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A' ion: Theodore E. Quay, Director
Standardization Project Directorate

Subject: **SBWR – TRACG Containment Model "Road Map" (Non-Proprietary).**

Reference: GE/NRC TRACG Containment Meeting, August 21 and 22, 1995, at GE San Jose, CA.

The enclosure to this letter is the non-proprietary version of the TRACG Containment Model "road map" as agreed to in the referenced meeting. The "road map" shows how the models described in the TRACG Model Description Licensing Topical Report are applied for SBWR containment analysis. The enclosure describes the components of the SBWR containment, shows the TRACG input model used to characterize the containment, and details the specific physical models and correlation's used in the major containment regions and components.

Should you have any questions concerning the Subject document please contact Bharat Shiralkar of our staff on 408-925-6889.

Sincerely,

James E. Quinn

Enclosure: TRACG Containment Model (Non-Proprietary)

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TRACG Containment Model (Non-Proprietary)

The purpose of this document is to provide a "road map" that shows how the models described in the TRACG Model Description Licensing Topical Report are applied for SBWR containment analysis. The first section of this document describes the components of the SBWR containment. The second section shows the TRACG input model used to characterize the containment. Finally, the third section details the specific physical models and correlations used in the major containment regions and components.

1. Containment Components

Figure 1 shows a schematic of the SBWR containment and reactor pressure vessel (RPV). The main components of the containment are:

- Drywell
  The drywell is composed of an upper drywell, bounded by the drywell head, top slab, containment walls, and the diaphragm floor separating it from the wetwell. The upper drywell (indicated by 1 in the figure) constitutes the largest portion of the drywell volume. A break in the Main Steam Line as well as the opening of the Depressurization Valves (DPVs) would discharge flow into this region. The annulus region of the drywell (indicated by 2) comprises the region between the RPV and the inner wall of the wetwell horizontal vent duct system. A break in the Gravity Driven Cooling System (GDCS) line would be expected to discharge flow into this region. The lower drywell is a separate region that is connected to the drywell annulus by 14, 0.8 m OD, annulus to lower drywell connecting vents . Liquid discharged into the upper drywell or the annulus region 1 (e.g. from a broken GDCS line connected to a GDCS pool) will drain into the lower drywell. A break in the bottom drain line could discharge flow to the lower drywell.

- Wetwell
  The wetwell consists of the suppression pool (4) and the wetwell vapor space (5). The wetwell is bounded by the diaphragm floor on top, containment outer wall and wetwell inner wall on the sides and the floor of the containment. During blowdown flow from the Safety Relief Valves (SRVs) is directed to the suppression pool and quenched via the SRV discharge lines. Flow from the LOCA break and DPVs is directed from the drywell to the suppression pool and quenched via the suppression pool horizontal vent system. Any flow through the Passive Cooling Condenser (PCC) vents is also discharged to the suppression pool.

- GDCS Pools
  Three GDCS pools (6) are located in the upper drywell. During the GDCS phase of the post-LOCA transient, the GDCS pools discharge into the RPV downcomer, following the opening of squib valves and the check valves in the 3 divisionally separated GDCS lines. During the intermediate and long term phases of the

post-LOCA transient, the GDCS pools receive condensate from the P units. One GDCS pool receives the condensate from two PCC units; one receives condensate from the third PCC unit; and the third is not connected to the Passive Containment Cooling System (PCCS). Each PCC unit condensate return line is designed with a loop seal to prevent reverse flow of steam or noncondensibles in the condensate return line.

- PCC Pools
  The three PCC pools (7) are located outside (above) the containment. Each contains a PCC unit. The three pools are interconnected.

- PCC Units
  The SBWR has three PCC heat exchanger units (8). Each is comprised of two modules with inlet and outlet headers and 248 tubes in parallel. The PCC units are connected to the top of the upper drywell and discharge condensate into the GDCS pools. Noncondensibles and uncondensed steam are vented to the suppression pool. The vent submergence is 0.9 m less than that of the top horizontal LOCA vent. Thus drywell noncondensibles and uncondensed steam are purged preferentially through the PCC vent line.

- Isolation Condenser (IC) Pools
  The three IC pools (9) are located outside (above) the containment. Each contains an IC unit. The three pools are interconnected with each other and with the PCC pools.

- IC Units
  The SBWR has three IC heat exchanger units (10). Each consists of two modules with inlet and outlet headers and 248 tubes in parallel. The IC units are connected to stub tubes, which are attached to the RPV steam dome. Condensate is discharged into the downcomer of the RPV. Noncondensibles can be vented from the upper and lower IC headers to the suppression pool. This venting processes requires manual action by the operator.

- Depressurization Valves
  There are 6 DPVs (11) in the SBWR. Four DPVs are on the RPV stub tubes. (The steam supply lines for the three IC units are also connected to three of these stub tubes). The other two DPVs are on the Main Steam Lines. The DPVs discharge into the upper drywell.

- Safety Relief Valves (SRVs) and quenchers
  Eight SRVs (12) relieve RPV pressure by discharging steam into the suppression pool. Steam is discharged though quenchers to minimize chugging and condensation loads. The quencher submergence is greater than that of the top row of horizontal vents.

- Horizontal vent system
  The SBWR has eight sets of horizontal vents between the drywell and the suppression pool. Each set of three vents consists of three horizontal vents (13) attached to a vertical vent pipe. The top row of horizontal vents is approximately 0.9 m below the bottom of the PCC vents.

- GDCS Equalizing lines
  Three GDCS equalizing lines (14) connect the suppression pool to the RPV downcomer. During the long term portion of the post-LOCA transient, the squib valves in these lines will open if the level in the downcomer drops to 1 m above the top of the active fuel and a time delay of 30 minutes has elapsed.

- Vacuum Breakers
  The SBWR has three vacuum breakers (15) connecting the upper drywell to the wetwell vapor space. The vacuum breakers will open to relieve a negative pressure difference between the drywell and the wetwell.

2. TRACG Nodalization

The TRACG model used for SBWR analysis includes a representation of the RPV and the containment. All the major components referred to in the previous section are present in the model. Table 1 details how each component is represented in the TRACG model.

3. TRACG Physical Models used in Containment Regions

The SBWR containment is represented by a combination of 3-dimensional and 1dimensional TRACG components. All these components utilize the same conservation equations and constitutive correlations. The major physical models used in each region are discussed below.

Break

The critical flow is calculated based on the upstream pressure, enthalpy and void fraction. The void fraction will depend on the position of the two-phase level in the downcomer.

In many thermal hydraulic codes (RELAP, other versions of TRAC), the kinetic energy terms in the energy equation are eliminated using the momentum equation. This leads to a form of the energy equation which is nonconserving when discretized; i.e. the energy leaving the RPV is not exactly equal to that deposited in the containment. In TRACG, the kinetic energy terms have been retained in the energy equation and the discretization is in a conserving form.

Later in the transient, the flow through the break will no longer be choked. TRACG effectively calculates the minimum of the Bernoulli flow from the momentum

equation and critical flow. The flow calculated from the momentum equation cannot exceed the critical flow. At low pressures, the flow will not be limited by critical flow.

Drywell

The drywell is modeled as a 3-dimensional region, with 4 radial rings in the upper drywell and 2 radial rings in the annular and lower drywell regions. This allows natural circulation patterns to develop, if calculated, with upflow in one ring and downflow in another. The three-dimensional conservation equations for mass, momentum and energy are applied in this region.

Specific models are discussed below:

Turbulent Shear between Cells

The TRACG model for turbulent shear between cells at cell boundaries is not being used. Thus, there is no shear between adjacent cells. All flows in the drywell are driven by buoyancy and wall shear.

Noncondensible Distribution

TRACG has a mass continuity equation for one species of noncondensible in addition to steam. The noncondensible is treated as a perfect gas and its properties are specified in terms of the gas constant, R and the specific heat c_{pg}. The noncondensible gas (or mixture of gases) has the same temperature and velocity as the steam in a given cell. The partial pressure of the noncondensible gas is calculated based on the temperature and mass of gas in a cell (Perfect Gas Law). Dalton's law relates the partial pressures of steam and noncondensible to the total pressure. Note that there are no requirements for the steam to be at saturation conditions corresponding to its partial pressure.

The TRACG model for molecular diffusion of noncondensibles driven by concentration gradients is not used. Noncondensibles are transported solely by bulk convection. Diffusion effects will be small for nitrogen and air. Transport by diffusion could be significant for helium, and to a lesser degree, for hydrogen. Buoyancy effects are not treated at a local level; i.e., steam and noncondensibles have the same velocity in a cell. However, buoyancy effects will be accounted for on a global level. For example, if a light noncondensible is injected into a cell, a natural circulation pattern will develop between adjacent rings, and lighter fluid will rise to the upper regions. (GE plans to implement an additional mass balance equation for a second noncondensible gas species in TRACG.)

Wall Friction Correlations

The flow regime in the drywell is mostly single phase vapor. In some cells, a dispersed droplet high void fraction regime may exist. This corresponds to cells where

liquid from the break or from the GDCS pool with a broken line is falling to the lower regions of the drywell. In some cells, a liquid film can form on the wall because of condensation. The single phase friction factor is utilized. The Reynolds number is calculated based on the axial velocity in the cell adjacent to the wall and the hydraulic diameter of the cell in the direction of the wall. In case a two-phase flow regime is present a two-phase multiplier will be applied.

Interfacial Shear Correlations

For the droplet flow regime, the models will be employed to calculate the interfacial shear between vapor and droplets. For cells with wall liquid films, the annular flow correlations are used.

Wall Heat Transfer

The important modes of wall heat transfer in the drywell include forced and free convection to vapor and condensation heat transfer.

For forced convection, TRACG uses the Dittus-Boelter correlation, based on the cell velocities and properties. The hydraulic diameter of the cell in the direction of the wall is used in the correlation. The vapor properties are calculated at the cell fluid temperature.

For free convection, the McAdams correlation is used. Again, the cell temperature is used for the calculation of vapor properties and the cell hydraulic diameter for the calculation of the Grashof number.

TRACG will evaluate both the free and forced convection correlations and use the higher of the two calculated values. The same correlations are used for horizontal surfaces.

The condensation correlations are included. A Nusselt condensation correlation is used with multiplicative factors for shear enhancement and degradation by noncondensibles. In these equations, the liquid film Reynolds number Re_l is defined as: $Re_l = 4\Gamma/\mu_l$, where Γ is the condensate flow rate per unit perimeter of surface and μ_l is the liquid viscosity. The Reynolds number Re_m is based on the cell hydraulic diameter, vapor velocity and vapor properties. The correlation accounts for the degradation by noncondensibles through the use of the Vierow-Schrock degradation factor. The ratio of the mass fraction of the noncondensible species to the mass fraction of steam in the cell is used as the correlating parameter.

Fogging of Drywell Vapor

Heat transfer from the vapor in a cell will result in cooling of the vapor. If the temperature drops below the saturation temperature of the steam corresponding to its

partial pressure, condensation will occur. Generally, in this situation a cold wall will be present in the cell. A liquid film will form on the surface because of condensation. This will be typically the dominant form of condensation in the cell. If the temperature drops below saturation in a cell that has no heat transfer surfaces, liquid droplets will form (fogging) by condensation of steam. In this situation, a droplet flow regime will exist. Interfacial heat transfer between droplets and vapor will be calculated. Interfacial shear between the droplets and steam is calculated.

In general, heat transfer from the vapor is more likely to lead to condensation on the walls. Fogging is more likely to occur as a result of adiabatic expansion of steam from pressures higher than 30 bar.

Wetwell Vapor Space

The wetwell vapor space is also represented by 3-dimensional cells. Typically, two rings and two axial levels are employed in the TRACG model. This would allow for natural circulation in this region. The flow regimes in this region will be the same as in the drywell: single phase vapor, dispersed droplets resulting from entrainment from the suppression pool, and a condensate film on the walls. The models discussed in the preceding section for the drywell for turbulent shear between cells; noncondensible distribution; wall friction; interfacial friction; wall heat transfer; fogging and interfacial heat transfer apply also in the wetwell vapor space. One other model is important for this region, namely the heat transfer at the suppression pool interface.

Interfacial heat transfer at pool interface

The interfacial heat transfer coefficients on the vapor and liquid sides of the interface are included. The Sparrow-Uchida correlation is used to calculate degradation of heat transfer at the pool surface due to noncondensible gases.

Suppression Pool

The suppression pool is represented by 3-dimensional cells. At least two rings are used to represent the pool. The major phenomena of interest for the suppression pool include condensation of vapor bubbles, temperature distribution/thermal stratification and pool two-phase level.

Condensation of vapor bubbles

In the presence of noncondensibles, the bubbles will include steam and noncondensibles. The partial pressure of steam and noncondensibles will be calculated as stated earlier. The interfacial heat transfer from the liquid to the vapor is calculated. There is no degradation in heat transfer due to the presence of noncondensibles. This is based on large scale data showing complete condensation of steam in the bubbles.

Pool temperature distribution

An empirical model is used to force thermal stratification below the lowest thermal source to the pool. This is done by effectively limiting the amount of water that participates in the absorption of energy to that above the lowest discharge location (i.e., lowest active horizontal vent, SRV quencher or PCC vent). Above this elevation, TRACG will calculate circulation velocities which produce a well mixed region.

Pool level

The two-phase level model is used to calculate the pool level. The liquid and vapor side interfacial heat transfer coefficients are calculated. When the liquid surface is subcooled, the condensation at the surface is reduced by a degradation factor based on the Sparrow-Uchida correlation.

GDCS Pools

The GDCS pools are also modeled as part of the 3-D containment model. In practice, two pools are represented, with one accounting for the volume of two of the three pools. The representation is essentially 1-D, with each pool being characterized by one ring. The main phenomenon of interest for the GDCS pool is the pool level and the associated inventory of water in the pool. The two-phase level model referred to earlier is also applicable here. Heat transfer at the pool surface is modeled analogously to that for the suppression pool.

IC/PCC Pools

The pools are represented as part of the 3-D TRACG region, partitioned into the IC and PCC pools. The pools are allowed to communicate with each other at the bottom and the top. Two PCC pools have been combined into one, and the three IC pools into one. The pools are modeled with two rings each and with several axial levels. Heat transfer occurs from the PCC and IC headers and tubes to the water in the pools. Pool side heat transfer is calculated by the Chen correlation for boiling heat transfer.

(GE plans to use the pool boiling portion of the Chen correlation (Forster-Zuber) for the pool side heat transfer correlation in TRACG.)

IC/PCC Units

The IC and PCC units are represented by 1-D components simulating the inlet piping, headers, condenser tubes, condensate discharge lines and vent lines. One dimensional forms of the mass, momentum and energy equations are applicable. Heat is transferred through the walls of the tubes and headers to the respective pools.

Wall Friction Correlations

The flow regime in the PCC and IC is single phase vapor at the inlet. Due to condensation, a liquid film forms on the walls. The exit conditions consist of a draining liquid film, and a gas mixture that is rich in noncondensibles. The single phase friction factor is obtained. The Reynolds number is calculated based on the axial velocity in the cell and the hydraulic diameter of the cell. In the condensing region, a two-phase multiplier will be applied.

Interfacial Shear Correlations

For cells with wall liquid films, the annular flow correlations are used.

Wall Heat Transfer

The important mode of wall heat transfer in the PCC and IC is condensation heat transfer. Under conditions where condensation heat transfer is severely degraded by a large amount of noncondensibles, forced convection from the vapor to the wall will become the mode of heat transfer.

The condensation correlations are discussed. A Nusselt condensation correlation is used with multiplicative factors for shear enhancement and degradation by noncondensibles. The Nusselt correlation is expressed. The liquid film Reynolds number Re_l is defined as: $Re_l = 4\Gamma/\mu_l$, where Γ is the condensate flow rate per unit perimeter of surface and μ_l is the liquid viscosity. A shear enhancement factor is used. The Reynolds number Re_m is based on the cell hydraulic diameter, vapor velocity and vapor properties. The correlation accounts for the degradation by noncondensibles through the use of the Vierow-Schrock degradation factor. The ratio of the mass fraction of the noncondensible species to the mass fraction of steam in the cell is used as the correlating parameter.

(GE plans to use the Kuhn-Schrock-Peterson form of the condensation correlation in TRACG.)

For forced convection, TRACG uses the Dittus-Boelter correlation, based on the cell velocities and properties. The hydraulic diameter of the cell is used in the correlation. The vapor properties are calculated at the cell fluid temperature.

Depressurization Valves

The DPVs are modeled using the VALVE component, which is a 1-D component. The TRACG control system will trigger the DPVs to open based on the sensed level in the RPV downcomer. The primary TRACG model associated with the DPV is that of critical flow, which was referred to earlier in connection with the break.

Critical flow is calculated using a model which has been extensively qualified. The critical flow is calculated based on the upstream pressure, enthalpy and void fraction. Correlations for interfacial shear used in the calculation of interfacial shear in the RPV are incorporated. The void fraction will depend on the position of the two-phase level in the downcomer. Validation of the void fraction and two-phase level models is performed.

SRVs and Quenchers

The SRVs and associated piping are represented by 1-D components. TRACG will trigger the opening of the SRVs based on pressure or downcomer level. The quenchers are not modeled in detail. Condensation and chugging loads will not be calculated with TRACG. Critical flow models used for the SRVs have been discussed for the break and DPVs. Models for the condensation of SRV discharge were referred to in the section on the suppression pool.

Horizontal Vents

The horizontal vents are represented by 1-D TEE components. The 1-D level model is used in the vertical pipe that connects to the three horizontal vents. As the level drops in the pipe to "uncover" the horizontal vent, the vent will pass two-phase flow to the suppression pool. TRACG is not used for calculation of the pool swell, vent chugging or condensation oscillation loads.

Flow Regime

The flow regime in the vents is single phase liquid, until the vent begins to uncover. The flow to the vent is "donor celled" at the upstream conditions in the vertical pipe. TRACG calculates a transition from stratified to dispersed flow based on a critical Froude number.

Pressure Drop Correlations

The single phase friction factor is obtained. The Reynolds number is calculated based on the axial velocity in the cell and the hydraulic diameter of the cell. The pressure drop in the vent is actually dominated by the inlet and exit form loss coefficients. A two-phase multiplier will be applied for wall friction.

Vent Back Pressure

As the vent discharges vapor into he suppression pool, it will tend to move the liquid in the pool above the vent upwards as it expands. The inertia of this liquid tends to create a back pressure effect, reducing the discharge flow. This effect is accounted for in the TRACG momentum equation. The liquid mass in the inner ring immediately above the discharge location will have to be accelerated upwards as the vapor expands into the pool.

Equalizing Line

The equalizing lines are represented by a 1-D VALVE component. The correlations used for wall friction and singular losses are the same as described in the previous paragraph for the horizontal vents.

Vacuum Breakers

The vacuum breakers (VB) are represented by 1-D VALVE components. Two VBs are lumped together as one component. The VBs are triggered open at a set negative pressure differential between the drywell and wetwell. They will close at a lower value of the pressure differential. The VBs transport flow from the wetwell vapor space to the drywell at conditions corresponding to the cell in the wetwell vapor space to which they are connected. The correlations used for the singular losses are the same as described in previously for the horizontal vents.

Table 1. SBWR System TRACG Model

REGION	SBWR PLANT	TRACG MODEL
RPV		
lower plenum	multi-d	multi-d (VSSL01: L1/R1 and R2)
core	multiple 1-d	one 1-d (CHAN08)
bypass	Multiple 1-d	multi-d (VSSL01: L2/R1)
chimney	multi-d	multi-d (VSSL01: L3 to L6/R1)
downcomer	1-d	multi-d (VSSL01: L2 to L6/R2)
steam dome	multi-d	multi-d (VSSL01: 17 and L8/R1 and R2)
dryers/separators	multiple 1-d	models pressure loss
SRVs	eight 1-d	two 1-d (VLVE24 and VLVE28)
DPVs	six 1-d	three 1-d (VLVE12, VLVE13, VLVE19)
steam lines	two 1-d	one 1-d + break (TEE20, 23, 27 + PIPE11)
EQLs	three 1-d	one 1-d (VLVE07)
DW		
upper DW	multi-d	multi-d (VSSL01: L1 to L9/R1 and R2)
lower DW	multi-d	1-d (TEE35)
vacuum breaker	three 1-d	two 1-d (VLVE10 and VLVE42)
main vents	eight 1-d with three "T" connections	one 1-d with three "T" connections (TEE02, TEE03, TEE04, TEE09)
GDCS		
pools	three multi-d	two multi-d (VSSL01: L7 and L8/R5 and R6)
injection lines	three 1-d	two 1-d (VLVE48 and VLVE49)
PCCS		
inlet lines	three 1-d	two 1-d (PIPE22 and PIPE 83)
steam headers	three multi-d	two 1-d (PIPE92 and PIPE86)
tubes	1488 1-d	two 1-d (PIPE96 and PIPE87)
condensate headers	three multi-d	two 1-d (TEE26 and TEE88)
drain lines	three 1-d	two 1-d (PIPE 46 and PIPE84)
vent lines	three 1-d	two 1-d (PIPE52 and PIPE85)
pools	three multi-d	two multi-d (VSSL01: L11 to L17/R3 to R6)

Table 1. SBWR System TRACG Model (Continued)

REGION	SBWR PLANT	TRACG MODEL
ICS		
inlet lines	three 1-d	one 1-d (TEE21)
steam headers	three multi-d	one 1-d (PIPE91)
tubes	1440 1-d	one 1-d (PIPE95)
condensate headers	three multi-d	one 1-d (TEE25)
drain lines	three 1-d	one 1-d (VLVE47)
vent lines	three 1-d	one 1-d (VLVE51)
pools	three multi-d	one multi-d (VSSL01: L11 to L17/R1 and R2)

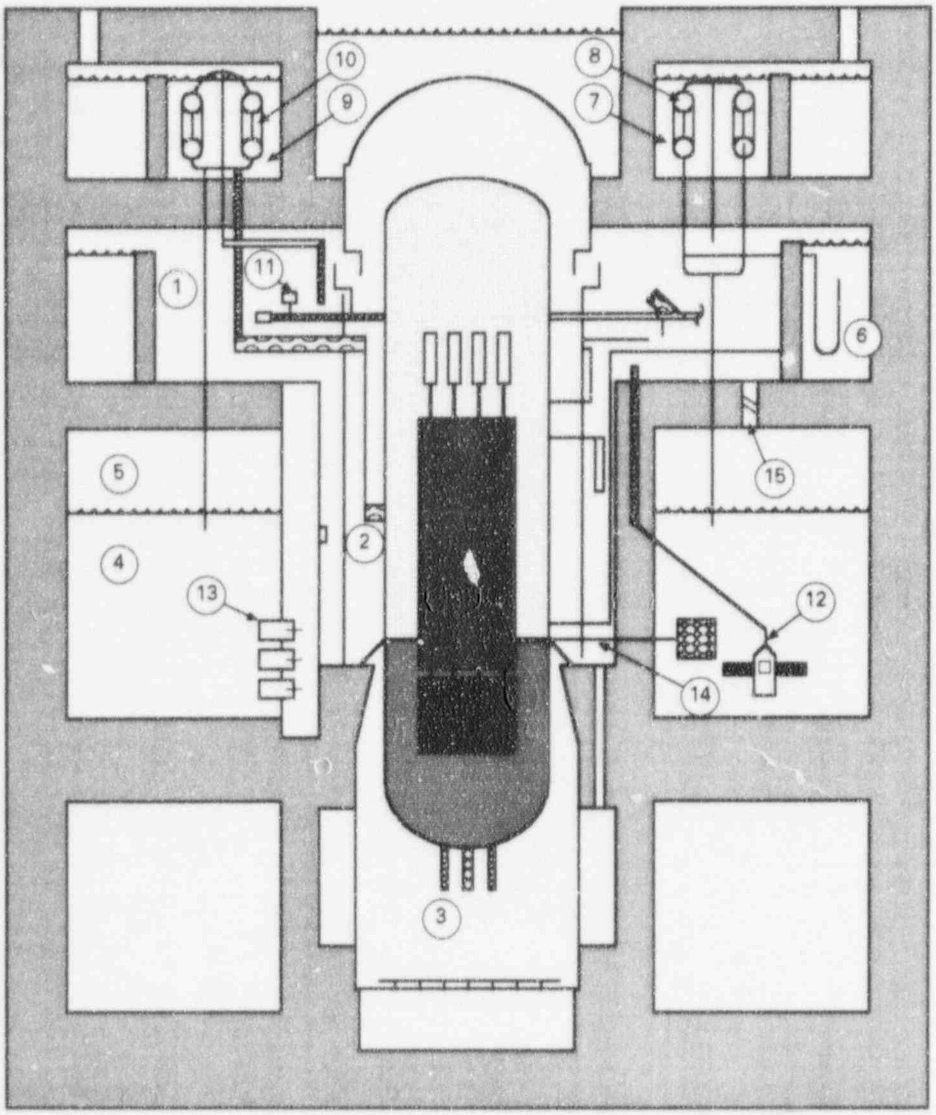

Figure 1. SBWR Containment