

# Offshore Bulk Power Facilities



Thermal discharges to the environment are common to fossil- and nuclear-fueled central power stations. Air discharges, too, are common—significant quantities of particulates and gases from fossil-fueled systems, small quantities of radioactive gases from nuclear—and each type of system has an impact upon its environs. Each of these problems is mitigated by offshore siting of bulk power facilities. Offshore siting also offers such distinct advantages as thermal enhancement of the waters to increase recreational and commercial values, and, a very important consideration along our west coast, earthquake-isolation of the bulk power facility. Not a practiced art, offshore siting brings with it new design considerations such as collision-avoidance and sea-driven platform motion effects on huge rotating turbines.

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Among recommendations<sup>1</sup> for priority research made by the Energy Policy Staff of the Office of Science and Technology is study of advanced bulk-power-facility siting practices, specifically that \$10,000,000 to \$20,000,000 be expended in offshore siting studies and development. This should indicate that such siting is

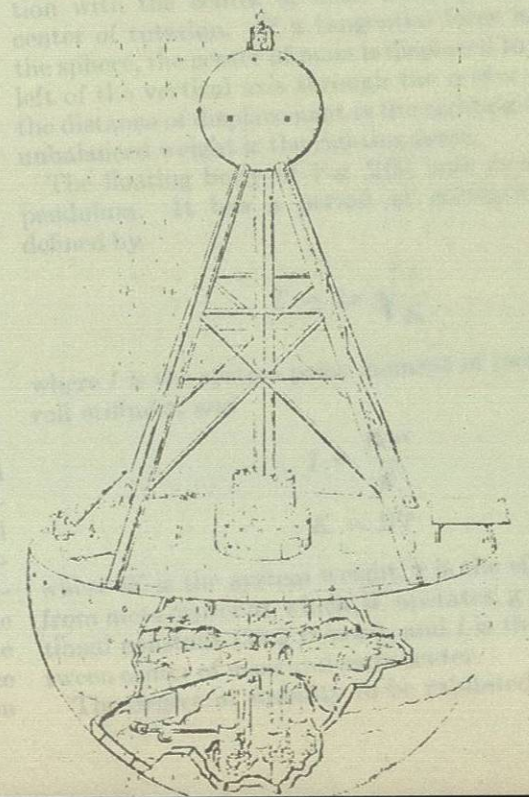
<sup>1</sup>Based on a paper contributed by the ASME Energetics Division. *Electric Power and the Environment*, Energy Policy Staff, Office of Science and Technology, Executive Office of the President, Aug. 1970, p. 44.

not routinely accomplished. Optional techniques include: (a) islands, existent and man-made; (b) bottom-mounted plants, floated to site and submerged or constructed in situ; and (c) floating platforms, tuned and un-tuned. Each has advocates and it is probable that each is a best solution in some certain specific circumstance.

The floating-platform technique is the subject of this article. It is shown in Fig. 1 with a 1000-MW(c) reactor power plant. Advantages include:

- 1 Construction of the hull and power-system platform is repeatedly accomplished by a skilled, stable shipyard workforce.
- 2 Dockside installation of the power system is also accomplished on a repeated basis by a trained, stable

Fig. 1 Tuned-spherical-platform offshore bulk power facility.



was not very favorable is indicated by the sale of 60 from the U.S. brought by ship in 1873 [12].

In both Iran and India, nocturnal ice-formation techniques have been generally adopted. In Iran, ice-formation, perhaps in the form of rock pools and movable covering ponds, can improve the nocturnal technique. Even when ice cannot be obtained, solar radiation can cool shallow rock pools 15% or more below early morning temperature. This cool water may be indirectly circulated by thermosiphon action around underlying rock sheets to serve as the heat sink for the ice-formation in developing countries. Thermosiphon circulation of rock-pool water cooled nocturnally and covered in the daytime by movable insulation might be adapted, in part of the U.S., for storage of vegetable crops. The same movable insulation can be used in another space being heated.

Studies are underway to determine those areas which have climatic factors favoring rooftop appliances for natural air conditioning, winter heating and cooling, dehumidification, and air purification. Present physics make these processes feasible for use in some climatic regions today. Experiments carried in these areas aided by further improvements in plastics and by additional studies of diurnal energy flows will extend the range of applicability.

Extensive use of radiative heating and cooling devices in the American Southwest is cited for future use. The disposition of the people, the need for new housing and cities, and the search for major companies for new markets may finally necessitate use of natural energy forces.

Reports from 1775 to 1875 indicate that Iran (California) to Alghabed trenches were dug 2 ft deep and allowed to dry. Then insulation—such as wool, straw, corn stalks or straw (a "black-baking" and was "reformed better for the purpose than wool")—was added to within 6 in. of ground level. From December to mid-February, winds were usually strong. When they came gently from the northwest, they brought water than the more humid prevailing wind, and shallow plates were placed in the trenches. Water was added in the plates to a depth expected to be approximately 0.5 in., sometimes 1.5 in. The plates were covered with a material in a point where the cooling tower water temperature is a point where radiation caused freezing for crystals appearing in some plates were thrown across the other plates in a similar manner when air temperatures were 41 or 47 F. The ice was carried to pits, ground, water, watered, and frozen into a solid block. With the surface insulated and further covered by a thin layer of snow, the ice lasted into the summer months. Some factories produced 150 tons per season; others made as much as 10 tons per night. That the economics

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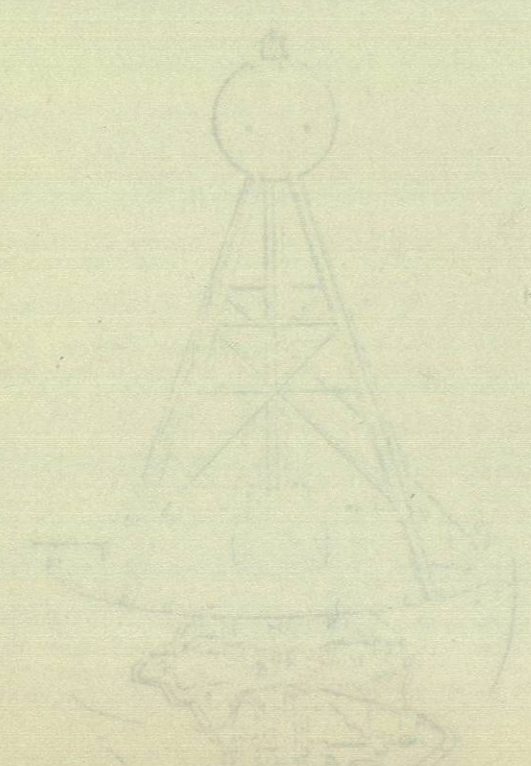
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thermal discharges to the environment are common to fossil and nuclear-fueled central power stations. Air discharges, too, are common—significant quantities of particulates and gases from fossil-fueled systems, small quantities of radioactive gases from nuclear—

The design of a floating offshore bulk power plant is a complex task. It involves the integration of various disciplines, including structural engineering, mechanical engineering, electrical engineering, and marine engineering. The design must take into account the harsh marine environment, the need for stability, and the requirements of the power plant itself.

1. Construction of the hull and power-system platform is typically accomplished by a skilled shipyard workforce.

2. Location of the power plant is also determined by a variety of factors, including the availability of a suitable site, the need for access to the power plant, and the need for access to the power plant.



workforce; this will increase the reliability of the operating system, a safety as well as an economic nuclear-power-plant consideration.

3. Mooring-site preparation is an economic operation vis-à-vis construction of island and subsurface offshore sites; a greater flexibility in site selection is also obtained.

4. The bulk power-plant facility is mobile, i.e., transportable; it can be towed to site, moved in response to changed requirements, returned to the shipyard to take advantage of technology improvements, etc.

Problems peculiar to the floating platform include:

1. Compliancy: The platform must be sufficiently stiff, i.e., noncompliant, that turbine-shaft misalignments (shafts can be as much as 200 ft long) do not cause turbine-generator failure.

2. Gyroscopic forces: Roll created by wave action must be made so minimal that side loads on the rotating turbine mass result only in negligible gyroscopic forces on turbine bearings and bearing mounts.

3. Mechanical loads: Platform motion in response to winds and waves must be minimal in order that loads on moorings and electric power transmission lines are not excessive.

The optimally noncompliant platform is a sphere. When used with a large secondary mass, the spherical platform can be "tuned" to have a natural roll frequency much lower than the exciting frequency of all conceivable waves; thus gyroscopic forces of consequence are eliminated and mechanical loads are minimized by constraining motion (heave) to be along the vertical axis (roll was removed by tuning). The spherical shape also assists in load reduction, since changes in draft due to acceleration and deceleration

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...of a paper contributed by the IBM Research Division, Yorktown Heights, New York, dated 1972.

along the vertical axis are uniformly evidenced as buoyant-force changes equally applied around the circumference of the system.

**Tuned Spherical Platform**

To understand the principle of the tuned spherical platform, one must keep in mind these facts about a free-floating spherical body:

- 1 It has a center of mass whose location is determined by the system fabricator/designer.
- 2 It has a fixed center of rotation.
- 3 This center of rotation, the meta center, remains at the geometric center of the sphere regardless of how mass is distributed on or within the sphere.
- 4 All forces imposed on a free-floating spherical body operate inherently through, i.e., are vectored or directed through, the center of rotation.

Use can be made of the foregoing facts to design and fabricate an extremely stable, seaworthy platform for bulk power facilities. The sequence of sketches in Fig. 2 illustrates how.

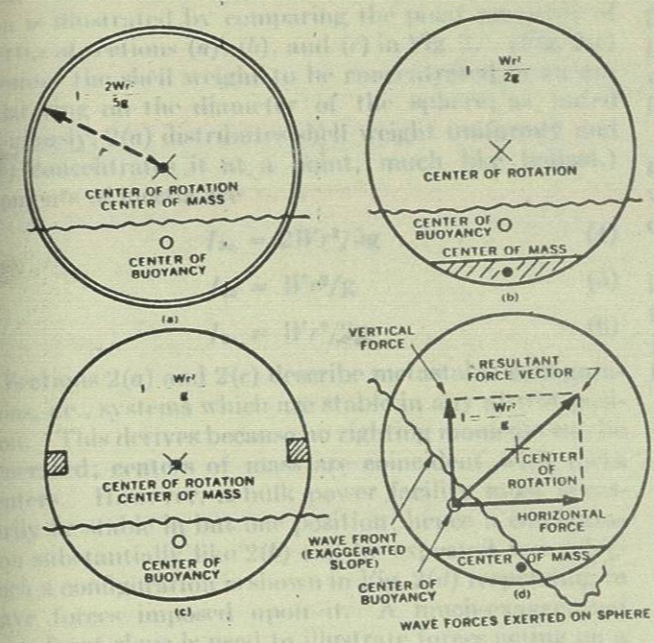


Fig. 2 Comparison of spherical buoys of different mass distributions.

Fig. 2(a) is simply a floating sphere with its weight uniformly distributed in its shell. Obviously, the centers of mass and rotation are coincident. In such a configuration the system is totally unstable with respect to roll. If a tangential force were applied to the sphere, it would begin spinning about the center of rotation; since the center of mass is at the center of rotation, no righting moment would exist and the spinning of the sphere would only be reacted and stopped by frictional forces at the sphere-air-water interfaces.

The foregoing implies that stability in roll is, in part, dependent on establishing a righting moment. Fig. 2(b) illustrates most simply how a righting moment is established. It assumes that the weight of the spherical shell is concentrated at a point on the circumference of the sphere. Two things happen: (1) The center of mass is displaced from the center of rotation to the surface of the sphere and (2) the sphere assumes a position with the center of mass immediately below the center of rotation. If a tangential force is applied to the sphere, the center of mass is displaced to the right or left of the vertical axis through the center of rotation; the distance of displacement is the righting arm and the unbalanced weight is the righting force.

The floating body of Fig. 2(b) acts as a compound pendulum. It has a period of oscillation which is defined by

$$T = 2\pi \sqrt{\frac{I}{K}} \quad (1)$$

where  $I$  is the system polar moment of inertia,  $K$  is the roll stiffness, and

$$I = \frac{Wr^2}{g} \quad (2)$$

$$K = Wl \quad (3)$$

where  $W$  is the system weight,  $r$  is the effective radius from meta center at which  $W$  operates,  $g$  is the gravitational constant (32.2 ft/sec<sup>2</sup>), and  $l$  is the distance between center of mass and meta center.

The degree of stability to be exhibited by a floating

about the vertical axis...  
...of the system.

To understand the principle of the tuned spherical platform, one must keep in mind that the center of buoyancy is fixed and the center of mass is movable.

1. It has a center of mass whose location is determined by the system laboratory hardware.  
2. It has a fixed center of rotation.  
3. The center of rotation, the center of buoyancy, and the center of mass are collinear and the center of mass is distributed so as to allow the platform to rotate about the center of rotation.

Fig. 3 Comparison of spherical buoy of different mass distributions. The buoyancy center is fixed and the center of mass is movable.

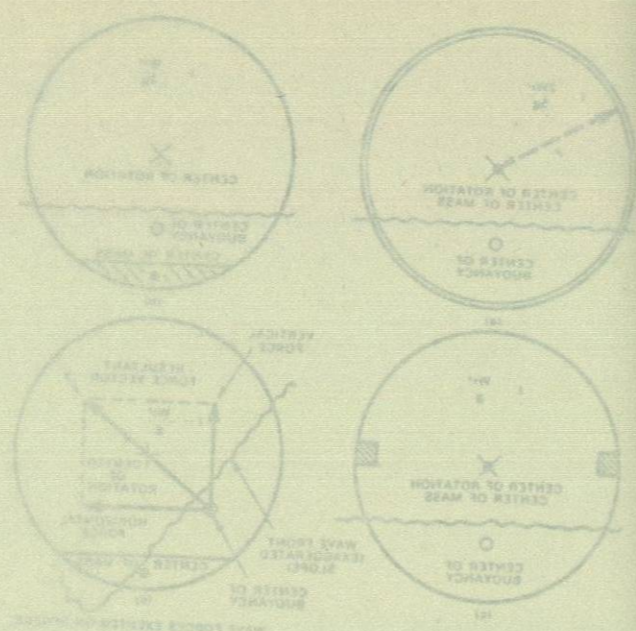


Fig. 4 Maximum slope angle of wave. The graph shows wave height vs. period for different sea states.

Fig. 5 Reference-Design Tuned-Platform Nuclear Power Plant. A conceptual layout of the power system.

Fig. 6 Enclosed-system volume is 13M cu ft; a 300-ft-dia sphere weighing 66M lb houses the power system.

(1)  $I_{aa} = 2Wr^2/5g$   
(2)  $I_{ab} = Wr^2/g$   
(3)  $I_{ac} = Wr^2/2g$

Sections 2(a) and 2(c) describe metastable configurations, i.e., systems which are stable in any at-rest position.

This derives because no righting moments can be generated; centers of mass are coincident with meta-centers.

Reference-Design Tuned-Platform Nuclear Power Plant

A 1000-MW(e) tuned-spherical-platform offshore floating bulk nuclear power facility, as an example, lacks the additional complexity of system design that would be introduced by an ever-changing on-board fossil-fuel supply.

A boiling-water reactor system would be comprised generally as in Table 1. A pressurized-water reactor would have a similar total weight with component distribution as in Table 2.

A conceptual layout of the pressurized-water system is presented in Fig. 5; a mass-distribution approximation is shown in Fig. 6. Enclosed-system volume is 13M cu ft; a 300-ft-dia sphere weighing 66M lb houses the power system. Total bulk-power-facility weight is

platform is, in part, determined by its period of oscillation; that this is largely determined by mass distribution is illustrated by comparing the polar moments of inertia of sections (a), (b), and (c) in Fig. 2. (Fig. 2(c) assumes the shell weight to be concentrated in an annular ring on the diameter of the sphere; as noted previously, 2(a) distributes shell weight uniformly and 2(b) concentrates it at a point, much like ballast.) Moments of inertia are

(4)  $I_{aa} = 2Wr^2/5g$

(5)  $I_{ab} = Wr^2/g$

(6)  $I_{ac} = Wr^2/2g$

Sections 2(a) and 2(c) describe metastable configurations, i.e., systems which are stable in any at-rest position. This derives because no righting moments can be generated; centers of mass are coincident with meta-centers. However, a bulk power facility must necessarily be stable in but one position; hence a configuration substantially like 2(b) can be expected to evolve. Such a configuration is shown in Fig. 2(d) responding to wave forces imposed upon it. A much-exaggerated wave-front slope is used to illustrate forces acting on a ballasted (tuned) sphere. Note that the spherical platform has not rolled in response to the wave front. The wave front has caused the center of system buoyancy to move, but the centers of system mass and rotation remain fixed; as a result, the system is translated vertically and horizontally but not rotationally. This in part is the case for the spherical platform. A non-spherical body, e.g., a boat or barge hull, would not react similarly to the passing wave front. The shift in center-of-buoyancy location would be accompanied by a shift in the meta-center and hence in the meta-center-to-center-of-mass distance; roll would result.

In the intended application, a long period of spherical-platform oscillation is desired. This permits the platform to act as a "low-pass" filter of imposed wave forces. The platform, having a man-adjusted natural frequency longer than the forcing frequency of nature-adjusted waves, will, as a consequence, fail to be excited, i.e., rolled, by them. Platform stability will have been achieved through:

- 1 Selection of a platform shape having a fixed center of rotation.
- 2 Adjustment of the system center of mass such that desired roll stiffness (righting moment) exists.
- 3 Coincident adjustment of the system mass elements such that the system polar moment of inertia and roll stiffness define a system having a natural frequency not excited by seas to sea state 8.

Spherical-Platform Loadings

Roll is combatted in an offshore floating bulk-power-facility platform to ease platform compliancy constraints, to reduce gyroscopic forces on turbine-generator systems, and to minimize mechanical loads on moorings and power transmission lines.

Wave height and slope are the forcing functions on the platform. These are defined by Figs. 3 and 4. Significantly, a situation is described which indicates that a platform having a natural period of about 40 sec would be virtually unaffected by seas to sea state 8.

Fig. 3. Maximum spectra of ocean waves.

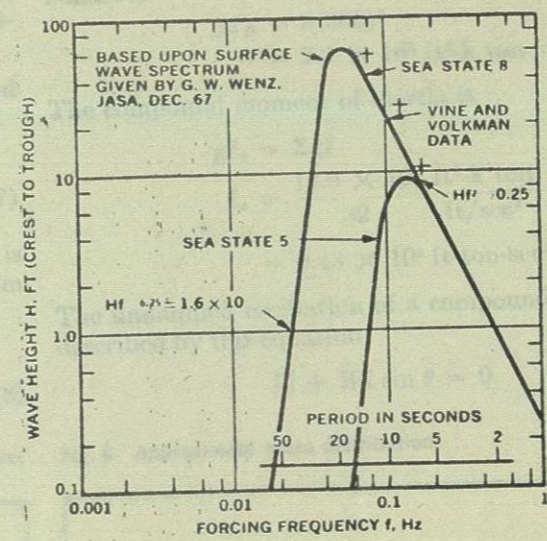
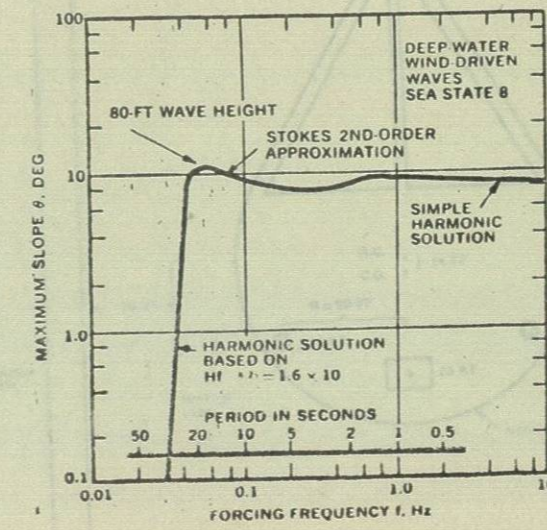
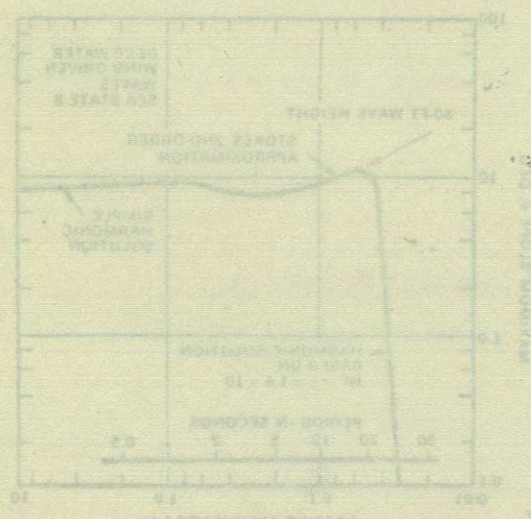
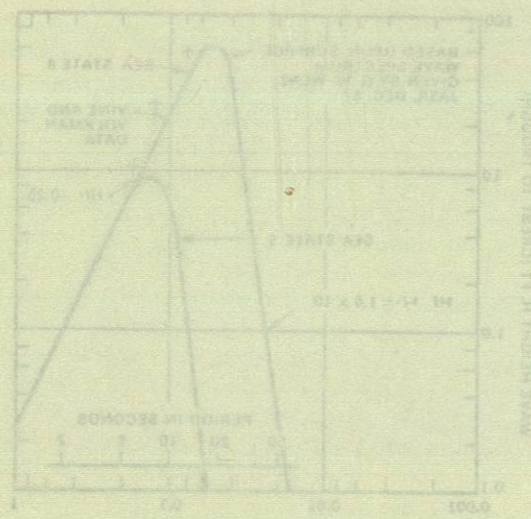


Fig. 4 Maximum slope angle of wave.



Reference-Design Tuned-Mass-Damper System  
 A 1000-MW(e) tuned-mass-damper system is shown in Fig. 5. The system consists of a spherical platform having a diameter of 180 ft and a height of 300 ft. The platform is supported by a central vertical column. The system is designed to provide roll stability and reduce roll motion during sea states. The platform is divided into several functional areas, including crew quarters, recreation, labs, and control. The system is designed to be stable in any direction and to provide a comfortable environment for the crew.



Reference-Design Roll Response to Sea States  
 The system compound moment of inertia with respect to the meta center must be determined before roll response can be calculated. Several simplifying assumptions are made:  
 1. Reactor and steam-generator mass is concentrated at a point on the axis 90 ft from the meta center.  
 2. Turbine-generator-system and condenser mass is concentrated in an annular ring at a 90-ft radius from the centerline and 70 ft below the meta center.  
 3. The spherical-platform shell is continuous and ignores the struts to hold the water-ballast tuning tank.

Equations for roll response:  

$$gI_R = 25 \times (90)^2 = 2.03 \times 10^5 \text{ ft}^2\text{-k ton} \quad (7)$$

$$gI_{TG} = m_{TG}(90^2 + 70^2)/2 = 1.24 \times 10^5 \text{ ft}^2\text{-k ton} \quad (8)$$

Fig. 5 Conceptual layout of a 1000-MW(e) pressurized-water reactor. The diagram shows a cross-section of the reactor vessel with various components labeled: Tuning Water Tank (8k tons), Crew Quarters and Galley, Recreation, Labs, Control, Electrical Switchgear Yard, H.P., COND, F.W.H., WATER LINE, PRES, S.G., COND, F.W.H., WATER LINE. The reactor is supported by a central vertical column.

TABLE 1 Boiling-Water Reactor System

Subsystem	Weight (Millions of Pounds)
Reactor containment and pools	50
Nuclear steam-system equipment	3
Other reactor equipment	3
Turbine-generator equipment	24
Plant water	103

85,000 tons; such an equipped structure is well within shipyard construction capabilities and is, in fact, smaller than many ships.

Reference-Design Roll Response to Sea States

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Fig. 5 Conceptual layout of a 1000-MW(e) pressurized-water reactor.

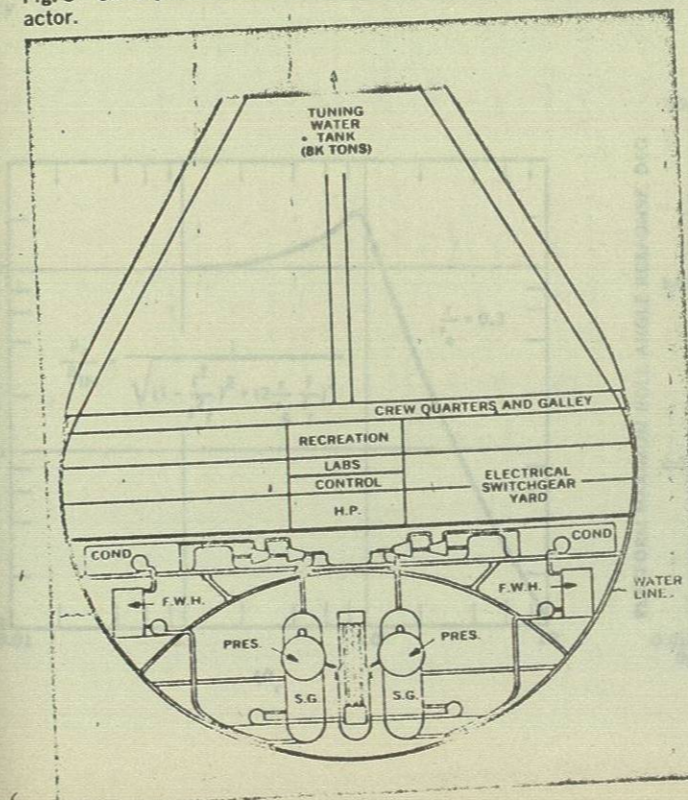


TABLE 2 Pressurized-Water Reactor System

Subsystem	Weight (Millions of Pounds)
Reactor, pressure vessels, and pools	25
Nuclear steam-system equipment	25
Other primary-loop equipment	3
Secondary condenser and feed-water heater	3
Turbine-generator equipment	23
Plant water	24
	103

Equations for roll response:  

$$gI_S = 2M(150)^2/5 = 2.97 \times 10^5 \text{ ft}^2\text{-k ton} \quad (9)$$

$$gI_B = 8(300)^2 = 7.2 \times 10^5 \text{ ft}^2\text{-k ton} \quad (10)$$

The compound moment of inertia is  

$$gI_o = \Sigma gI = \frac{13.9 \times 10^5 \text{ ft}^2\text{-k ton}}{32 \text{ ft/sec}^2} = 0.43 \times 10^8 \text{ ft-ton-sec}^2$$

The undamped oscillation of a compound pendulum is described by this equation:  

$$I\ddot{\theta} + Wl \sin \theta = 0 \quad (12)$$

Fig. 6 Approximate mass distribution. A diagram showing the mass distribution of the reactor vessel. It features a central vertical column supporting a spherical platform. The platform has a radius of 90 ft and a height of 300 ft. The meta center (M.C.) and center of gravity (C.G.) are located 14 ft from the center. The structural mass is 33 kt. The diagram also shows the location of the reactor and turbine-generator equipment.

Fig. 6 Approximate mass distribution.

