# CONTENTS

(Section 12)

# 12. SHIP ACCIDENTS

## 12.1. Introduction

The NS Savannah is designed to comply with the highest standards of safety in respect to conventional ship hazards as well as the potential hazards associated with the operation of a nuclear propulsion plant. The following basic safety criteria were established early in the program.

1. The NS Savannah shall be as safe as any other vessel in her class with respect to the usual hazards at sea.
2. No hazardous radiation exposure shall result from any credible accident.

The accidents to which a ship is exposed in normal operation include collision, grounding, flooding, sinking, heavy weather, fire, and explosion - all of which are analyzed in detail. It should be noted that these hazards are considered principally from the standpoint of release of radioactive material rather than from the conventional aspects of safety of life at sea. The safety of the crew from the normal hazards of ocean travel is adequately handled by compliance with existing maritime regulations. Normal ship safety requirements are treated only to the extent that they affect the NS Savannah's ability to avoid or withstand severe damage. The special hazards associated with war service (ballistic and mine damage) are not considered.

## 12.2. Conventional Ship Safety

The safety of any ship depends on three factors:

1. Care and judgment of responsible personnel.
2. Complete and immediate knowledge of potential hazards by responsible personnel.
3. Complete control of the vessel and equipment at all times.

Only factor 3, and to some extent factor 2, can be ensured through component and system design.

The principal requirements for complete control of a ship are the maintenance of power to the shaft and adequate steering power. On the NS Savannah, means for fulfilling these requirements are provided to an unusual degree.

Electrical power is assured by the installation of three independent sources in addition to the two normally used 1500-kilowatt ship's service turbine generator sets. Two 750-kilowatt auxiliary diesel generators will start and provide power to the main switchboard automatically within 15 seconds. In case of reactor scram or shutdown, the stored heat in the system will maintain power through the ship's service turbine generators until the auxiliary units are brought into service. If for any reason the two auxiliary diesel generators are not available, fail to start, or fail to parallel, the 300-kilowatt emergency diesel generator will supply sufficient power to operate vital systems. The emergency generator, located on the navigation bridge deck, is provided with independent switchgear and is started automatically from continually charged hydraulic accumulators.

A 750-horsepower reversible electric motor is installed for auxiliary propulsion in case of main propulsion unit failure. The NS Savannah develops about 6 knots in a mild sea with this auxiliary motor. Power for the motor is taken from either of the auxiliary diesel generators.

The NS Savannah's head reach, the distance required to stop from design speed, is comparable to that of other ships in this class. A head reach of 4380 feet was measured on the final acceptance trial.

There are two conning stations on the NS Savannah; one on the bridge and the other at the after steering station on the docking bridge. If the conning stations are incapacitated, the ship can be maneuvered manually from the steering gear room.

The steering gear has two independent steering plants, each capable of handling the rudder under design conditions. A crossover in the steering engine room transfers control from one plant to another. There are two electric, bridge-activated, steering control systems to operate either steering plant. In addition, a hand pump is supplied to allow positioning of the rudder if the main hydraulic plant fails. Both hydraulic pump systems and both electric steering control systems can be shifted from either the engine room or the bridge. This flexibility satisfies the need for separate emergency steering gear. It is concluded that the steering gear has more than adequate backup.

The rudder, propeller, and shafting are the only vital units without backup - a characteristic of all single-screw ships. Loss of these units is an infrequent occurrence. While such situations are dangerous in that the ship is out of control, countermeasures are well defined. Anchoring in restricted waters and the use of tug services in open sea constitute the normal countermeasures.

Avoiding potential ship hazards is primarily a function of communication and navigation. The wheelhouse and the navigation bridge on the NS Savannah are designed for maximum visibility, and the internal communication system is excellent. The NS Savannah's navigational equipment assures responsible personnel of accurate information on potential hazards.

The most important factors in safety at sea - care and judgment - do not result from the design of a ship. They are the results of crew training, experience, and vigilance. The NS Savannah's officers and technical staff are selected and trained with great care.

## 12.3. Collisions

Almost all collisions between ships at sea can be traced to errors in the judgment of responsible personnel. Collisions attributable to equipment failure occur only rarely. Since collisions cannot be eliminated through design, provisions must be made in a nuclear-powered ship to protect the reactor and containment against the effects of collisions.

A thorough study of collision records was undertaken to determine the mechanisms of collision and to define the magnitude of damage to be expected. In the course of the investigation, the available data on some 60 major collisions were reviewed. Data were collected from USCG reports on collision circumstances, ABS and United States Salvage Association damage surveys, testimony of passengers and crew members who had experienced collisions, and U.S. Navy damage reports. Additionally, statistical data on ship collisions were obtained from U.S. Salvage, Lloyds, and underwriting organizations.

The data were first reviewed for evidence and magnitude of shock damage. The acceleration or deceleration of large masses could conceivably damage vital reactor components and rupture pipelines. Specially strengthened and armored vessels, as well as conventional merchant ships, were included in the study.

No evidence whatever of shock damage was found in any collision. Hence it is concluded that shock values in collision are less than those to which merchant ship foundations and mountings are normally designed (~2 g). Additionally, testimony of personnel involved in collisions of the most rigid ships (battleships) revealed that no shock could be felt as the vessels collided. Since personnel are often thrown off their feet in a seaway, this testimony indicates that the upsetting forces are even less than those encountered in severe roll, pitch, and heave (~0.6 g). Further substantiation obtained by analytical methods indicated even lower accelerations. Since all nuclear components on the NS Savannah are estimated to be capable of withstanding shock loadings of approximately 1 g without primary system rupture, it is concluded that the NS Savannah's power plant will not sustain shock damage in any conceivable collision. This shock resistance eliminates any possibility of nuclear component damage when the NS Savannah is the striking vessel since penetration is not a problem in this case.

The mechanisms of penetration in collision were also investigated. It was found that a good correlation exists between the kinetic energies of the colliding vessels and the structural damage incurred. The principal components contributing to collision resistance were identified as decks and transverse bulkheads on the struck ship, and the decks, longitudinal bulkheads, and angular components of the shell on the striking ship. Therefore, on a given ship, the decks are the main collision barrier.

From the relationship of kinetic energy and collision damage, it is possible to predict, with a considerable degree of accuracy, the depth of penetration resulting from a collision of any two vessels. The depth of penetration that the NS Savannah would experience in a hypothetical collision with another vessel can, therefore, be predicted; and within limits, the ship's structure can be designed to withstand effects of a collision of any given magnitude.

The limit of penetration without reactor system damage is assumed to be the reactor compartment longitudinal bulkhead. The deck scantlings of the NS Savannah are increased above those of conventional ships to the extent that only about 0.7% of the world's merchant fleet (approximately 300 ships) could penetrate to this bulkhead.

The probability of a collision in which penetration beyond the reactor compartment longitudinal bulkhead would occur has been evaluated for the NS Savannah. The calculated value of this probability is about $7 \times 10^{-5}$, or, within the limits of accuracy of this data, between $10^{-4}$ and $10^{-5}$. This figure is believed to be conservative and is actually closer to $10^{-5}$. A probability of one in 100,000 over a 20-year life compares favorably with the high range of values given in a study by the AEC for the release of substantial amounts of fission products outside containment. The highest probability for such an accident quoted in this report was $10^{-5}$ per reactor-year. Over a 20-year period this value would be $2 \times 10^{-4}$, or essentially a factor of 10 higher than that which is considered the best value for a similar accident involving the NS Savannah.

In estimating the probability of a dangerous collision, it was found that accidents involving passenger ships take place most frequently within approach areas. An approach area, defined as extending from the principal seamark at the harbor entrance to the point of departure 100 miles from the nearest land, is characterized by the merging of sea lanes at harbor approaches, heavy traffic, and relatively high ship speeds. Therefore, since the area of highest collision probably extends out to 100 miles at sea, the exposure risk of the general population is less than that for most land-based reactors.

Very few collisions are recorded involving passenger ships in harbors, and none are included in the statistical sample used to develop the probability data. In the rare event of a harbor collision, the very low speeds used would preclude penetration of the reactor compartment.

The findings of the collision studies are summarized as follows:

1. Collision offers no danger of shock damage to the reactor components.

2. Containment rupture resulting from collision in a harbor is practically impossible.

3. Collisions involving containment rupture are limited to areas outside harbors. The probability of such an event over the life of the ship is very low, in the order of $10^{-5}$. This figure compares favorably with values given by the AEC for an uncontained release from shore-based reactor plants. Additionally, since the area of greatest danger extends to 100 miles at sea, the degree of probable isolation is greater than that for any shore-based power reactor.

Therefore, it is concluded that the NS Savannah can be operated anywhere in the world with little fear of a dangerous release of radioactive material as a result of collision.

## 12.4. Grounding

The effects of grounding are similar to those of collision, because crushing of the ship's structure and shock may be expected. In all sever cases of grounding, extensive crushing of structures held accelerations to very low levels, indicating that shock in grounding is of little concern from the standpoint of reactor safety.

The damage sustained in grounding is strongly dependent upon the state of the sea and the type of bottom on which the grounding takes place. In harbors or sheltered waters, structural damage is generally limited to that incurred in initial contact and the ship has little tendency to work. The majority of these groundings are bow-on or stern-on and would not normally involve the reactor compartment. Damage to the inner bottom near the reactor compartment could result from certain infrequent harbor groundings. Release of the low-level, liquid wastes stored in the inner bottom tanks is conceivable in these cases; however, the low level of activity of the wastes will have limited the hazard to the general public. The probability of even a very limited release of low-level waste is considered negligible.

On very rare occasions ships have been known to lie over on one side upon grounding or upon sinking in shallow water. This heeling action occurs over a relatively large period of time, making shutdown of the plant possible. The reactor primary system and other vital auxiliaries are sufficiently braced to prevent dislocation of components should this occur. No failure of primary system or containment can result from the ship resting on its side.

Grounding in unprotected waters results in more extensive damage because of the working of the ship by the action of the sea. In the worst case, the ship may pivot about the point of contact and eventually break up. Such breaks will not occur in way of the NS Savannah's reactor containment, because of the deliberately designed discontinuities in the hull girder forward and aft of the reactor compartment. This has been modified to some degree in the case of the hull girder forward of the reactor compartment by the reinforcement of the port and starboard sides of A-deck in the way of hold hatches 3 and 4 with continuous longitudinal and transverse intercostal girders.

However, calculations for the ship's strength in the way of the reactor compartment as compared with hold 4 indicate that the structure in the way of the reactor compartment is still considerably stronger against bending in a vertical plane than the structure forward of the reactor compartment. It is particularly stronger in the bottom section modulus, which indicates that the ship could sustain substantially higher secondary stresses from hydrostatic loads or grounding concentrations in the way of the reactor space. Calculations for bending in a horizontal plane indicate that the section through the reactor compartment is about 22% stronger than the section through hold 4 after reinforcement.

Once the reactor compartment section has broken free of the water-borne sections or after the water-borne sections have sunk, the relatively short containment vessel, with its great strength and weight, will have little tendency to move under wave action, and structural damage will be greatly diminished. Under these conditions, release of low-level wastes and loss of demineralizers and other equipment outside of the containment must be assumed. The demineralizers are small, heavy, and well protected, and therefore are unlikely to release their resins to the sea. The small radioactive inventory in the waste tanks is not considered a source of danger to the environment because areas in which such groundings can occur are fairly remote.

Ship grounding occurs much less frequently than collision. Cargo ships in a liner-berth type service usually call upon well-charted ports, and their officers and pilots are generally well aware of the local hazards. As a cargo ship in this type of service, the NS Savannah is much less likely to be grounded than vessels in other types of service.

## 12.5. Heavy Weather

Under heavy weather conditions, the NS Savannah is exposed to the most severe loadings on equipment foundations and structures. Since accelerations in collision and grounding are much less than those imposed by roll, pitch and heave, the design of the NS Savannah was dictated by the heavy weather considerations.

Although considerable data have been compiled on roll, pitch and heave in moderate-to-very rough seas, only spot reports are available for extreme conditions. Since extreme conditions occur at rather rare intervals, long periods of careful measurement at sea are required to obtain an adequate statistical sample. Therefore, maximum accelerations under extreme conditions cannot be defined at present.

For many years, it has been the practice to design merchant ships to severe conditions (less than extreme), with relatively high safety factors. The soundness of this approach is evidenced by years of experience in which ordinary merchant ships have survived hurricane seas without damage.

In September 1964 and in February 1965, the NS Savannah encountered severe storms at sea. After the latter storm, buckling of A-deck in the way of hatch 4 on both port and starboard sides was quite apparent. As a result of investigation, data collection, and calculations, it was concluded that the hull had ample strength reserves against static forces arising from bending on standard waves. However, the buckled deck was produced by overstressing under sagging compression after initial deflection from other causes. These ship motions occurred in heavy and confused seas, while in a light ship condition.

The A-deck was reinforced during the NS Savannah's 1965 Galveston Outage to provide greater resistance to buckling of the deck plating under sagging compression, so that the resulting stresses will be axial with respect to the plating. Calculations show the deck stresses are well below generally acceptable values. The longitudinal girders provide assurance that the plating will remain in position to absorb these compressive stresses without additional bending stresses due to deflections. The reinforcement is considered adequate to minimize the possibility of a future recurrence of the deck buckling.

The NS Savannah propulsion machinery was designed with the following specifications for roll, pitch, and heave.

1. Maximum roll 30 degrees from the vertical, with periods of 13 and 23 seconds (center of roll 20 to 30 feet above the baseline) in light and loaded conditions.
2. Pitch and heave - maximum pitch amplitude of 7 degrees combined pitch and heave accelerations, 0.25 to 0.30 g at the reactor.

These criteria represent very severe conditions, and in no case will they be exceeded by a factor as great as two. Ship motion can be sharply reduced by changing course and speed in heavy seas. The ship's stabilizers can also be used to control the ship's motion.

The safety factors employed in the design of the NS Savannah are considered adequate, and it is estimated that all her components can withstand accelerations of at least 1 g, and in most cases 2 g. Since the maximum loading (static plus dynamic) defined by the design criteria is about 0.6 g (roll), the margin is fully adequate for maximum sea conditions. No damage to machinery components from ship motion has resulted in previous storms or is expected under any sea condition.

## 12.6. Fire and Explosion

The NS Savannah has been designed to the highest standards of fire protection; the fire protection systems are capable of protecting the ship from the most severe fire hazards.

Three fire pumps are installed—two in the machinery space and one in the shaft alley. The shaft alley fire pump is connected to the emergency switchboard, assuring electric power even if the machinery area is damaged. The carbon dioxide smothering system can protect the largest compartment on the ship. There are three independent fire detection systems in addition to the manual detection and alarm systems.

Fire from an external source is not considered a threat. External explosions present only a missile hazard, and the reactor and containment are well protected by the ship's structure and the reactor's shielding. The possibility of internal fire and explosions is minimized since the NS Savannah will not carry dangerous cargo during experimental commercial operation. The chief threats posed by internal fires are loss of power and damage to shielding, containment, and vital reactor equipment. The possibility of fire within the containment vessel has been virtually eliminated by minimizing the use of combustible material and limiting the oxygen available in the closed vessel. However, a carbon dioxide extinguishing system is installed in both the containment and the reactor compartment to limit damage should a fire develop. Although a fire in the reactor compartment could cause shielding damage, partial loss of shielding is not crippling since reduced power and/or establishment of exclusion areas would permit continued operation. The major source of machinery space fires has been eliminated aboard the NS Savannah because there is no main propulsion boiler nor associated fuel oil systems.

The NS Savannah's firefighting systems are believed capable of extinguishing any fire that might occur. Damage to the reactor system should be negligible and, in general, limited to shielding. Hence fire is not considered a threat to nuclear safety.

## 12.7. Flooding and Sinking

Loss of decay heat removal capacity caused by complete loss of electric power is the major problem in flooding and sinking. Flooding without sinking is of little concern since power for decay heat removal is available from the emergency generator on the navigation bridge deck. In sinking, it is assumed that decay heat removal will be interrupted, resulting in at least partial core meltdown and fission product contamination of the containment vessel.

Preservation of containment in sinking is assured by flooding manways (located in the containment shell) which open automatically when the ship submerges in deep water. When the pressures are equalized inside and outside the containment vessel, the manways close automatically, sealing the vessel. This protects the containment shell against external pressures in deep sinking.

## 12.8. Salvage

Salvage methods depend on the depth of the water since operational difficulties increase with depth. In less than 300 feet of water, almost complete control of the containment is possible. Salvage connections, sized to take a standard U.S. Navy diver's hose, are located on the head of the containment shell cupola. These connections permit sampling and purging of the containment contents. If permanent immobilization is required, the same connections can be used to fill the vessel with concrete.

If sinking occurs in water less than 100 feet deep, the ship and the containment may be raised and salvaged. At these depths the containment is flooded with salt water. Under extreme diving conditions, which limit underwater salvage, the ship's structure could be removed from the containment vessel and the containment raised by tidal lift.

Below 300 feet, the ship is inaccessible to salvage. The flooded containment vessel is a very effective waste disposal package. With the low corrosion rates in deep water, it will take many years for the sea water to penetrate the containment shell. Most of the fission products will be contained within the massive primary system, and the probability of environmental contamination is negligible.

The methods of immobilization and recovery used to salvage the sunken vessel can also be used to salvage the grounded vessel. The accessibility of the grounded vessel, however, will generally simplify the operation.

In conclusion, little or no hazard to the environment is anticipated from either the sunken or the grounded ship.