NUCLEAR SHIPS AND THEIR SAFETY

Ships propelled by atomic power are no longer a distant dream. Their technical feasibility has already been demonstrated and a number of projects are rapidly taking shape. The developments that can be expected in the coming years will be of far-reaching consequence to the economics and technology of merchant shipping and give rise to peculiar problems in regard to safety.

It is not enough to seek solutions to these problems from the standpoint of an individual technical or industrial group, or even that of a nation; the whole subject needs a detailed review at the widest international level. Shipping itself is essentially an international operation and the hazards that it may entail are seldom of a purely national or even regional character. This is particularly true of nuclear shipping in view of the special hazards associated with all nuclear operations.

Several aspects of nuclear ship propulsion, with special reference to nuclear safety, were discussed at an international symposium at Taormina, Italy, from 14-18 November 1960. About 175 scientific, administrative and legal experts from 19 countries and six international organizations participated in the meeting, which was held by the International Atomic Energy Agency in co-operation with the Inter-Governmental Maritime Consultative Organization. Some 40 papers were presented and discussed on a number of specific topics grouped under the following headings: Economics and National Activities in Nuclear Ship Propulsion; International Problems and General Aspects of Safety for Nuclear Ships; Nuclear Ship Projects from the Angle of Safety; Ship Reactor Problems; Sea Motion and Hull Problems; Maintenance and Refuelling Problems; and Safety Aspects of Nuclear Ship Operation.

Opening the symposium, H. de Laboulaye, IAEA's Deputy Director General in charge of Technical Operations, pointed out that the first civilian nuclear ship - the Soviet icebreaker "Lenin" - was already on active duty, the first nuclear merchant ship - the "Savannah" of the USA - had been launched a few months ago and these two were expected to be followed by several other prototype nuclear ships. Even if the number of nuclear ships actually sailing in the course of the next few years were very limited, several questions must be settled without delay. Among the particular problems to be discussed at the Taormina symposium were safety of reactor operation in a ship, especially in relation to ship movements, the handling of highly radioactive nuclear fuels, storing or disposal of wastes in the course of ship operation, and possible contamination of the sea and estuaries in the case of accidents. Mr. de Laboulaye said that perhaps the symposium would "make it possible to establish certain criteria defining the degree of safety for nuclear ships both in their construction stage and when they become operational".

In another opening address, B. Focaccia, Vice-President of the Italian Committee for Nuclear Energy, called for increased efforts to make nuclear shipping competitive with conventional modes of propulsion, despite the present difficulties which characterize all experimental phases of technology. He called attention to the special advantages of nuclear ships, particularly their enormous autonomy and high cruising speed.

Economic Considerations

The rate at which nuclear ship propulsion will develop will naturally depend to a large extent on its economic competitiveness. It was, however, pointed out at the Taormina symposium that in the absence of operational data the economic calculations were bound to be theoretical and tentative. A number of paper studies had been made but it was doubtful if such studies could further advance an understanding of the present position or of the problems to be solved. True, some data were available on the operation of land based reactors; it was also true that the development of low cost reactors would contribute to the economic competitiveness of nuclear shipping. But as E. Norton (UK) explained in a paper on the economic aspects, the problems to be worked out were not confined to the provision of a suitable low cost reactor. This point was also emphasized by J. J. Zamparo (Italy) who said: "The simple substitution of a reactor plant for the conventional power plant never results in a financial advantage for nuclear propulsion. An economic progress will be made only when nuclear plants are installed in ships especially designed for the characteristics of the nuclear reactor considered."

Mr. Zamparo presented a comparative economic analysis of the various cost estimates for conventional and nuclear ships. Referring to published estimates for nuclear tankers, he reported that "the gap between conventional and nuclear propulsion has been narrowed substantially by utilizing a direct cycle natural circulation boiling water reactor propulsion system." Speaking generally about the present estimates, he pointed out that "marine nuclear plants are now incorporating a considerable degree of over-design" and the relevant reactor cost would be the one reached "only after a number of identical power plants have been built, so that the safety factors may be lessened

Soviet icebreaker LENIN

and the construction cost reduced through the production of multiple units."

What is therefore essential is to acquire the necessary experience in the design, construction and operation of nuclear ships. The accumulation of this experience will take some years and require money and planned effort, but a balanced program of practical endeavor in the actual building and operation of nuclear ships is as indispensable as research and development aimed at low cost reactors. In the initial stages, some government participation may be necessary in view of the large investment required, but it was pointed out at the symposium that all major technical advances are accompanied by a process of cost reduction and there is no reason to believe that this will not take place in marine reactor technology.

National Programs

It is encouraging that recognition of this need for actual experience is reflected in a number of projects which have been initiated in different countries. Some of these projects consist of preliminary technical studies, but in some cases they incorporate elements of more advanced research and development.

A survey of nuclear ship propulsion activities in Western Europe was recently made by the European Nuclear Energy Agency (ENEA) of the Organization for European Economic Co-operation (OEEC), and the results of the survey were briefly described at the Taormina symposium by L. W. Boxer of the OEEC. Some of the highlights of the survey are:

Belgium - 30 firms are jointly financing the study of a high pressure heavy water reactor suitable for either marine or land-based application. Another working group is simultaneously studying the type of vessel that would be suitable for such a reactor.

Denmark - Danatom, a group of Danish industrial enterprises interested in atomic energy applications, has concluded a three-year study of the economics and technology of a pressurized water reactor system for marine propulsion as compared with two conventional systems in a tanker of given size and power.

France - From three proposals received as a result of a design competition, the French Atomic Energy Commission has selected a system based on a gas cooled, graphite moderated, enriched uranium reactor for a research and development program. The design of a land based prototype reactor with these characteristics is well advanced.

Germany - Several studies by German companies are under way with the support of the Federal German Atomic Ministry. A joint German-American company, Interatom, is working on the design of an organic moderated reactor for marine purposes. A research and development program is also under way and a decision on the construction of the country's first nuclear ship will be based on the outcome of this program.

Italy - A joint research and development program, started by Fiat and Ansaldo, is aimed at developing different methods for the use in merchant ships of reactors cooled and moderated by light water.

Netherlands - The first nuclear propulsion studies in the Netherlands were made by industry. It is now intended to start a three-year research and development program under the joint auspices of Reactor Centrum Nederland, private interests and the universities. The program will concentrate on pressurized water reactors.

Norway - An association of Norwegian shipowners (Rederiatom) has financed the study of a light boiling water reactor for a tanker. The Norwegian Institutt for Atomenergi intends to adopt the results of this study as the basis of its own research and development program.

Sweden - Several reactor types have been studied as to their suitability for marine propulsion. These include the organic moderated, the high temperature gas cooled, and the boiling water systems. No research and development program has, however, begun.

United Kingdom - Many studies have been made by government-sponsored organizations as well as by private industry. In addition to the reactor types currently considered suitable for marine propulsion, a new concept has been investigated, namely the steam cooled, heavy water moderated reactor. The British Ministry of Transport has invited tenders from industry for nuclear propulsion units based on the organic moderated and the indirect cycle light boiling water reactors.

Papers by Japanese authors discussed the studies and research taking place in Japan. M. Yamagata of the Japanese Nuclear Power Ship Research Association said that both government and private organizations were carrying out intensive preparatory studies. He also disclosed that the Japanese Atomic Energy Research Institute had made a contract with the General Electric Company for the construction of a

10 MW power reactor of the boiling water type for demonstration purposes.

The Savannah

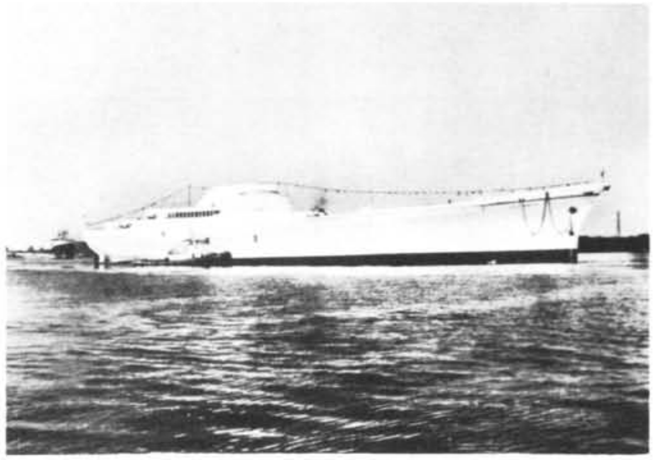
The United States project for the construction of the Savannah, the first nuclear merchant ship in the world, naturally received special attention at the symposium and several papers dealt with various aspects of the project.

W.C. Ford (USA) told the meeting that the project now had entered its operational phase as the start-up tests had begun in May 1960. These tests include six phases: (i) component tests to determine the adequacy of the machinery, installations and instrumentation; (ii) system and component tests under simulated operating conditions prior to fuel loading; (iii) the actual fuelling and zero power physics measurements; (iv) power operation at the dockside (the power to be progressively increased to 40 per cent of capacity); (v) sea trials for endurance and testing of emergency power systems, progressive speeds, manoevering and machinery; and finally (vi) extended sea trials involving long, arduous endurance tests, reactor core studies, evaluation of the maintenance and operation procedures and staff training.

The author pointed out that no amount of research and development as normally understood would get round the difficulty and expense of having to build the first nuclear ship, the testing of which really must be regarded as part of the development program. Only after the initial expenditure in facilities and equipment had been written off, could a country look to nuclear ships that could in fact compete with the conventional ones.

The problem of initial cost was also mentioned in the paper on the ENEA survey presented by L.W. Boxer, who suggested that it might be a good idea to have a multi-national project so as to reduce the cost to be borne by individual States. In the case of ENEA, such a project could be sponsored by its maritime Member States and would be comparable with other multi-national projects launched by ENEA, such as the "Dragon" project. The construction of a European ship would also facilitate the establishment of a common policy for the acceptance of nuclear ships in European ports.

In describing the Savannah project, special emphasis was laid on its safety aspects. C.K. Beck (USA) described the pressurized water system chosen for the Savannah reactor as inherently the most stable and proven in US experience. The control system had been designed on a conservative basis and alternate and emergency power sources had been provided. All radioactive wastes from the reactor would be contained and there would be no discharge during normal operations. An extensive monitoring system had been established and the reactor core had been provided with double containers. Special protection against collisions had been introduced. Giving further details, Mr. Beck said that the same conservatism



US nuclear ship SAVANNAH

had been applied in all aspects of construction work and formulation of operational procedures.

Discussing the problems of refuelling and the disposal of wastes in connection with the Savannah, D.F. Bollender (USA) pointed out that the core of the Savannah reactor had been designed for a life of three-and-a-half years but it was planned to exchange it after 18 months so as to gain experience. The refuelling involved tricky technical problems; in one operation, for instance, it would be necessary to lift the head and control rod mechanisms out of the reactor and the weight involved amounted to 75 tons. All wastes, liquid and solid, would be contained until the ship returned to its base where they would be transferred to a specially constructed service barge. The liquid wastes would be processed on board the barge and the solid wastes would be contained in a spent fuel pit and later transferred to processing plants for disposal.

C.P. Murphy (USA) said that the Savannah was ready to comply with all the provisions of the Convention on Safety of Life at Sea which had been revised in London in May 1960 and now contained a special chapter on nuclear ships. Whenever the Savannah would request entry into a port it would submit to the competent authorities a very detailed safety assessment document so as to enable an independent evaluation to be made. It might sometimes be necessary for the authorities to request outside consultation by individual experts of ship classification societies. He suggested that IAEA and IMCO might be kept informed of all decisions taken so that an international register could be established and made available to all interested authorities.

Safety Aspects of Reactor Systems

A number of reactor systems that might be suitable for marine propulsion were discussed at the symposium, with particular reference to their safety aspects.

The Ansaldo-Fiat nuclear ship project was described in a paper by L. Chinaglia (Italy). The reactor chosen for this project is of the closed water cycle type, with a power capacity of 75 MW. It has already reached a high degree of development and still further improvements are possible; it has also demonstrated its safe and reliable characteristics. The studies on its possible use in a nuclear ship were started in 1957 by Fiat and soon afterwards Ansaldo joined the project. Mr. Chinaglia said that improvements in the early design would probably result from the experience of the Savannah; the United States had supplied detailed data on the Savannah project and several Ansaldo and Fiat engineers had followed the construction work at American shipyards. The proposed ship would be a 50 000-ton tanker to be operated according to normal commercial practice; it would not be a demonstration ship like the Savannah. Mr. Chinaglia said that the safety provisions in the plant designs had been made on a very conservative basis because of the absence of any operational experience, and this had been responsible for a significant part of the total estimated costs. All the safety provisions would, however, be re-evaluated so as to arrive at the safest, simplest and most economical design.

The safety aspects of marine gas cooled reactors were discussed in two papers, one from the General Electric Company (UK) and the other from General Dynamics (USA). The authors of the British paper, T. J. O'Neill and M. C. Hartnell-Bevis, gave an account of the safety aspects of a graphite moderated reactor for a 20 000 shaft horse power marine installation. The design, it was stated, is inherently stable and the steam turbine system guarantees gas flow requirements under virtually all conditions; there is a multiple shut-down system to ensure that any faults will not result in metal melting. The American project, described in a paper by W.C. Moore, is aimed at developing a high temperature reactor coupled with a closed cycle gas turbine system for marine uses.

Model, shown during the Taormina symposium, of the projected Fiat-Ansaldo nuclear tanker to be powered by a pressurized water reactor

S.G. Bauer and M.H. Kendon (UK) gave details of the safety analysis of a steam cooled marine reactor, i.e. a reactor of the pressurized tube type moderated by heavy water and cooled by dry steam. They pointed out that a safety analysis was an intrinsic part of the development of any reactor concept, but were of the opinion that there should not be any general rules that might hamper progress; each reactor must be studied as a separate project. Another paper from the UK - by W. Smith and E.A. Ryder - dealt with the control and instrumentation of an organic moderated and cooled marine reactor. The reactor system is designed to propel a 65 000-ton tanker.

A description of a marine propulsion system based on an organic moderated reactor was also given by two German experts, O. Knecht and H. Mausbeck. They discussed several types of accidents that could lead to the release of considerable quantities of radioactivity and showed how the design of the proposed 30 MW system provided for their control; they concluded that the design provided adequate safety for the application of the reactor to marine uses. Another paper from Germany, by H.J. Brüchner, contained an account of the special safety measures that must be adopted if a propulsion system based on a boiling water reactor is operated on the direct cycle; these measures would be necessary for the safety of the ship and the crew because under direct cycle operation radioactive steam is fed directly into the propulsion turbine. Mr. Brüchner said that even with the intricate and costly safety provisions, the direct cycle type would be more economical than the indirect one.

J. Wilhelmsen (Norway) discussed the response of a boiling water reactor to ship movement with special reference to what might be described as an atomic rock-'n-roll project. The project is intended to study the behavior of the marine reactor under simulated sea-going conditions, for example in rolling and pitching conditions such as are likely to occur at sea. In this experiment the reactor is contained in a floating sphere with a diameter of 24 meters which can be given the desired motion by two propellers at the bottom of the sphere. The preliminary results obtained from these rock-'n-roll studies indicate that marine conditions may significantly limit the freedom in designing the boiling water plant, and that again would influence the economic possibilities of the reactor for marine propulsion. Mr. Wilhelmsen, however, urged increased experimental work under simulated conditions so as to obtain a better understanding of the reactor behavior.

Mr. Y. Fujise (Japan) described a project for a small experimental nuclear ship reactor of the pressurized water type with a power output of 30 MW. Studies are being made with particular reference to safety features.

Some Special Problems

Certain aspects of safety in nuclear propulsion give rise to a set of technical requirements that are peculiar to a marine reactor system. For example, manoeuverability may result in sharp power variations and the propulsion plant must be designed accordingly.

Again, a special problem arises from the effects of sea motion, and research is being conducted on the external forces acting on a marine reactor in rough sea. A paper from Japan, presented by I. Uchida, described studies on these forces made on board the 10 000-ton merchant ship "Hodakasan Maru" during three long voyages. It was found, for instance, that in heaving and pitching conditions the smallest acceleration effect was near midship. Another Japanese paper described experiments aimed at devising methods to minimize the damage to a ship reactor from a collision. The experiments showed that it would be advisable to leave space between the wall of the reactor and the shell of the ship's side and to stiffen the latter with horizontal girders and traversers and increase its thickness.

Problems of reactor shielding are more important for marine units than for land based plants, not only in view of possible collisions, but also because of the fact that the operating personnel of a ship is likely to be in the vicinity of the reactor even in their leisure hours. J.C. Brown (UK) said that although there were no universally agreed standards on which to base a shield design so far, it would be appropriate to follow the recommendations of the International Commission on Radiological Protection (ICRP) for the maximum permissible radiation doses. All members of the ship's crew could be regarded as "radiation workers" for whom ICRP allows a maximum dose of 5 rems per year. Passengers on board a nuclear ship must not be exposed to more than half a rem per year, but according to Mr. Brown this would not present any great problems because the passenger accommodation would normally be kept away from the machine rooms and because it would in any case be impossible to accumulate as much as half a rem on one trip shorter than four months.

Discussing refuelling problems, R. Anscomb (UK) showed how the reactivity of a marine reactor core could be maintained over long periods by providing considerable excess reactivity from the outset. Another method would be to provide only a moderate excess reactivity coupled with refuelling facilities on board. This would mean periodic shut-downs of the rèactor at intervals of one to three months. A third method would be similar to one often used in land based reactors, that is to have facilities to replace and reshuffle fuel elements while the reactor is in operation. The advantage of this method, however, is partly offset by the accompanying engineering and operational problems.

Among the safety problems during ship operation are those of radioactive waste disposal and accidental release of radioactivity. In a paper on waste disposal problems, C. Roberts (IAEA) recalled that the International Atomic Energy Agency had already carried out an expert study of problems concerning the disposal of wastes into the sea; another expert group would consider how the techniques of oceanographic radiation monitoring could be standardized with the object of establishing uniform regulations. Mr. Roberts emphasized that the safety experience of nuclear ships, particularly in the first years, was of great importance because "the growth of adverse public opinion could quickly limit the usefulness of nuclear ships".

A paper by W.B. Cottrell and three other scientists of the Oak Ridge National Laboratory, USA, gave an account of the results of an analysis made by the laboratory of the theoretical consequences of reactor accidents that might be associated with the Savannah. Safety considerations arising from the operation of nuclear ships in ports or harbors were discussed in other papers. A paper on general safety considerations was presented by J.M. Pawlikiewicz (Poland).

Papers on the classification of nuclear ships were presented by representatives of the international classification society, Veritas, and Lloyds Register of Shipping. B. Hilldrew stated that Lloyds had formulated provisional rules concerning the classification of nuclear ships as a guidance to nuclear ship designers. He said it appeared that the reactor best suited to marine use would be one already proven on land and modified to meet the special demands imposed by marine propulsion.

H.N.E. Whiteside (IMCO) gave a report on the 1960 London conference on Safety of Life at Sea, which had adopted a number of new regulations concerning nuclear ships. Another paper from IMCO, by A. Raspi, dealt with certain legal problems in connection with nuclear shipping.

Mr. Krarup (Denmark) referred to the various rules and regulations which had been formulated or proposed and said that such rules should concentrate on laying down general principles rather than detailed procedures. He added: "The nuclear engineering of tomorrow must not be fettered by safety considerations which originate in today's lack of experience."

Summing Up

At the closing session H.N.E. Whiteside of IMCO made a brief review of the discussions at the symposium and summed up its broad conclusions. He said the discussion indicated that the nuclear tanker seemed nearest to becoming commercially operational but, even in that case, a long time must pass before it could be economically competitive with its conventional counterpart. Considerable research and development would still be necessary and experience must be gained with actual sea-going nuclear ships.

As regards safety, Mr. Whiteside said it seemed clear that marine reactors could be made safe provided certain precautions were taken. A considerable body of opinion was opposed to the introduction of detailed regulations which might hamper future development. Much attention had been devoted to the problems peculiar to different types of marine reactors. It seemed clear that optimum shielding designs had not yet been found. It had also been agreed that a nuclear ship must be able to manoeuvre at least as well as a conventional ship and a reactor type which could ensure safe manoeuverability with a minimum of auxiliary equipment was particularly desirable. Enough was not yet known about the forces acting upon a ship in bad weather, and hence about the effects of sea movements on marine reactors.

Mr. Whiteside said that the conclusions of the symposium might be summarized as follows:

Nuclear ships could be built with a sufficiently high standard of safety to make the risks involved acceptable;

It was unlikely that any nuclear merchant ship built within the next few years would be economically competitive with its conventional counterparts;

Nuclear merchant ships should nevertheless be built with a view to gaining the experience which would make it possible to build better ones;

Much of the experience required could only be obtained under sea-going conditions;

Any rules and regulations laid down at the present stage of development must be flexible and must not be such as to hinder further development;

Much had still to be done, particularly in regard to waste disposal, shielding, exposure levels, internationally acceptable construction standards and the effects of sea motion upon nuclear ships.

ATOMIC ASSISTANCE IN 1961

More than 100 experts provided by the International Atomic Energy Agency will be working in different parts of the world this year, assisting the Agency's Member States in building up their national programs of peaceful atomic development. Some of the experts are already in the field. A number of these countries will also receive from the Agency a wide variety of nuclear equipment.

This program of technical assistance is financed from two sources - the Agency's General Fund which is made up of voluntary contributions from its Member States and funds made available to the Agency under the United Nations Expanded Program of Technical Assistance (EPTA). For the part of the program to be financed out of the Agency's own funds, the Agency's Board of Governors has authorized a total expenditure of $513 100, subject to the availability of funds, i.e. adequate voluntary contributions to the General Fund.

The total allocation of EPTA funds to the Agency for the two-year period 1961-62 is $1 393 600 (of which approximately half is available in 1961), and is meant not only for the provision of experts and equipment but also for training fellowships and regional projects.

The countries which will receive Agency assistance in the form of experts and equipment this year are: Afghanistan, Argentina, Austria, Brazil, Burma, Ceylon, Chile, the Republic of China, Denmark, Greece, Guatemala, Iceland, Indonesia, Iran, Iraq, Israel, Japan, the Republic of Korea, the Republic of Mali, Mexico, Morocco, Pakistan, the Philippines, Senegal, the Sudan, Thailand, Tunisia, Turkey, the United Arab Republic, Vietnam and Yugoslavia.

The assistance is being given in response to specific requests from the Member States, and the fields in which it is needed vary from one country to another. Most branches of nuclear science and technology are covered by the program, but some of the requirements appear fairly common. The largest need seems to be for expert advice in the applications of radioisotopes in agriculture and medicine, which is understandable in the light of the basic and most urgent needs of underdeveloped economies. There is also a widespread demand for specialists in radiobiology; studies in this field are useful not only because of their relevance to agricultural and medical research but also because they are essential in devising adequate methods for radiation protection. A number of experts will be needed to formulate health physics regulations, to train personnel in radiation monitoring and dosimetry or to establish radiation protection services.

Several Member States are interested in the exploitation of indigenous reserves of nuclear raw materials and have asked for experts to assist them in prospecting or in the more advanced stages of actual production. The importance of radiochemistry is also recognized and several specialists in that field will be needed this year. Other subjects in which expert advice or practical assistance is needed include electronics, nuclear engineering, metallurgy, reactor design, and nuclear and other branches of physics.

Some details of the individual projects of technical assistance are given in the following country-wise analysis.