THE SAFETY CONTAINMENT FOR NUCLEAR POWERED SHIPS

H. LETTNIN

Shipbuilding Department,
Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt mbH,
D-2054, Geesthacht-Tesperhude, Germany

SUMMARY

The safety containment of a nuclear power plant has to prevent the release of radioactive material in the environment in case of any credible accident. It has to maintain its integrity under all possible accident conditions, such as pressure and temperature build-up, explosions and damaged mechanical parts acting as missiles.

In addition to these loadings, the safety enclosure on board of a nuclear powered vessel has to withstand additional stresses. The ship and its internal components are exposed to additional accelerations induced by sea motions. Steps are being made in analyzing the sea motions of the different sea regions by means of probability methods to get real design data. But due to the complexity of the investigations, the supervising authorities have chosen a more practical approach based on experiences with a great number of ships of different sizes and types. A fixed value of 0.5 g and/or 1.0 g, respectively, is required as additional acceleration for the layout of the containment foundation and all safety devices. Due to the roll, pitch and heave, the above mentioned figure has to be taken into consideration in all directions. In addition, the designer has to pay attention to inclinations in the different directions, in case of heeling with angles up to 45°.

A special problem are vibrations excited by sea motions, ship propeller or auxiliaries. While the frequency of roll, pitch and heave is below one cps and therefore usually of no concern for the nuclear plant, ship propeller excitations have to be analysed very carefully to avoid resonances of reactor components.

Sea motions in connection with different loading conditions lead to longitudinal, transverse and torsional stresses of the ship's structure. Especially "open" container ships, ships with small deck stripes only as upper structure can suffer strong distortions of the ship's body which have to be taken into consideration for the foundation of the safety enclosure. This question is of special importance if a fully integrated safety containment into the ship is chosen. Furthermore, attention has to be paid to the layout of the containment in case of possible shock loadings by ship collisions or groundings and opposite to a land-based plant, the outer pressure build-up in case of sinking. A further difficulty is the restricted space on board of a ship.

The usual solution for the safety enclosure is the dry containment (i.e. a pressure shell which withstands the highest possible pressure in case of a LOCA). This type of containment is used for the nuclear powered ships "Savannah", "Otto Hahn" and "Mutsu". A more advanced design is the wet containment using a pressure suppression system for the pressure restriction in the enclosure. Due to the low pressure, the safety enclosure can be fully integrated into the ship's structure using longitudinal and transverse bulkheads as parts of the containment. The different construction principles shall be discussed, using as examples the N.S. "Otto Hahn" and the study for a 80 000 shp nuclear propelled container ship.

1. Introduction

The safety containment is one of the most important safety devices in every nuclear power plant. It has to prevent the release of radioactive material to the environment in case of any credible accident. The safety containment has to maintain its integrity under all possible accident conditions such as pressure and temperature build-up, explosions and damaged mechanical parts acting as missiles. The safety enclosure on board a nuclear powered vessel has to withstand not only the abovementioned stresses, but also additional stresses which result from the maritime environment. The different design criteria shall be discussed in more detail and the selected solutions shall be shown.

2. Design Considerations for a Ship Reactor Plant

2.1 Accelerations

In contrast to land-based plants, the ship and its power plant is exposed to additional accelerations induced by sea motions. The acceleration values are dependent on weather condition, sea region, type of vessel and loading condition to mention only the most important influences. Due to the difficulties of getting reasonable design data, the classification societies [1] [2] [3] [4] [5], as supervising authorities for the ship's safety, have chosen a more practical approach based on experience. The German classification society GERMANISCHER LLOYD, as one example [1], requires an additional vertical acceleration of 1 g maximum for the layout of all essential reactor components, e.g. the safety containment. Figure 1 shows calculated accelerations of the NS "OTTO HAHN" along the ship's length. The approximately parabolic shape of the curve with maximum values at the ship's end is typical. To take this into account the newest rules of the classification society for nuclear vessels have been modified. In the range of the afterbody the design accelerations have to be increased, whereby the maximum acceleration is at the vessel's stern. This increase is in addition to the 1 g design acceleration. The safety containment is not only exposed to accelerations in the vertical direction but also in every transverse direction and in the longitudinal direction. The accelerations due to grounding or collision lead to smaller values than 1 g, which has been confirmed by calculations and experiences [6] [7].

2.2 Inclinations

No land-based power plant will come in the situation of inclinations up to 45°. The design of the safety enclosure on board ship has to take into account inclinations in different directions due to roll and pitch. Therefore, the safety containment as one of the most important safety devices has to be layed out for a heel angle up to 45° and trim angle depending on the ship's length. The inclinations must be combined with additional accelerations of 0,5 g, which are required under normal operation conditions. The safety containment must also maintain its integrity at an angle of 180° in the very improbable case of the capsized vessel.

2.3 Vibrations

The safety containment on board ship is exposed to vibrations in a range of far below 1 cps until up to about 80 cps. Sources of excitations are sea motions, oscillating propeller forces and excitations from auxiliaries.

The roll, pitch or heave vibrations with frequencies far below 1 cps are too low for vibration excitations on board. On the other hand, excitation frequencies of 50 cps and more of the auxiliaries are too high. Therefore, the most important vibration source with regard to the reactor and its components is the propeller with frequencies between 5 and 25 cps and large excitation energies.

Depending on revs and number of blades, usually the first and second order have to be taken into account and must be analysed very carefully to avoid resonances of reactor parts.

2.4 Sinking

In case of an assumed sinking of a nuclear vessel, the safety containment must be protected against collapse by the rising water pressure. As the safety enclosure must maintain its integrity under all circumstances, also in case of sinking, sufficiently large flood openings must be provided for. Another point of view is the danger of destroying important reactor components by a collapsing safety enclosure. The layout of the flood openings depends, among other things, on the sink velocity, which is different for every ship and every loading condition. Furthermore, it depends on the free inner volume of the safety containment, the pressure height during opening, and so on [8] [9]. The difference between inner and outer pressure must not exceed the outer design pressure, which is in the range of 3 atm gauge. In case of a cylindrical safety vessel with large diameter the layout for the outer pressure determines the construction.

2.5 Installation of the Safety Containment on Board

A series of problems specifies the installation of the safety containment on board ship. Contrary to the rigid foundation of land-based nuclear plants, the bedding in a ship cannot be assumed as rigid. Due to the working of the ship in heavy seas and due to the loading conditions, the whole ship structure is exposed to deformations which cannot be neglected. Therefore the bedding system must allow relative motions between ship and safety containment. In case of "open" container ships with only small deck stripes as upper structure, the displacements due to longitudinal and transverse stresses are superposed with displacements due to high torsional stresses.

2.6 Other Design Criteria

Other design criteria for safety containments that are the same for land-based reactors shall only be mentioned. The main task of the containment, the prevention of the release of radioactive material, is the same. The design for inner pressure and temperature build-up in case of a LOC-accident, the consideration of explosions and fire protection of the containment on board and the consideration of missile effects of damaged mechanical parts are all alike. The design of the safety enclosure has to take into account the possible effects of explosions occurring during a collision with a crude oil or gas tanker. The newest trend is that airplane crashes on a ship need to be considered.

3. Safety Containment Design

The most common design of a safety containment is the dry containment. This safety enclosure is capable of containing the whole vaporized primary coolant in case of a LOC-accident at the correspondingly elevated pressure and temperature. The pressure and temperature build-up is a function of the mass of primary coolant and of the inner free volume. The larger the volume the smaller the pressure and temperature build-up. The usual design of a dry safety containment is a cylindrical shaped vessel, which is also used on board of the nuclear powered ships "SAVANNAH", "OTTO HAHN" and "MUTSU".

As performances increase, the mass and sometimes the pressure of the primary coolant grow. In such cases a dry safety containment necessitates enormous free volumes and, therefore, large dimensions of the containment shell, if the shell plating is not to exceed reasonable limits. Land-based power plants, corresponding to their performance, use large safety containments with diameters in the range of 50 m. Although the necessary performances for fast ships are smaller than land-based reactor stations, such dimensions are entirely impossible on board ship.

A possible solution is the pressure relief system [10], where in case of a LOC-accident the first pressure impact will be lead by relief openings into ship compartments to avoid too strong a pressure build-up.

A more encouraging way is the pressure suppression system or wet containment. The safety enclosure consists of three parts, drywell, wetwell and expansion room, which are connected by pipes. In case of a LOC-accident the vaporized primary coolant gathered in the drywell will be lead by pipes into the heat sink, the wetwell, where the steam condenses. Air and inert gases are gathered in the expansion room. Manifold calculations show that the maximum pressure build-up will be only in the range of 2 - 3 atm gauge. This system offers the integration of the safety enclosure into the ship, saving costs and building time. Longitudinal and transverse bulkheads can be used as structural elements in a well-known shipbuilding manner. Special attention has to be paid to the gas-tightness to hold the leakage rate in the same order of magnitude as for other similar safety containments.

It shall only be mentioned that instead of a wetwell tank an ice condenser can be used as heat sink. But such arrangement is too impractical for ship board use.

4. Design Examples

The selected containment principles for the design of light water reactors on board ship shall be discussed using two examples.

The first example of a dry safety containment is the arrangement on board of NS "OTTO HAHN". Figure 2 shows the cylindrical vessel enclosing the reactor of the FDR-type. It is designed for an inner pressure and temperature of 14,5 atm gauge at 200° C. The foundation or bedding system consists of 24 slid bearings arranged in a circular manner acting as ball-and-socket joints.

In the upper part horizontal tension rods connect the safety containment with the ship compartment. This bedding system allows relative motions between the containment and the ship to a relatively large extent. The vessel can withstand an outer pressure of maximum 3,5 atm gauge and is designed for additional accelerations of 1 g in any direction. Vibrations excited from the propeller or other sources can not be noticed in the reactor area.

The second example is based on a comprehensive study of a nuclear propelled 80 000 shp container ship. The performance is eight times greater than that of the NS "OTTO HAHN". Because a dry containment was not possible, the wet containment was chosen, the pressure suppression system for the EFDR-reactor. A further step is the full integration into the ship structure. Figure 3 shows the general arrangement of the power plant. Apart from the cylindrical drywell, the safety enclosure consists of longitudinal and transverse bulkheads and partial decks. The inner layout pressure is 4 atm gauge at 90° C. Due to the flat bulkheads the inner and outer design pressure is equal. Only in case of the drywell is the maximum outer pressure limited to 2,5 atm gauge.

The pipe arrangement must be such that the pressure suppression system works at heel angles up to 45°. A special problem was the strength of the joints to the adjacent ship structure. An extensive strength investigation has been carried out by the German classification society GERMANISCHER LLOYD to determine the feasibility of an integrated safety enclosure on board ship [11]. The results show that there is no severe strength problem. The strong cross section in the reactor area allows only small deformations due to the additional grounding and collision protection structures and the closed deck in this area (Figure 4). Additionally, the integrated safety enclosure reinforces the cross section and, therefore, the interaction between ship and containment is negligible and the function of the containment is not impaired in any way.

To demonstrate the reliable functioning of the pressure suppression system, our company has installed an experimental safety enclosure where drywell and wetwell are full scale models. Many parametric studies will be carried out, among them the investigation of the condensing procedure. The investigations will start during summer 1973.

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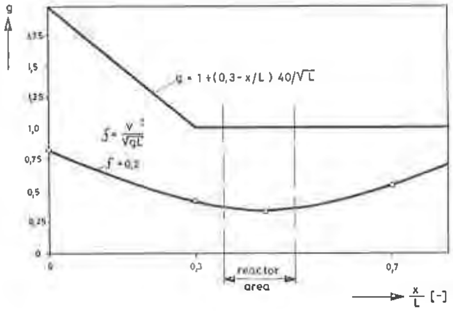

Fig. 1

Calculated heave and pitch accelerations for N.S. „OTTO HAHN" and design values required from classification society GERMANISCHER LLOYD

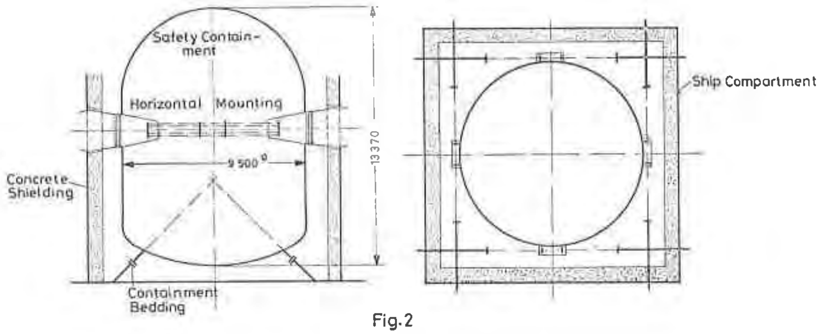

Fig. 2

Bedding System of Safety Containment of NS „OTTO HAHN"

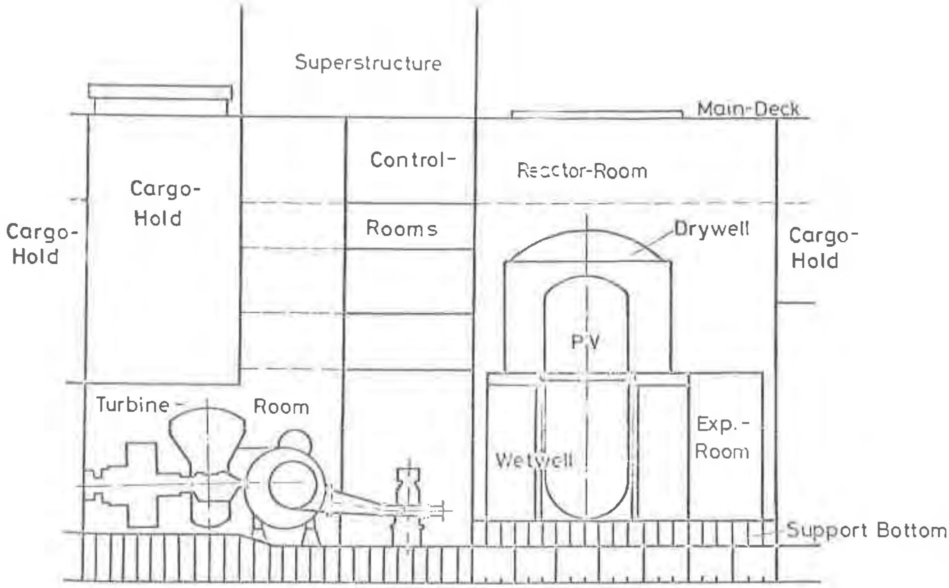

Fig. 3

Arrangement of Nuclear Propulsion Plant

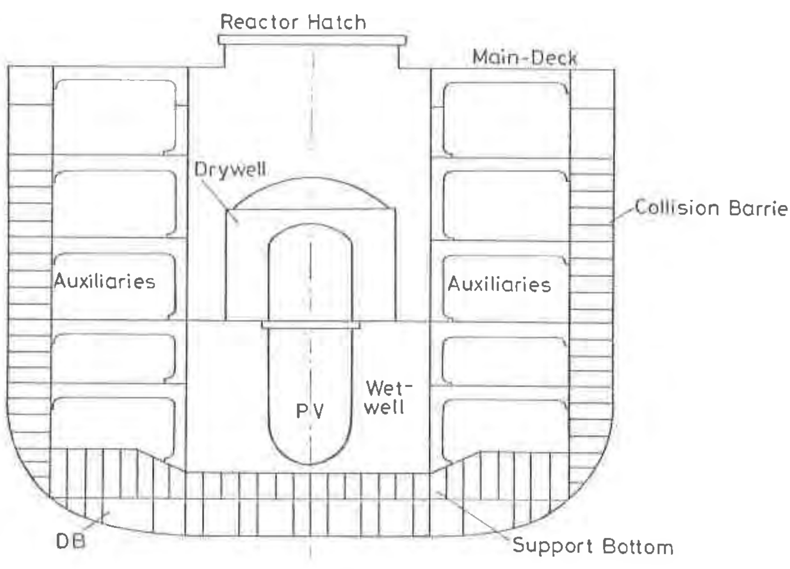

Fig. 4

Cross Section of Reactor Compartment