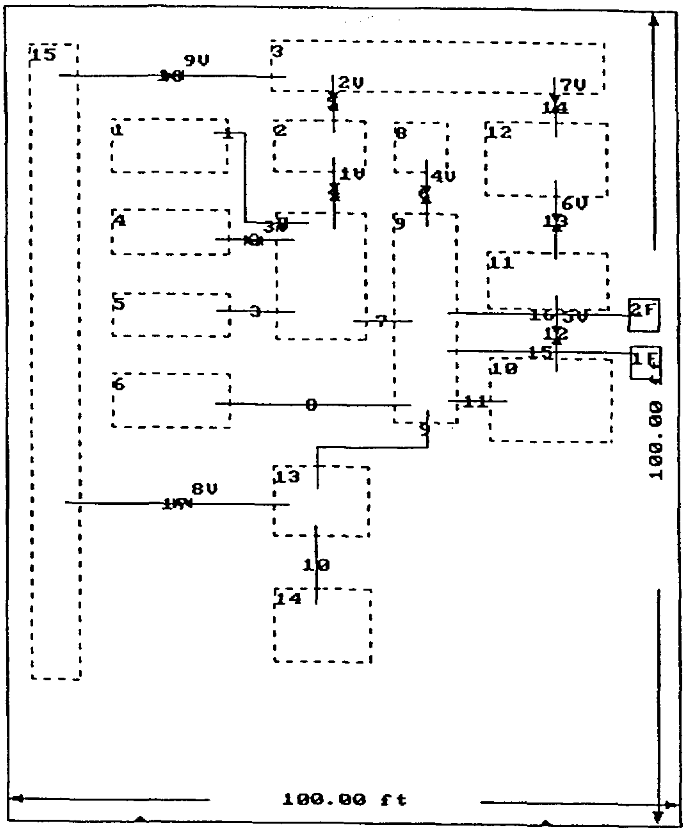
GOTHIC (Generation of Thermal Hydraulic Information for Containments) code is sponsored, approved and licensed by Electric Power Research Institute. The code is developed by Numerical Applications, Inc., Richland Washington using experience gained in COBRA-TF, COBRA-TRAC and COBRA-NC series of codes. The intention was to develop best estimate, efficient and qualified code for analysis of PWR, BWR and general confinement buildings (containments), both steady state and transient, for nuclear power plant design and operation analysis, for equipment qualification and for licensing issues. The code solves conservation of mass, momentum and energy equations for multiphase (vapor phase, continuous liquid phase, droplet phase) multicomponent (water, air, H, noble gases) compressible flow. Constitutive relations predict interaction between phases for nonhomogenous nonequlibrium flow. Heat structures are modeled as 1D unheated or 1D, 2D, or 3D heated structures. All hydraulic volumes use 3D or lumped or mixed approach. It is possible to simulate operation of engineered safety equipment (pumps, fans, valves and doors, vacuum breakers, spray nozzles, heat exchangers, heaters and coolers).

Version 3.4e of the GOTHIC containment analysis package was used in calculation of NPP Krsko IB. The GOTHIC model is prepared based on MECL Plant Layout Drawings and walkdown.

There are two relevant High Energy Line Break (HELB) sequences for IB rooms on EL 100.3: break in Steam Generator Blowdown Processing System line (SGBDB) and break in Auxiliary Feedwater Turbine Driven Pump steam supply line (AFPTLB). Three locations, in rooms IB10, IB09, and IB08, are analyzed for SGBDB up to blowdown heat exchanger. The AFPTLB is located in IB05.

There are 15 control volumes in the GOTHIC model of IB at elevation 100.3, shown in Figure 1. 13 volumes represent rooms IB01 to IB10, IB13, IB14, and IB15. The outside air is explicitly modeled as volume number 15, with initial conditions 32 C, 101.325 kPa, 60% RH. The volume number 3 is lumped representation of turbine building and is connected to the model through door located in IB08.

The height of all rooms is 6.32 m. The free volume is based on the geometry of the room and estimation of the space occupied by the equipment in the room. The value between 5% and 20% is used to take into account presence of the internal equipment and structures. Hydraulic diameter is estimated based on geometry and main flow path orientation. The initial conditions for all IB volumes are the same, 32 C, 101.325 kPa, 60 % RH, zero liquid fraction.



Correspondences between NEK location and GOTHIC control volumes

NEK	GOTHIC
IB 01	13
IB 02	14
IB 03	6
IB 04	5
IB 05	4
IB 06	1
IB 07	7
IB 08	2
IB 09	8
IB 10	9
IB 13	10
IB 14	12
IB 15	11
Turbine Building	3
environment	15

Figure 1. GOTHIC model for NEK IB at elevation 100.3

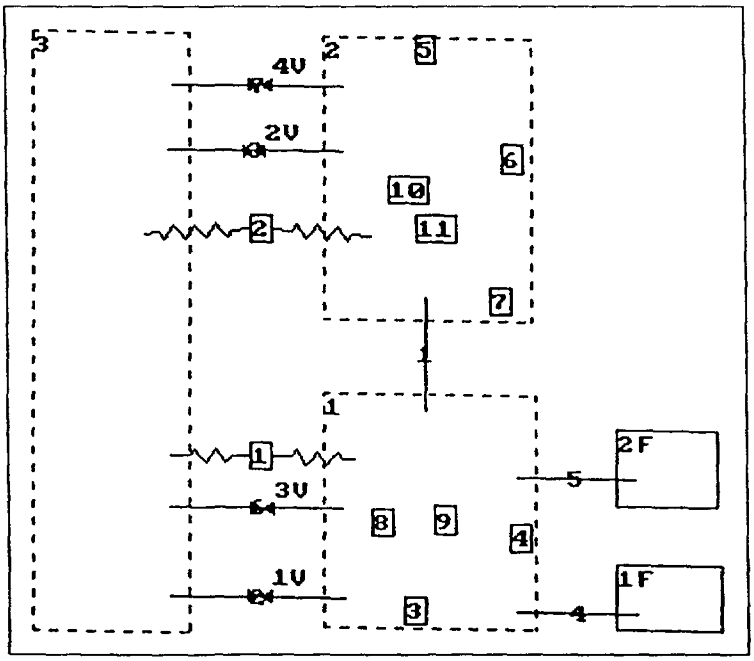
The control volumes are connected using flow paths (junctions). There are 18 flow paths in IB el. 100.3 GOTHIC model. Flow paths 15 and 16 represent breaks, and they connect flow boundary conditions 1F and 2F to the affected room. In the case of SGBDB boundary conditions are heat and mass sources for liquid and gas. The door opening criteria is differential pressure larger than 13.789 kPa (2 psia) in all cases except for door between room IB05 and IB07 (room with turbine driven AF pump). Due to different construction of the door differential pressure of 27.578 kPa (4 psia) is used. The same pressure is used for breaking doors in direction opposite to normal direction of opening.

There are 64 heat structures in the model and only the heat structures representing walls, floor and ceiling in the rooms were modeled.

For IB rooms on EL. 107.62 limiting conditions are caused by double ended MSLB and MFLB accidents. Figure 2 presents the GOTHIC model for IB at elevation 107.62. Volume 1 is IB room 24 and volume 2 is lumped representation for rooms 25, 26, and 27. The break can occur in either of the rooms. Rooms 28 and 29 at the same elevation are isolated and were not taken into consideration. Volume 3 represents environment air. The free volume of the rooms IB24 and IB25-27 are 996.47 m^3 and 3145.7 m^3, respectively. The height of the rooms is 7.2 m. The free volume is based on the geometry of the room and estimation of the space occupied by the equipment in the room. In both cases the value of 20% is used to take into account presence of the internal equipment and structures. Hydraulic diameter is estimated based on geometry and main flow path orientation. The initial conditions for two IB volumes are the same, 46 C, 101.325 kPa, 60 % RH, zero liquid fraction. The outside air is at 27 C, 101.325 kPa, 60% RH.

There are 7 flow paths in GOTHIC IB el.107.62 model. Flow paths 4 and 5, representing breaks, connect flow boundary conditions 1F and 2F to the affected room. In MSLB cases boundary conditions are heat and mass sources from faulted and non-faulted steam generator. Two cases are calculated, one with FSAR data and another with RELAP5 calculated values. In FLB case there is only one GOTHIC flow boundary condition, and one corresponding flow path. The flow paths 2, 6 and 3, 7 are used for blow-out panel modeling. There are 3 blow-out panels in room 24 and 3 blow-out panels in room 25. The opening criteria is differential pressure (pressure inside IB minus outside air pressure) larger than 13.789 kPa (2 psia). Three panels are collected in one flow path, and then the flow path is splitted axially in two in order to promote mixing with outside air and cooldown after decrease of break flow.

There are 11 heat structures in present model. Only the heat structures representing walls, floor and ceiling in the rooms were modeled.



Correspondences between NEK location and GOTHIC control volumes	
NEK	**GOTHIC**
IB 24	1
IB 25, 26, 27	2
environment	3

Figure 2. GOTHIC model for NEK IB at elevation 107.62

RESULTS

a) IB at elevation 100.3

The mass flow and energy flow for Steam Generator Blowdown Line Break was calculated with RELAP5/mod2 code. After initial increase during break opening flow is more or less constant. The liquid mass flow is 7.8 kg/s, and gas mass flow is 0.79 kg/s. The liquid and gas enthalpies are 1.197 10^6 J/kg and 2.787 10^6 J/kg, respectively. The breaks are sequentially located in IB10, IB09 and IB08.

The behavior of transients initiated by breaks in IB10 and IB09 are very similar. Temperatures in affected rooms are shown in the Figure 3 for SGBDB in room IB-10. In the first phase pressure and temperature in all connected rooms (IB 1, 2, 3, 4, 6, 7, 13) are increasing uniformly and the temperature difference between rooms is very small. The thermodynamic conditions in all rooms with closed doors are the same as were at the beginning of the transient. When the pressure difference is greater than 13.789 kPa (2 psia) the door opening is initiated, equalizing pressure in connected rooms. Due to low inertia of gas mixture and low Dp characteristic of the flow, high volumetric flows of short duration are initiated. After opening of the doors the new dominant flow paths are formed for circulating of hot mixture from break location to the sink location. In calculated cases preferred flow path was IB10-IB01-ENVIRONMENT, with two additional paths IB08-IB07-IB10 and IB14-IB15-IB13-IB10. The rooms on this flow paths experience higher temperatures than neighboring rooms.

In the first phase of the transient temperature increase is controlled by heat input and heat capacities of the air and heat structures. In the second phase gas content of the room will be replaced by mixture flowing from the source to the sink (due to pressure difference) and relative position of the room determines temperature conditions in it. That means that is very important to identify possible flow paths in the connected rooms and room with lowest pressure (usually outside air or some of the large volume rooms inside building). Due to lumped representation of volumes and lack of axially distributed flow paths there is no thermally induced mixing between rooms. That will cause slower decrease of the temperature in the rooms after end of break flow at 1800 s.

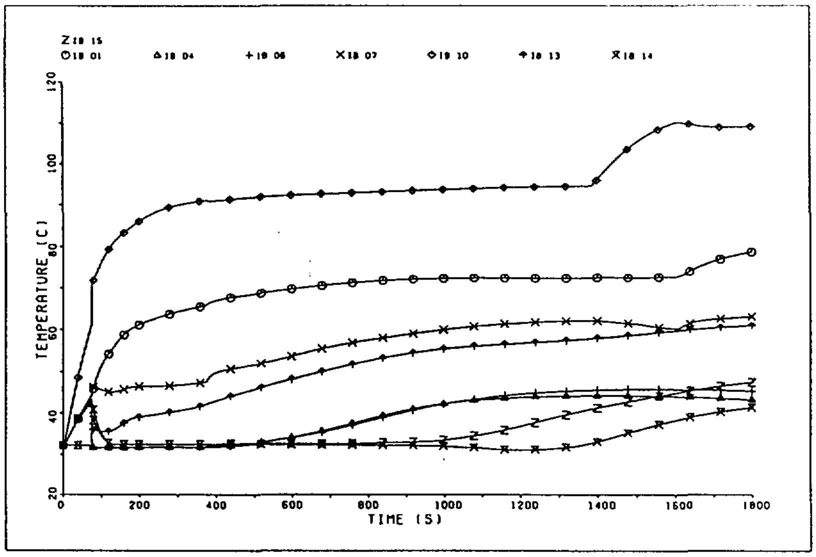


Figure 3. Temperature in the various rooms in IB at elevation 100.3 after SGBDB in room IB10

In the case of SGBDB in IB08 the pressure has increased to 115.14 kPa in about 8.3 s and door toward rest of the turbine building opened. There is no further pressure or temperature increase because flow area of opened door are much larger than break area. The pressure in the room is reduced and initial gas content is replaced with steam-air mixture with approximately constant temperature about 125.8 C.

The mass flow and energy flow for AFPTLB. was calculated with RELAP5/mod2 code, with break located in IB05. After initial increase during break opening flow is more or less constant. Gas mass flow is 124.3 kg/s and gas enthalpy is 2.794 10^6 J/kg. The blow-out panels opened in 0.1 s and after that pressure and temperature are constant at 102.76 kPa and 158.8 °C (figure 4). Other IB rooms were not affected.

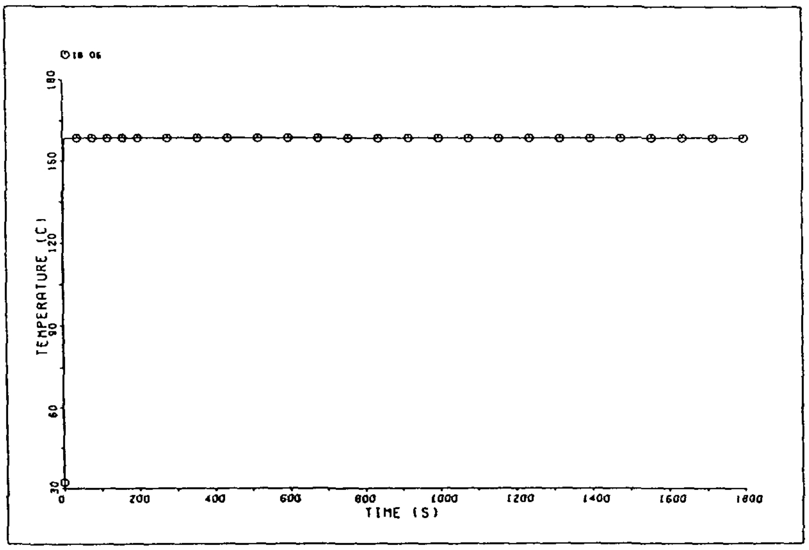


Figure 4. Temperature in the room IB05 after AFPTLB

b) IB at elevation 100.3

The calculation of ambient conditions after MSLB and MFLB was performed for 1800 s, assuming break isolation at that moment. Although analyses were done for breaks in both rooms (IB24 and IB25), for representation only results for MSLB in room IB24 and MFLB in IB25 are shown on Figures 5 and 6. There were three different calculations, two MSLBs (one with FSAR mass and heat input and another with RELAP5/mod2 results) and one FLB (RELAP5/mod2 calculated mass and energy release).

Both MSLB cases have similar pressure behavior, fast pressure increase till opening of blow-out panels (115.14 kPa), and then fast decrease to pressure slightly above atmospheric pressure. The pressure increase is faster when the break is located in the same room, and it is faster for MSLB with FSAR data. The blow-out panels trip set point is reached at 0.1 s in MSLB with FSAR data, and at 0.2 s in MSLB with RELAP5 data. When the same heat and mass input is introduced in IB24 and IB25 higher pressure is experienced in IB24 due to smaller volume. Maximum pressure reached is 130. kPa in IB24 at 0.2 s.

Maximum temperature is determined by steam superheating in MSLB case with FSAR data. The steam superheating exists between 60 and 80 s and maximum temperature reached in IB24 is 222.9 °C at 72.7 s, and 160.5 °C at 72. For RELAP5 calculated values maximum temperature is 143. °C at 28.5 s (IB24), and 133 °C at 49.5 s for IB25.

After 100 s temperature decreased in both rooms and for both MSLB cases. After about 80 s there is no larger mass and energy exchange through communication between rooms. In about the same time the flow in lower flow paths of both panels change direction and cooler air from outside is introduced in IB rooms. This is the reason why the temperature remains more or less constant in IB24 (equilizing heat source and the heat sink) and further decreasing in the IB25. At 1800 s flow through the break is stopped and fast cooldown is initiated.

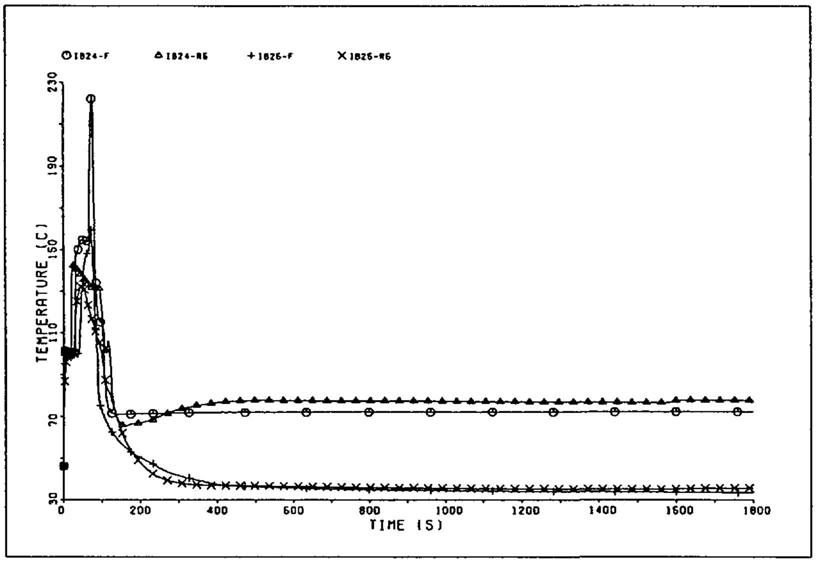


Figure 5. Temperature in rooms IB24 and IB25 after MSLB in IB24; FSAR (-F) and RELAP5/mod2 (-R5) mass and energy source

In MFLB case leakage through blow-out panels in IB25 is enough to limit pressure increase to 110.7 kPa, without panels blow out. The temperature in room IB25 increase to about 100 C, in the beginning of the accident, and decrease slowly due to partially opened blow-out panels. In the second part of the calculation this temperature is limiting in temperature envelope of the room thermal-hydraulic conditions. The leak through panels in IB25 is the reason for very slow temperature increase (above initial) in the room IB24.

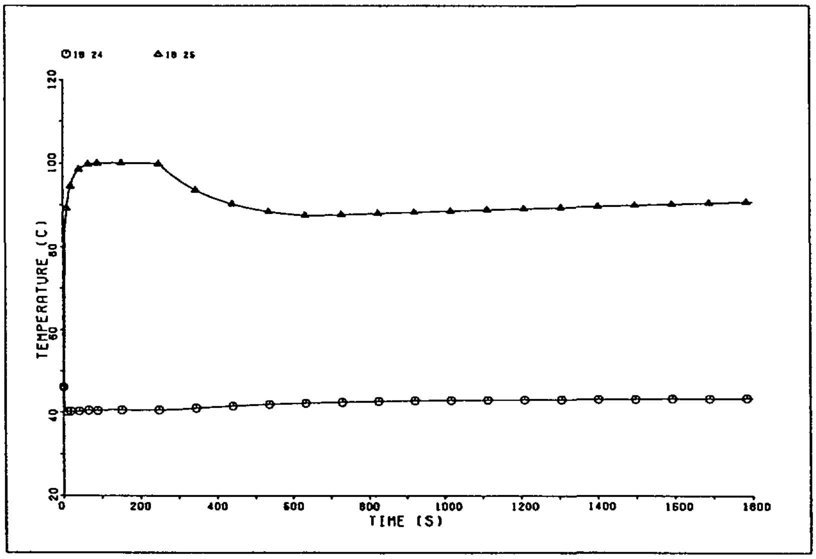


Figure 6. Temperature in rooms IB24 and IB25 after MFLB in IB25

CONCLUSION

The typical set of calculation, neccessary for determination of ambient parameters following HELB in various locations of the plant, are presented. Based on the system operation and piping location four different HELBs were identified and analyzed.

In IB at elevation 100.3 limiting accidents are Steam Generator Blowdown Break (SGBDB) in rooms IB008, IB009 or IB010 and also affecting rooms IB001, IB002, IB003, IB004, IB006, IB007, IB0013, IB0014 and IB0015 and Auxiliary Feedwater Pump Turbine Steam Supply Line Break in the turbine driven AF pump room (room IB005).

MSLB and MFLB are limiting transients for IB at elevation 107.62. The rooms that are affected are: IB024, IB025, IB026 and IB027. MSLB is responsible for peak temperature (223 °C) and peak pressure (limited on 130.0 kPa with blowdown panels opening in rooms IB024 and IB025). Analysis of MFLB resulted in higher temperatures over the long time accident period.

There are no postulated breaks and there are no significant heat sources in the IB at elevation 115.55, so analysis for that elevation was not necessary.

On the basis of this calculations, pressure and temperature profiles for each room sholud be prepared. After that, considering Equipment Qualification parameter values during, normal, abnormal, accident and post-accident conditions, EQ zones and maps are defined, in a way that is suitable for implementation in the EQ process. There is no set methodology for preparing EQ zones and EQ maps, this process is plant specific and should involve engineering judgement in assigning environmental conditions to the plant physical layout.

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