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ON NUCLEAR POWER AND ITS FUEL CYCLE

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Nuclear Merchant Ship Propulsion

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1. INTRODUCTION

The first nuclear powered ship, the submarine NS NAUTILUS was launched by the United States in 1954. Since then, more than 25o nuclear powered submarines and surface warships have been put into service by the United States, the Soviet Union, Great Britain and France. Today there are more reactors operating aboard ships than in nuclear powered stations.

The first application of nuclear propulsion for non-military purposes was already made more than twenty years ago, however, until now only five ships have been brought into service.

Table 1. Civil nuclear ships

name and country	use	period of construction	gross tonnage (GRT)	total displacement (t)	capacity (tonnes deadweight) (tdw)	service speed (knots)	thermal reactor (MW)	propulsive power (shp)
NS LENIN UdSSR	ice breaker	Aug.56 -Sept.59 rebuilt 1966-70		16000		18	3x90, after re-building 2x90	44000
NS ARKTIKA UdSSR	ice breaker	- 1974		19300/ 23460				75000
NS SAVANNAH USA	freighter and passenger vessel	May 58 -May 62	15585	22170	9400	20	74	22000
NS MUTSU JAPAN	research and freight vessel	Nov.68 -1973	8350	10400	2400	16,5	36	10000
NS OTTO HAHN FRG	research and bulk freight vessel	Sep.63 -Dec.68	16870	25790	14040	15,75	38	10000

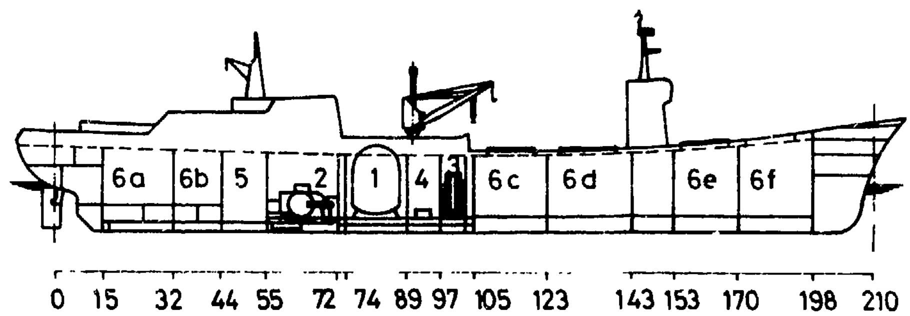
The ice breaker NS LENIN originally equipped with three reactors has been reconstructed in 1966-70 and is now powered by two modern pressurized water reactors. The operational experience has been reported as excellent.

The NS ARKTIKA is the flagship of a new generation of Soviet ice breakers. The next ship, the NS SIBIR is presently under construction.

The NS SAVANNAH has been in service for eight years and travelled 477,ooo sea miles. After having successfully demonstrated her feasibility she was decommissioned in 1970.

The reactor of the NS MUTSU reached criticality for the first time in 1974. An underdesign of the reactorshielding, however, is still delaying further trials, and the ship is not yet operating.

The NS OTTO HAHN (Fig. 1) is the first nuclear propelled vessel with a pressurized water reactor of the integrated type. The reactor with a thermal power output of 38 MW produces 11,ooo shp, developing a ship's speed of approx. 17 knots.



1.... Reactor plant
2.... Machinery plant
3.... Spent fuel pool
4.... Auxiliary systems
5.... Auxiliary boiler
6.... Cargo holds

Main dimensions		
Length	(O.A.)	171.80 METER
Length	(B.P.)	157.00 Meter
Beam	(MLD)	23.40 METER
Draught	(MLD)	9.20 METER

Fig. 1: NS OTTO HAHN, general arrangement

The ship is designed as ore carrier and classified as reactor and passenger vessel. The six cargo holds have a total capacity of more than 13,ooo m^3. NS OTTO HAHN is subdivided by 13 transverse bulkheads into 14 watertight compartments to meet the two-compartment standard.

From commissioning in 1968 NS OTTO HAHN has been now in service for almost nine years. During this time the ship has covered a total of approx. 470,ooo nauticalmiles carrying 630,ooo tons of cargo during more than 1oo voyages. Before starting the commercial phase a comprehensive test and research program has been performed. Ship and reactor plant have been tested under extreme sea and weather conditions showing the sea worthiness and reliability of the ship and its nuclear propulsion plant. The operational experience is excellent. The availability of the plant at sea during the commercial operation phase was nearly 100 %. Fig. 2 shows the power history for 1975 resulting in an availability of 93 % for 1975.

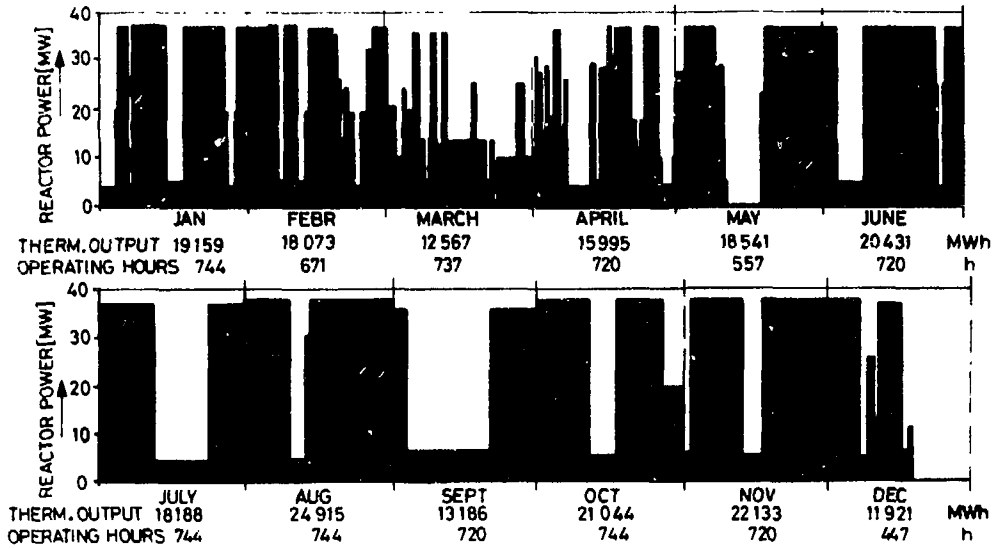


Fig. 2 N.S. OTTO HAHN, POWER HISTORY 1975

A more detailed power history in restricted waters entering a harbour is shown in Fig. 3 for the port entry of Hamburg.

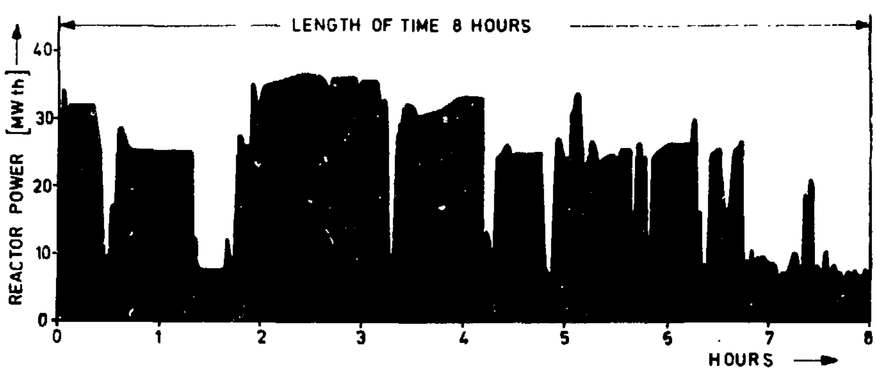


Fig. 3 N.S. OTTO HAHN, PORT ENTRY HAMBURG

2. TECHNOLOGY OF NUCLEAR PROPULSION

2.1 Design requirements

The design of nuclear propelled merchant vessels bases on well-known ship building techniques and proven light-water reactor technology. The main problems arise from the specific marine environment for the reactor plant, ship safety aspects and from the integration of ship and reactor.

2.1.1 Marine Environment

In contrast to land based nuclear plantsthe ship and its power plant are exposed to additional accelerations and inclinations induced by sea motions. Design values for additional accelerations and inclinations depend on type of vessel and location of the reactor on board. Typical values for containerships are in the range of up to 0,7 g, respectively up to 30°.

2.1.2 Ship safety aspects

A special collision barrier and grounding protection structure in the reactor area protect the reactor and the safety related components against mechanical damages by collisions or grounding. Nuclear ships fulfill the two-compartment standard. Any two adjacent compartments can be flooded without loss of stability or buoyance. Sufficient ship stability under all loading conditions in case of intact and damages vessel has to be provided to avoid capsizing. In spite of all safety measures sinking of a vessel can not be absolutely excluded. Therefore, flood openings in the safety enclosure are provided to avoid a collapse by outer pressure and to maintain enclosure of activity. The highest fire protection standard is required. Pressure waves as consequence of deflagrations must not impair the integrity of the reactor's safety enclosure or the ship's body.

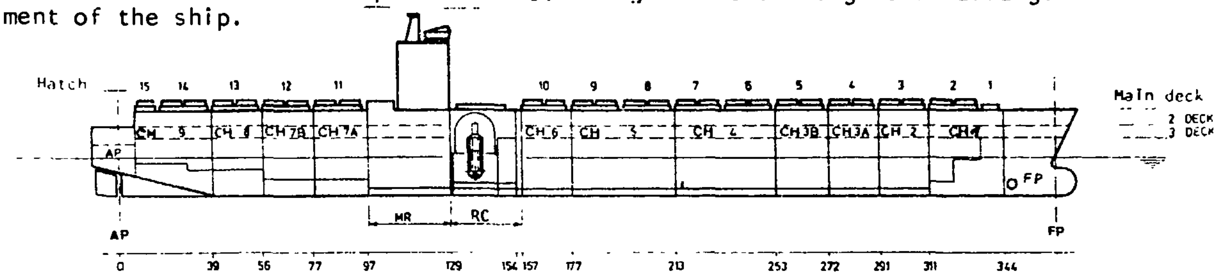
2.1.3 Integration of ship and reactor

For the installation and operation of nuclear propulsion plants aboard ships specific conditions have to be considered:

Vibrations:	Each ship is exposed to vibrations excited by sea motions, oscillating propeller forces and auxiliaries.
Foundation:	Interactions between ship and reactor plant must be taken into account for the arrangement of the reactor components.
Space and weight:	The limited space aboard ship requires a compact reactor design. The localized heavy weight of a reactor effects longitudinal strength, trim and stability.
Isolated operation:	The power plant aboard ship is an isolated system without possibilities of outside energy supply in case of emergency.
Load following:	Due to manoeuvering requirements a high (up to 4%/sec) load following capability is necessary for ship reactors.

2.2 Design of an advanced nuclear ship (NCS-80)

In the Federal Republic of Germany the design of a nuclear propelled container vessel has been completed in 1976. Fig. 4 shows the general arrangement of the ship.



Main dimensions

Length	(O.A.)	289.54 METER
Length	(B.P.)	275.54 METER
Beam	(MLD)	32.24 METER
Depth	(MLD)	25.00 METER
Draught	(MLD)	11.00 METER

AP.... After peak
FP.... Fore peak
MR.... machinery room
RC.... Reactor compartment
CH.... Cargo hold
AP.... After perpendicular
FP.... Fore perpendicular

Fig. 4: NCS-80, general arrangement

The large freeboard gives extra buoyancy and a stability range up to a theoretical heel of 90°. The hull structure consists of an all-welded double shell construction, forming wing spaces from the tank top up to the main deck. The double bottom runs from aft to collision bulkhead forward. Additional strength problems arise for the open container ship in connection with the locally concentrated reactor weight, but have been solved satisfactorily. A good manoeuvrability is an essential safety factor. In addition to the two main propellers a bow thruster of 1,5oo shp increases the manoeuvrability at reduced speeds in narrow waters. For an emergency propulsion an electric motor can be coupled to the gear box of each propeller shaft. This system has a power output of 1,5oo kW electrical, sufficient for a ship speed of approximately 6 knots. The nuclear reactor EFDR-80 is an advanced design of the FDR-reactor of NS OTTO HAHN and has a thermal output of 220 MW. Fig. 5 shows the arrangement of the reactor in the ship.

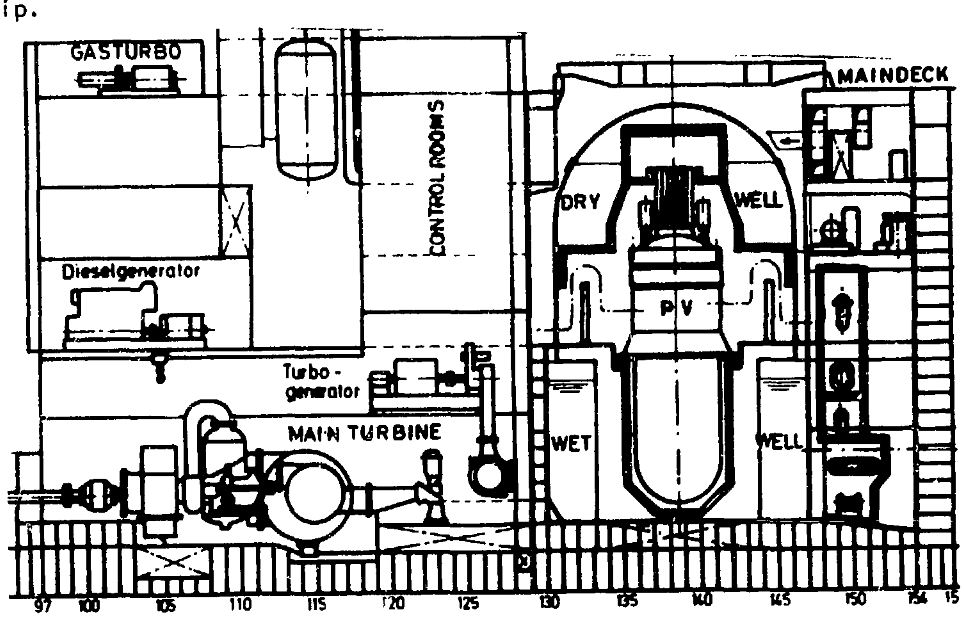


Fig. 5: NCS-80, Reactor and Machinery Space

The pressure vessel contains core, control rod drives, primary coolant pumps and the steam generator. Pumps and control rod drives are mounted on the top closure of the pressure vessel. The primary coolant pressure is maintained by self-pressurization by means of saturated steam above the freewater surface within the pressure vessel.

Thus, with exception of the primary purification system, all essential components usually in contact with primary water are contained within the pressure vessel. This means a particularly safe and compact construction. Ship and reactor fulfill all the above mentioned design requirements. The licensability of the concept has been approved by the licensing authorities of the Federal Republic of Germany.

3. ECONOMIC ASPECTS

For naval vessels and special civil ships, like ice breakers, ligistic considerations play an important role and favour base independent nuclear propulsion strongly. For merchant ships, like container ships, bulk carriers and tankers, economic factors are of utmost importance.

As in case of land-based nuclear power stations the potential economic advantage of nuclear ships results from the lower costs for the nuclear fuel cycle. For example, for NCS-80 with a 2-zone reshuffling core the nuclear fuel cycle costs amount to approximately 8 mill/shph which is about one half of the equivalent costs for conventional propulsion.

On the other hand, the investment costs for nuclear propelled ships are higher than for equivalent but conventionally powered ships. For the first nuclear container ship of the design described above the investment costs excl. interest and escalation during construction have been estimated to be about twice as high as for a comparable conventional unit.

The biggest parts of the additional investment result from the nuclear steam supply system, engineering and construction management services and electric plant equipment. Auxiliary systems, safety containment and shielding add substantial amounts. The high investment costs for NCS-80 contain typical first-of-its-kind costs and would be significantly reduced in case of series production.

Considering overall transportation costs, the higher investment costs for nuclear ships have to be more than offset by the lower fuel costs because the other operating costs for a nuclear ship are somewhat higher than for a conventional unit. Influencing factors are the increased costs for insurance for nuclear third party liability, slightly higher crew costs and additional costs for repair, maintenance, inspection and the fuel element reloading procedure.

For the prototype nuclear containership economic competitioness could not be expected. Whether future ships of this type if built in series are economically superior is not yet certain, although a detailed design and price estimates are now available and in spite of the large know-how gathered during the project phase. The main reasons are the uncertainties in the investment costs for future units and the today hardly predictable development of conventional as well as nuclear fuel costs. It has also to be taken into account that until now only limited efforts have been made to optimize a nuclear transport system and to exploit the full potential of nuclear propulsion.