NUCLEAR SAFETY

PROBLEMS ASSOCIATED WITH THE RECEPTION OF NUCLEAR POWERED SHIPS IN BRITISH PORTS

BY

COMMANDER K. I. SHORT, D.S.C., R.N., A.M.I.MECH.E., A.M.I.MAR.E.
(Admiralty Nuclear Propulsion Safety Officer)

The following article is the substance of a lecture delivered by the Author to the Summer School in Health Physics (Radiation Protection) at the Imperial College of Science and Technology in July, 1961.

INTRODUCTION

The number of combinations of different types of reactor installation and different types of ship which have been proposed over the last few years is legion. While basically all such combinations can be expected to present similar problems when considering entry into ports, each will, however, have several which are peculiar to it.

In order to narrow the field, it is proposed to limit this article to a single combination—that of the Pressurized Water Reactor in a submarine. This approach has the additional merit that it deals with real rather than projected or postulated ships. We are already receiving United States Navy nuclear submarines in British ports and have had to face up to all of the problems involved.

Although the information in this article is not classified the following anecdote will serve as a reminder of the damage that can be done by quoting remarks out of context. On one occasion, in answer to a question from a Medical Officer of Health and in order to emphasize the smallness of the hazard which might exist from direct radiation, a misguided reference was made to the fact that we were working to genetic rather than lethal dose limits. This appeared in the Press, after passing through several hands, something like this, ' We are assured it is not lethal, but would merely have a genetic effect, in other words we can tolerate a future race of abnormal children in return for the benefits conferred '.

For those who may not have already seen it, attention is drawn to the ' Report of the Committee on the Safety of Nuclear Powered Merchant Ships ' published February, 1960, by Her Majesty's Stationery Office—Command 958. This Committee which was formed by the Ministry of Transport included representatives of every skill and profession which might conceivably be interested in the subject. The report makes very easy reading and it is thoroughly recommended as a basic document for the subject under discussion.

The Pattern

The pattern through which this article leads is shown in detail in FIG. 1 but only the more important features will be highlighted.

The Reactor

FIG. 2 shows a schematic diagram of a typical pressurized water reactor nuclear propulsion plant. Brief reference is made to this in order to point out some of its intrinsic safety features.

The whole system can be divided into two portions :

(*a*) The primary circuit, and
(*b*) The secondary circuit.

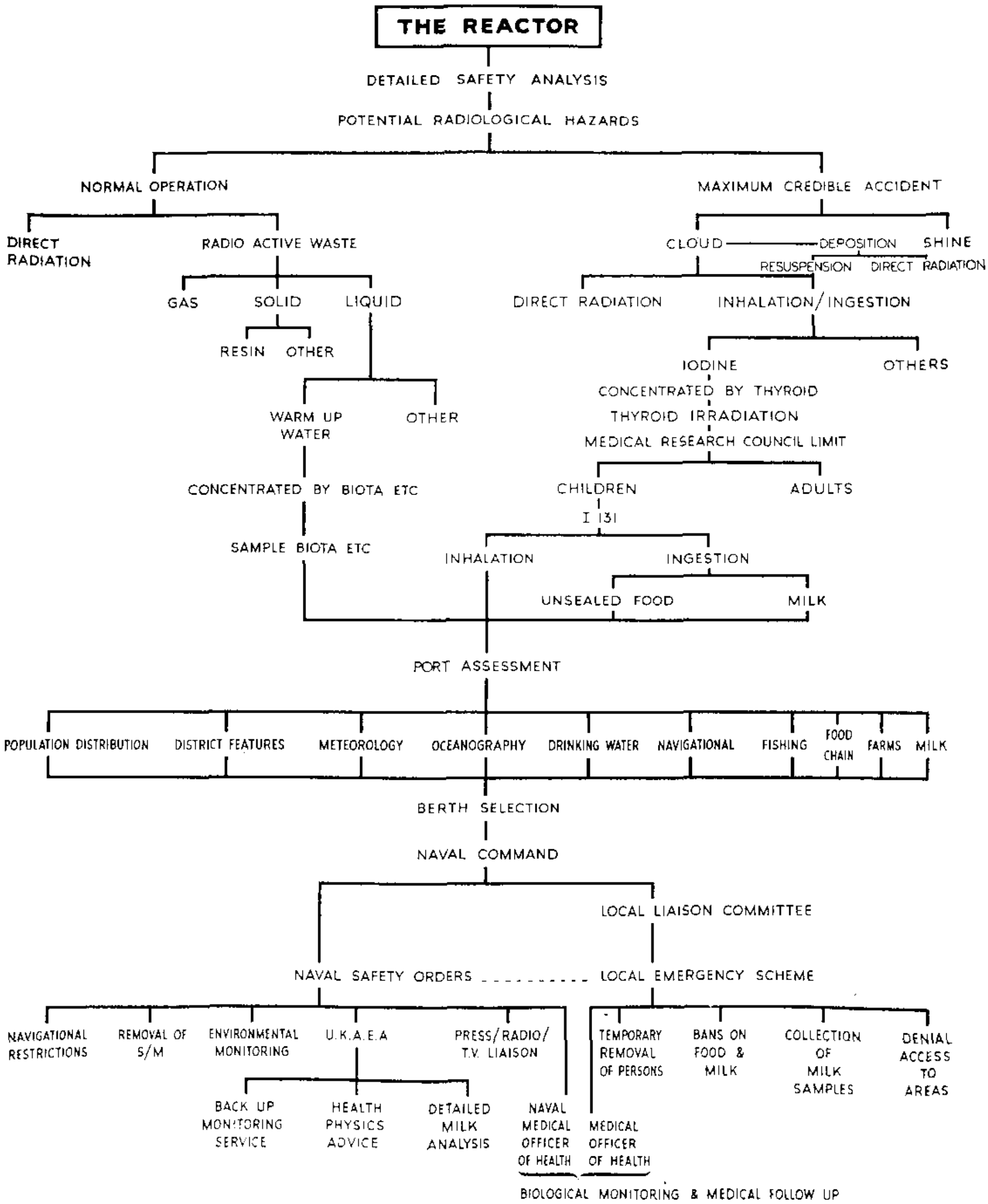

FIG. 1—THE PATTERN

Secondary Circuit

Taking the secondary circuit first, it will be seen that there is virtually a conventional steam turbine system. Water is pumped from the condenser into the steam generator, which takes the place of the boiler in a conventional system. Steam then passes to the turbine which drives the propeller or, in the case of an electric generator, drives the dynamo. After work has been extracted from it, the steam passes to the condenser where it becomes water and is ready to go round the circuit again.

The steam and water in this circuit are not radio-active so the associated piping, turbines, condenser and pumps do not require any shielding.

Primary Circuit

The primary circuit is a completely closed loop with five main elements—the

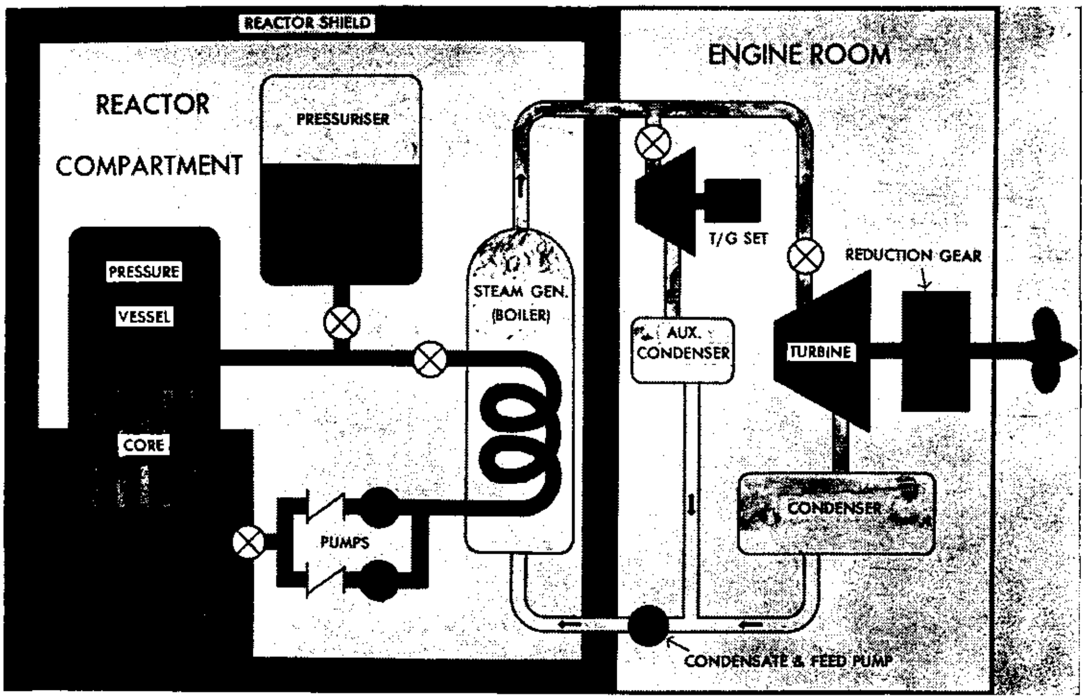

FIG. 2—SCHEMATIC DIAGRAM OF A TYPICAL PRESSURIZED WATER REACTOR NUCLEAR PROPULSION PLANT

reactor pressure vessel, the pressurizer, the steam generator, main coolant pumps and associated piping.

The first point to note is that the whole of this circuit except for the top of the pressurizer is completely filled with water.

Water is pumped by the main coolant pumps to the reactor pressure vessel which contains the enriched uranium fuel elements. The water is heated by the fission process taking place within the fuel elements and then passes to the steam generator. In the steam generator the primary coolant transfers heat to the secondary circuit and then passes back to the inlet of the main coolant pumps to start cycling the loop again.

In order that components of the secondary circuit should not be too large and in the interest of efficiency the steam must be generated at a reasonably high pressure. It follows then that the primary circuit water entering the steam generator must be at as high a temperature as is practicable.

In order to raise the temperature of the primary coolant above 212 degrees F. and avoid the formation of steam, it must be maintained at a high pressure. Hence the name Pressurized Water Reactor.

It is the function of the pressurizer to maintain this high pressure under all conditions and changes in load demand. It does so by means of a steam bubble which is maintained within narrow limits at constant pressure in its top half. If the water level in the pressurizer rises, it compresses the steam bubble and tends to increase the system pressure. Water sprays are then automatically injected into the steam bubble condensing some of the steam and restoring the operating pressure. If the water level in the pressurizer falls, the steam bubble will expand tending to decrease the system pressure. Electric heaters inside the pressurizer then cut in automatically, generate some more steam and restore the operating pressure in the system.

The whole of the primary circuit and coolant emits ionising radiation while the reactor is operating. It is, therefore, wholly enclosed within shielding.

The Reactor

The reactor consists essentially of an array of canned fuel elements immersed in water. This water has two functions : not only does it cool the fuel elements and transfer heat to the secondary circuit in the steam generator, but it also acts as the neutron moderator.

The function of the neutron moderator is to reduce the speed of the neutrons to that at which they have the best probability of being captured by the particular fuel being used. This slowing down is accomplished in the P.W.R. by the water molecules between the fuel elements. If this water is cold, there are more water molecules present in a given volume than if it is hot, so it moderates better.

Now let us see what happens in the reactor if the submarine is going along at, say, 10 knots and suddenly increases speed to 16 knots. To do this, the secondary circuit extracts more heat from the primary circuit in a given time than it was previously doing. So the primary coolant returning to the reactor is now colder—there are more water molecules between the fuel plates—moderation is improved and the reactor automatically delivers more power to meet the increased demand.

If, alternatively, the submarine had decreased speed by closing the turbine throttle the temperature of the primary coolant leaving the steam generator and entering the reactor would have increased because less heat was being extracted from it in a given time. Thus there would be fewer water molecules between the fuel plates—the neutron moderation would be less and the reactor would produce less power in concert with the reduced demand.

This self-regulating characteristic is a very important intrinsic safety feature of these reactors.

Containment

In the event of radio-activity escaping from the primary circuit, there is a natural barrier between it and the atmosphere in the shape of the submarine hull which, designed as it is to resist external water pressure at its maximum diving depth, is constructed to very high standards.

Safety Assessment

During the design of these installations a most elaborate series of safety documents and hazard assessments are prepared and reviewed. Every credible form of accident is considered in detail and its effect analysed.

Summary

This then is a very brief description of the main features of the installation with which this article is concerned. Of course, there are many other items of equipment associated with the reactor, for example, control rods, a water purifying circuit, instrumentation, interlocks, special safety devices and so forth. Some of these may be touched on as we go through the pattern but generally speaking they are of no immediate concern at this point.

Before proceeding to discuss the potential radiological hazards, the following features which have a bearing on the subject are summarized :—

(*a*) The primary circuit is specially designed and tested to eliminate all leaks. All joints are welded, the pumps have no glands, the valves are provided with special sealing caps, and so on.

(*b*) The fuel is contained inside pressure-tight cans which are themselves inside the primary circuit. The whole of the primary circuit is inside the containment which is also pressure-tight. During normal operation fission products have therefore three substantial barriers between themselves and the atmosphere. Should there be a leak in one of the cans this would show up in the primary coolant water. If small, it would be dealt with by the water treatment system—if large, the plant would be shut down. In either case, however, two of the original three barriers between fission products and the atmosphere would remain.

(*c*) The self-regulating characteristic of the system makes it virtually impossible for the reactor to run away through mal-operation or failure of some circuit or other.

(*d*) Despite the self-regulating characteristic every precaution is taken in the way of interlocks, duplication of circuits, training of operators, etc., to ensure that nothing can happen to damage the core or primary circuit.

(*e*) It should be noted that the primary coolant is NOT in contact with the fuel and can only become mildly radio-active. When warming up a cold reactor the water expands and the excess is discharged overboard through an ion exchange resin which still further reduces its radio-activity. This discharge is not harmful as will be mentioned later.

(*f*) Periodically small quantities of low activity radio-active gas collect in the pressurizer and are released underwater. They are mainly inert and are biologically insignificant.

(*g*) There is little similarity between a P.W.R. circuit and that of the Windscale pile where the well-known accident occurred. Apart from the differences in heat transfer medium and moderator, the P.W.R. has two more barriers between the fission products and the atmosphere than did Windscale.

(*h*) It is not possible for an atomic bomb type explosion to occur in these reactors.

POTENTIAL RADIOLOGICAL HAZARDS

What then are the potential radiological hazards which present us with problems when considering the entry of a nuclear submarine into a port?

Normal Operation

During normal operation there is direct radiation emitted from the reactor core. This radiation is, however, completely confined within the submarine by a system of shielding and presents no problem.

From time to time it is necessary to dispose of quantities of radio-active waste :—

(*a*) *Gaseous*

As mentioned previously, periodically the system must be de-gassed. The vented gas is of low activity, mainly inert and presents no problem.

(*b*) *Solid Waste*

There are two types of solid waste—the activated ion exchange beds and such things as filter papers, etc., from the laboratory. There is again no problem involved as either these are discharged in deep water or transferred to some other facility for disposal.

(*c*) *Liquid Waste*

There are two types of liquid waste—that discharged during warming up and samples, minor spills, etc. The former is discharged direct overboard, while the latter can be stored or discharged to some other facility.

The excess warm-up water is of relatively low activity and on discharge is immediately diluted by the water into which it is discharged.

Sea water already contains a considerable amount of radio-activity and it would be extremely difficult to measure any increase caused by very large quantities of this warm-up water. In any case the main problem is not one of examining an increase in gross activity but of examining the selective concentration of individual isotopes by fish, sea-weed, etc., which is in the food chain.

An assessment is therefore carried out for each harbour to determine its suitability for receiving this warm-up water. In practice, it has been shown that these discharges do not present any hazard or problem. In special cases samples of marine biota which have the concentrating facility are being collected and analysed from time to time as an additional measure of reassurance.

Thus under normal operating conditions no large problems are involved.

Accident Conditions

It is when we consider accident conditions that we start running into the real problems which must be considered when receiving a nuclear ship in a port.

The potential danger from a nuclear reactor arises from the fact that if its fission products are released to the atmosphere they may be carried as a ' cloud ' to areas many miles from the reactor installation and constitute a health hazard to people inhaling or ingesting them. Although every precaution is taken in designing, maintaining and operating reactors to prevent such a release from taking place, the possibility, however remote, of its happening under severe accident conditions cannot be entirely discounted.

Thus, it is prudent to face up to this possibility and plan precautionary and post-accident procedures.

The Maximum Credible Accident (M.C.A.)

In order to provide a basis for planning the concept of a maximum credible accident is introduced in design and hazard evaluation. In this expression the word ' maximum ' refers to the resultant hazard and not to the actual accident.

Thus an M.C.A. is one of possibly several credible accidents which would produce the (same) maximum hazard.

In designing it is customary to select the accident posing the most difficult design problems for detailed analysis even though the possibility of its occurring may be very remote.

In our case the M.C.A. is one which results in a severe leakage of fission products to the atmosphere. For design purposes the mechanics by which this leakage is brought about, i.e. the M.C.A. assumed, is as follows:—

(*a*) A complete fracture of one of the large primary circuit pipes—the two ends of which then bend away from each other so that flow can take place out of each of them without interference.

(*b*) Water and steam flow out of the broken pipe ends resulting in a complete loss of primary coolant from the circuit.

(*c*) A build-up of steam pressure follows within the containment.

(*d*) After a short interval the decaying fission products within the core, having lost their cooling water, produce enough heat to melt down the core.

(*e*) Fission products are released from the reactor fuel elements during the melt down and a proportion of them become dispersed within the containment outside of the reactor circuit.

(*f*) A metal/water chemical reaction takes place within the reactor making a contribution to the pressure within the containment. The time interval between the pipe fracture and this reaction is however long enough to have produced a sufficient reduction in the initial pressure, by the cooling effect of the surrounding sea water, to avoid its being exceeded by the subsequent metal/water reaction effect.

(*g*) A slow leakage of fission products is now assumed to take place from the containment to the atmosphere.

(*h*) The leaked fission products are now dispersed/carried by the wind.

(*j*) As a result of the dispersal of the fission products within the containment it becomes a source of direct gamma radiation.

Note:

Although this may seem to be rather a severe combination of events and to be straining credibility, it must be appreciated that more likely and apparently less severe combinations of events would produce hazards of orders not far removed from the M.C.A. assumed.

At this point, it should be remembered that the amount of fission products in the core will depend upon its past history, i.e., powers at which it has operated and for how long. Its inventory of relatively short lived fission products will depend upon its immediate past history.

Direct Gamma Radiation

The direct gamma radiation hazard from the hull on the basis of a two-hour exposure and a 25 rem limiting dose would be localized to an area around the submarine out to a radius of something well under 35 yards. In addition, there would be safe arcs ahead and astern enabling the submarine to be unmoored under simple health physics control.

The Cloud

The radio-active iodine component of the ' cloud ' is relatively so large from a hazard point of view compared with any or all of the other constituents that a plan which provides protection from it ensures protection from the effects of the other constituents. In addition, such a plan would also provide protection against the possibility of receiving an excessive dose of direct radiation from the ' cloud '.

The iodine hazard will arise from internal irradiation of the thyroid by radio-active iodine concentrated therein following inhalation or ingestion.

Medical Research Council

The Medical Research Council has considered the effect of ingesting iodine through the food chain following a reactor accident and has recommended that a dose of radiation of 25 rem to the child thyroid should not be exceeded.

In the absence of any other firm recommendation the International Commission on Radiological Protection has endorsed this M.R.C. statement.

Sense of Proportion

In making this recommendation, the M.R.C. stated that it had adopted a conservative approach. Later in ' Hazards to Man of Nuclear and Allied Radiations '—Command 1225 dated December, 1960, it stated that ' At any age thyroid cancer is a rare disease but a number of examples have been reported in children following doses of radiation which in a few cases were as low as 200 rads '.

At first sight, the 25 rem recommendation contains a substantial factor of safety below the lowest dose quoted as having caused injury.

There are good reasons for applying, what it is more appropriate to term, this factor of ignorance. One reason is, of course, the constant aim to keep radiation doses as low as possible, another the possible inadequacy of the information available upon which judgement could rely and indicate the safe use of a higher limiting dose—again, following ingestion there may be uneven concentration of the iodine in the thyroid producing ' hot ' spots for which some allowance has been made.

However, even if a child thyroid is subjected to a moderate overdose above 25 rem, there is still fortunately a high probability that no damage would ensue. Principally, because the thyroid weight varies considerably as between children and adults, the former cannot accept as much radio-active iodine as can the latter. It is generally accepted that an adult thyroid is relatively insensitive to radiation—as a result it can in practice accept even more radio-active

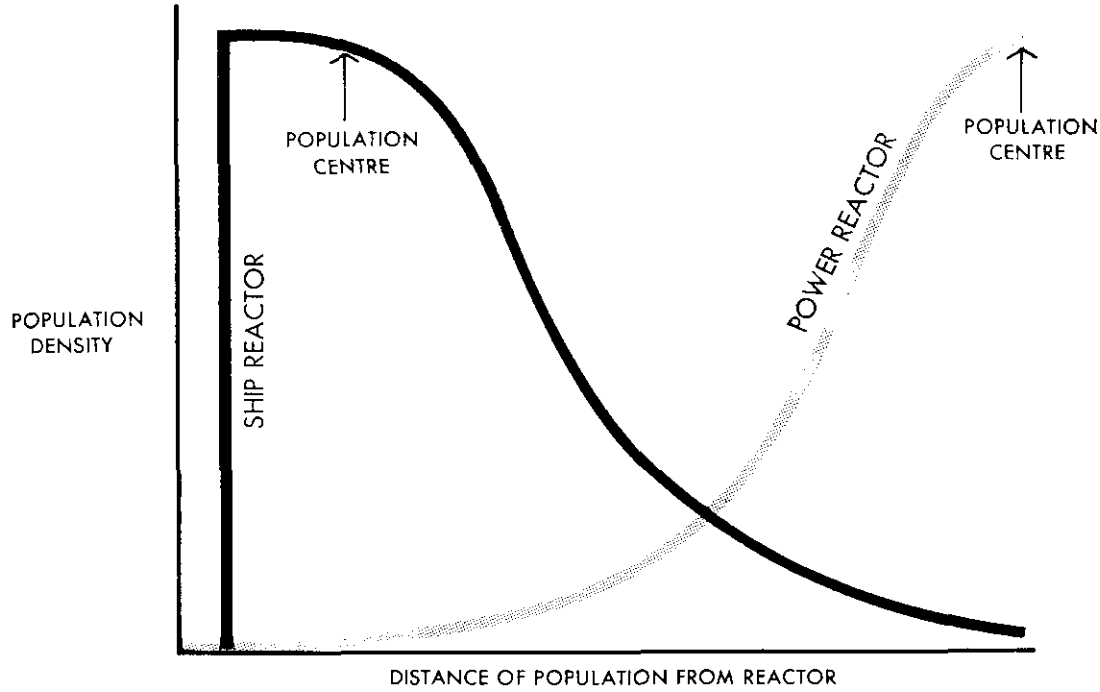

FIG. 3

iodine than considerations of weight and breathing rate alone indicate compared with children.

All our planning is based on the M.R.C. limiting recommendation of 25 rem to the child thyroid. Nevertheless, the difference between children and adult sensitivity is an important factor to bear in mind in adjusting emergency plans.

Iodine 131

For a normal operating reactor, that is to say one which is not in the stages of starting up or increasing power significantly—or for a reactor which has just been shut down—the ' iodine 131 ' component of the iodine presents the predominant hazard and a maximum uptake of this isotope can be specified which allows for a contribution from the other shorter lived iodine isotopes.

By assuming a standard breathing rate this maximum uptake is converted into a fixed dosage quoted approximately for most practical purposes as :—

$$0{\cdot}01 \text{ Curie secs/metre}^3$$

Now :—

$$\text{Uptake} = \text{Breathing rate} \times \text{Cloud Concentration} \times \text{Time in cloud}$$

$$\text{Curies} = \frac{\text{metres}^3}{\text{sec}} \times \frac{\text{Curies}}{\text{m}^3} \times \text{secs}$$

Thus :—

$$\frac{\text{Limiting Curies secs}}{\text{metre}^3} = \frac{\text{Curies}}{\text{m}^3} \times \text{secs}$$

By specifying a time in the cloud a cloud concentration which will result in the limiting uptake being reached is obtained.

Cloud Concentration

As a cloud is moved by the wind it will fan outwards from its point of release and it can be shown that under fair weather conditions, this results in its concentration varying inversely as approximately the square of the distance from the source. Once again, therefore, as doubtless you are already aware, the importance of distance as a radiation protection measure is emphasized. If we are in a ' cloud ' and then double our distance from the source, we can remain four times as long in our new position than we could in our former position for the same dose received. Or for the same time in the cloud we would only receive a quarter of the dose.

Additional Importance of Distance

The longer the time before the limiting dose would be reached, the greater the probability that, for example, the wind would change its direction or the submarine be moved. If the wind changes, although another area would then be in hazard, it gives the original area a respite and presents more time for submarine movement.

Lack of Distance Safety Factor

Having stressed the importance of the distance safety factor, let us see what the situation is in a port.

Dockyards and their ship berths are normally located very near to the hubs of population centres. Land based power reactors are normally deliberately located in relatively isolated areas. As a result, it is not possible to provide as large a distance safety factor between ship berths and the public as it is between land based reactors and the general public. (See FIG. 3.)

Offsetting Lack of Distance Safety Factor

Fortunately, however, submarine reactors have significant advantages over land based power reactors by which this lack of distance safety factor is offset :—

(*a*) They are of lower output—i.e., their fission product inventory must be lower even assuming full power equilibrium conditions.

(*b*) They are less likely to be operating or have operated for an extended period immediately preceding an accident as near their maximum output as would a power reactor be operating. Their fission product inventory would therefore be even lower than pure considerations of maximum output might indicate it could be.

(*c*) They are contained—in a particularly tough envelope.

(*d*) The submarine can be moved after an accident to an isolated position.

Collision

Perhaps here, for the sake of completeness, the obvious question, 'What about collision?' should be anticipated.

A submarine hull is extremely tough (apart from withstanding diving depth it has to be able to withstand depth-charging), and in the vicinity of a port a colliding vessel is unlikely to be going fast enough to penetrate it. If the pressure hull is not damaged, the primary circuit will not be damaged.

In the unlikely event of another ship penetrating the pressure hull in way of the reactor compartment and also damaging the primary circuit, it is inconceivable that the hole torn in the pressure hull would not be large. The submarine is mostly underwater, thus water would flood up the reactor compartment quenching the steam initially produced and destroying the driving medium of the cloud which might otherwise have been released. In addition, it is possible that melt down may be limited. The addition of some radio-active fission products to the water might present a temporary local problem but on a scale many orders of magnitude less than would a cloud.

PORT SAFETY ASSESSMENT

Having decided that there is a requirement to use a particular port, obviously the first thing to do is to select all of the berths which ordinary seamanship indicates would be suitable for a non-nuclear submarine of the same dimensions, draught, etc., as a nuclear submarine. A glossary of information is then prepared.

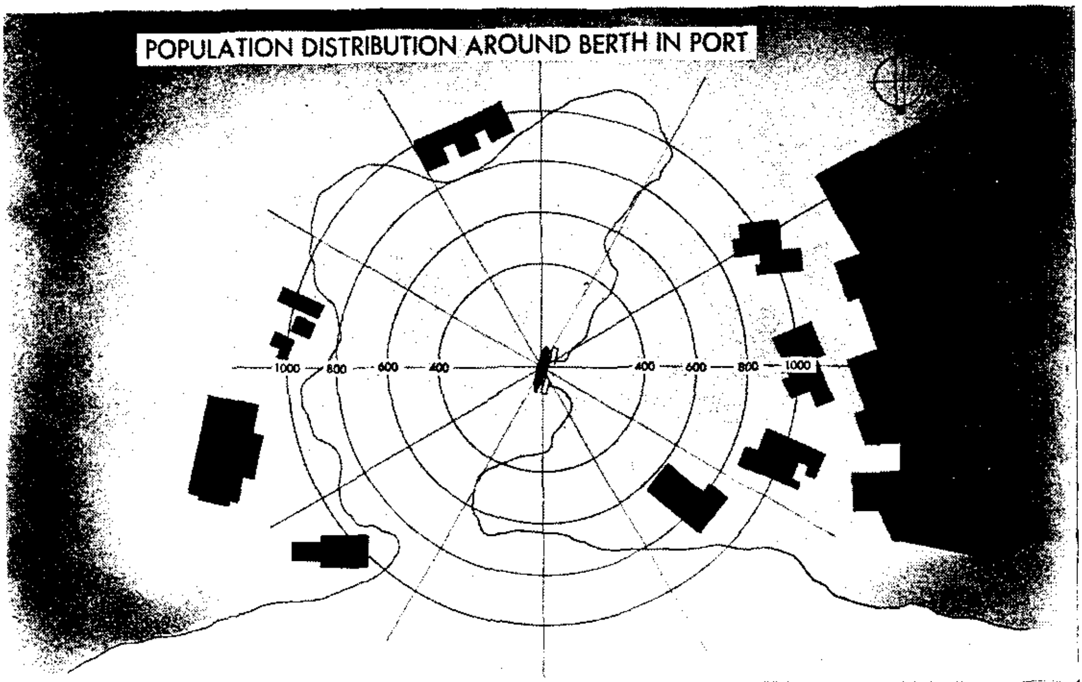

FIG. 4

Port Sketch Plan

A port sketch plan is produced showing each berth selected and main features out to approximately a mile as for example :—

(*a*) Hospitals
(*b*) Victualling yards, food storage depots, silos, food processing plants, breweries, etc.
(*c*) Utilities
(*d*) Service establishments and boundaries
(*e*) Ferries
(*f*) Schools
(*g*) Railway stations
(*h*) Sea passenger terminals
(*i*) Air strips
(*j*) Explosives
(*k*) Factories
(*l*) Bathing
(*m*) Reservoirs, and so on.

The distance of each such feature from each berth is tabulated.

Population Block Distribution

For *each* berth (or block of adjacent berths) considered, with centre at the berth and with circles indicating various ranges, blocks of population are defined. FIG. 4 shows a hypothetical harbour and indicates how this information is presented. 30-degree sectors are shown on this presentation.

Population Distribution

For *each* berth (or block of adjacent berths) the population is estimated in arcs of 30 degrees for various range brackets, e.g.,

0— 200 yards
200— 400 yards
400— 600 yards
600— 880 yards
880—1320 yards
1320—1760 yards

Meteorological Information

The following meteorological information is obtained :—

(*a*) A general statement on wind conditions including remarks on any funnelling, eddying, 'special' winds

(*b*) A Wind Rose

(*c*) Incidence of inversion conditions and heights

(*d*) Average rainfall in summer, winter and over the year. (This is needed to supplement oceanographic information in connection with verifying suitability of harbour to receive reactor warm-up water.)

In the British Isles wind and inversion data has, to date, not proved to be an important factor in berth assessment.

Oceanographic Information

(*a*) Fresh water rivers, etc., feeding harbour

(*b*) Estimate of rain water run off catchment area supplying rivers, etc., feeding harbour.

This information is needed in connection with verifying suitability of harbour to receive reactor warm-up water.

Drinking Water Supplies and Reservoirs

Out to say 5 miles are listed :—

(*a*) Sources

(*b*) Estimate of quantities

(*c*) Location

It is extremely unlikely that a submarine reactor accident would render water supplies unusable even if the reservoir were close in to the berth. But in order to provide authoritative reassurance, this information is examined.

Navigational

(*a*) Any restrictions on entry to, exit from, or berthing or unberthing in the harbour

(*b*) Remote anchorages available for disposal of a submarine after an M.C.A. or if some mal-functioning indicated that the probability of an accident occurring had increased

(*c*) Depth of water at Mean Low Water Springs at each berth

(*d*) Tidal information and local currents. (This information is again required in connection with the discharge of reactor warm-up water.)

Tugs

Availability of tugs to remove submarine in an emergency.

Fishing

The following information is obtained to verify the suitability of the harbour for the discharge of reactor warm-up water :—

(*a*) What fishing is carried out in harbour

(*b*) What is main fish caught in the harbour

(*c*) Is this an industry or, say, amateur rod and line

(*d*) The vicinity of edible shell fish

(*e*) Is seaweed harvested for use on land or in food.

Food

(*a*) What constitutes main portion of diet :—

(i) Fish, and type

(ii) Meat

(iii) Agricultural produce, etc., and is this obtained, in the main, locally.

(*b*) Is locally produced milk generally drunk by children.

Farms

(*a*) What is the general pattern of local farming

(*b*) Is much milk produced within say 6 miles of the berths or is it imported from outlying districts.

Hospitals

Some indication of the types of hospitals, old persons' homes, etc., within a mile of each berth. In particular for hospitals, whether they admit children and numbers likely to be involved in those within half-mile of the berths.

Information on a variety of other factors—dredging, sewage outfalls, Civil Defence and so on is collated.

While some of this information may not be immediately applicable to berth selection, in the interests of public reassurance experience has shown the wisdom of thorough consideration and of having the data available.

Judgement

As might be expected, the distance from and the population distribution around each berth is generally the principal factor in determining whether or not a berth is suitable for use by a nuclear submarine. Experience has shown that while the other factors considered may modify an assessment carried out purely on population distribution basis or indicate a preference between two otherwise similar berths or indicate the use of certain particular emergency measures, they do not generally significantly affect the outcome of the assessment. Nevertheless, they might in a future assessment and they must not be ignored.

Finally, a judgement is made on all the information available and an order of preference for berths is prepared indicating any special limitations on their use, e.g., state of reactor.

Assessment Review

The berth assessments carried out on the lines which have been briefly described are then submitted to a joint Admiralty and U.K. Atomic Energy Authority Committee upon which both the Ministry of Transport and Lloyds Register of Shipping are represented. This Committee approves, rejects or modifies the assessments so presented.

PRE-INCIDENT PLANNING

Because in ports it is generally found that the distance safety factor is limited and thus the time available following an accident to plan emergency measures may be short, it is considered essential to carry out a degree of detailed pre-incident planning of emergency measures. In doing so, it is necessary to strike a balance between no planning and over planning and to decide on the degree of planning necessary to meet the particular circumstances as defined, for example, by the characteristics of the berth, the frequency of the visits envisaged and so forth.

As will be described, our current concept of pre-incident planning involves the varied skills of a large number of persons and their efficient co-ordination. Since the first efforts, the contributions gradually provided by the various persons involved has enabled us to evolve a standard basic procedure. It is intended to run through that used for the Polaris submarines in the Holy Loch because as this was our first experience at making arrangements for frequent visits it was planned and organized in more detail than might be judged necessary at some other place.

The Three Elements

In essence, the three elements of our pre-incident planning consist of :—

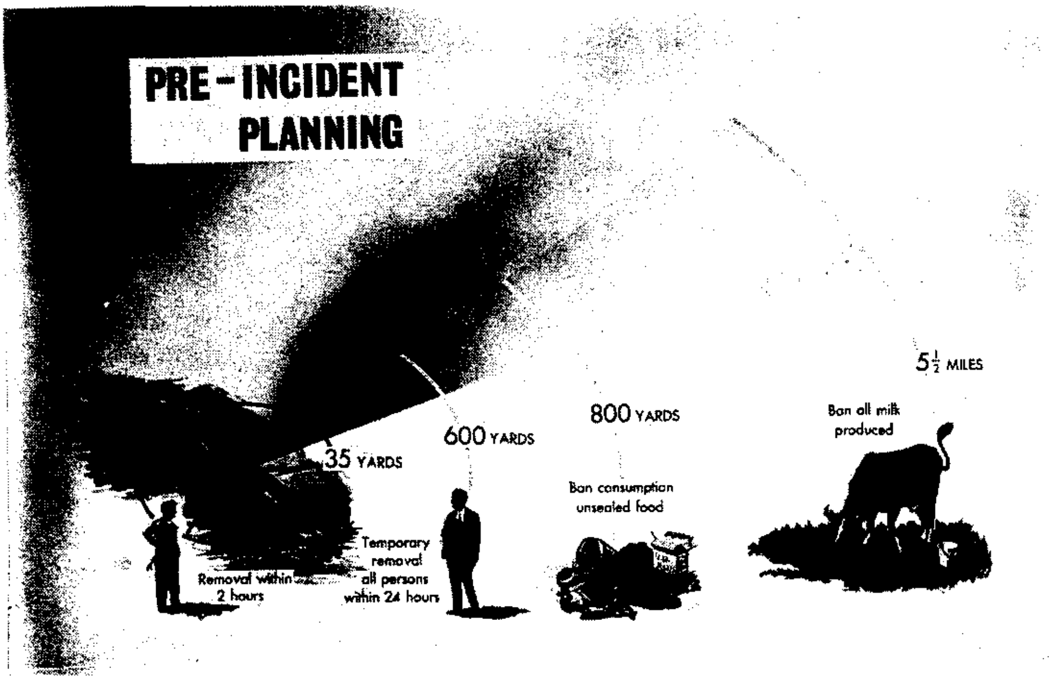

FIG. 5

(*a*) The Naval Command Safety Orders
(*b*) A Local Liaison Committee
(*c*) An Emergency Scheme

Co-ordination is effected by the Captain-in-Charge, Clyde, on behalf of the Flag Officer, Scotland.

The Naval Command Orders

The Naval Command Safety Orders consist of :—

(*a*) A statement of the hazard for which they cater—this is the M.C.A. already mentioned
(*b*) The general plan which is to be followed in the event of an accident
(*c*) Details of the action to be taken by the R.N. and U.S.N. elements in the Command.

The General Plan

FIG. 5 shows the general plan to be followed in the event of a serious release of volatile radio-active products. It provides for :—

(*a*) Evacuating all exposed personnel within 35 yards of the submarine immediately to protect them against gamma radiation emitted from the hull
(*b*) In a 30-degree sector down-wind of the submarine berth, or if there is no wind, in a whole circle of radii indicated by the ranges which follow :
 (i) Evacuate all persons within 600 yards to beyond 600 yards as soon as possible and in any case, within 24 hours to protect against excessive inhalation of iodine vapour
 (ii) Initiate a ban on the consumption of all exposed food-stuffs and unsealed liquids other than mains water supplies up to about half a mile
 (iii) Consider imposing a ban on the consumption of milk produced out to about 5½ miles
(*c*) The immediate deployment of a radiological monitoring team which is permanently in the area

ADMIRALTY

CHAIRMAN Representative of the C-in-C responsible for the area

DEPUTY Nominated Naval Officer in the area if not the above

SECRETARY

SAFETY OFFICER

ADMIRALTY NUCLEAR PROPULSION SAFETY OFFICER

LOCAL AUTHORITIES
(COUNTY BOROUGHS, BOROUGHS, URBAN DISTRICTS & RURAL DISTRICTS)

ELECTED REPRESENTATIVE CLERK MEDICAL OFFICER OF HEALTH CHIEF CONSTABLE	From community in which potential hazard is sited
ELECTED REPRESENTATIVE CLERK CHIEF CONSTABLE	From adjoining communities

LOCAL AUTHORITIES
(COUNTY)

ELECTED REPRESENTATIVE CLERK MEDICAL OFFICER OF HEALTH CHIEF CONSTABLE CHIEF FIRE OFFICER WELFARE OFFICER EDUCATION OFFICER	From county in which potential hazard is sited
ELECTED REPRESENTATIVE CLERK MEDICAL OFFICER OF HEALTH CHIEF CONSTABLE	From adjoining counties

OTHER AUTHORITIES

LOCAL REPRESENTATIVE of the Ministry of Housing & Local Government

LOCAL REPRESENTATIVE of the Ministry of Agriculture, Fisheries & Food

LOCAL REPRESENTATIVE of the Ministry of Transport

LOCAL REPRESENTATIVE of the Milk Marketing Board

LOCAL REPRESENTATIVE of the Ministry of Power

NATIONAL FARMERS UNION

REGIONAL HOSPITAL BOARD

RIVER BOARD

PILOTAGE AUTHORITY

HARBOUR BOARD

U.K. ATOMIC ENERGY AUTHORITY

FIRM ACTING AS ADMIRALTY AGENT

FIG. 6—COMPOSITION OF TYPICAL LOCAL LIAISON COMMITTEE

(*d*) The calling in of the services of a nominated U.K.A.E.A. establishment back up radiological monitoring team and Health Physics adviser

(*e*) If appropriate, the removal of the submarine to a more remote anchorage.

It will be appreciated that what has just been stated is an over-simplification of what may in fact prove to be necessary, but it does provide a basis upon which to apply variations as the circumstances of the particular accident and the radiological monitoring reports dictate.

In connection with the detailed action the following points should be noted :—

(*a*) Service respirators are effective against iodine vapour—by this is meant that they will remove a substantial amount of the iodine. They are not, however, 100 per cent effective

(*b*) The distances mentioned may require some extension for severe inversion conditions

(*c*) The action in the 30-degree sector is based on the possible effect of radio-active iodine inhalation or ingestion by children. If no children are present, the ranges for each action are reduced by a factor of three

(*d*) No harm will result if there are delays of several hours in putting the bans on consumption of food into force. In the case of food-stuffs, the ban is based on an assumption of a certain consumption rate of food over a period. In the case of milk, there is a delay period within the cow which provides a safety margin.

Duration of Restrictions

The duration of the evacuation necessary to protect against excessive inhalation of iodine will depend upon how long the source persists, whether it is moved and on wind changes. The exact figure could only be determined at the time by monitoring but it is not expected to be for more than 24 hours.

The ban on consumption of food-stuffs and milk may last for several weeks.

Public Reassurance

It will be appreciated that public reassurance will be required in the wake of a nuclear accident and the Naval Command Orders provide for this to be given with the minimum delay through all available channels.

The Local Liaison Committee

The Admiralty has adopted the same terms of reference for Local Liaison Committees which it sponsors as has been used for A.E.A. Local Liaison Committees—

> ' primarily to reassure local opinion on the hazards involved, to convey to the lay public the significance of any incidents and to create administrative machinery for the protection of the population in the event of a serious accident '.

This Committee is chaired by the Naval Command responsible for naval activities in the district and is composed of Local Authority, Ministry, and other representatives who have an interest in, or part to play.

It can be seen from FIG. 6 that this Committee is large and catholic. In order to facilitate its operation, a small drafting sub-committee is formed to prepare and submit detailed emergency plans to the Main Committee. At meetings of the Committee every facility is given for the asking of questions and every endeavour is made by the Admiralty to keep the members informed on every aspect.

Emergency Scheme

The Emergency Scheme is prepared by the Local Liaison Committee and constitutes the civilian counterpart of the Naval Safety Orders.

It contains details of evacuation measures, how farmers will be informed of milk bans, measures to be taken by the police, and so on.

MONITORING

There are two reasons for carrying out radiological environmental monitoring :—

(*a*) To protect the public

(*b*) To provide evidence with which the reactor operator can defend himself in the event of someone attempting to claim legal damages.

As described earlier, the only occasion when any gaseous fission products of biological significance can escape is under unlikely accident conditions. There is therefore no point in monitoring the atmosphere until an accident has occurred, in order to protect the public.

The radiation levels, which would be obtained during monitoring after an accident, and which would represent a hazard are so far in excess of the normal background radiation level that the latter can be ignored. In other words, it is not necessary to have a precise knowledge of the natural background radiation level in order to protect the public.

If the reactor operator desires to be in a position to defend himself against a charge that there has been a rise in the natural level of background radio-activity, then obviously it will be necessary to carry out very extensive and thorough pre- and post-operation background surveys. As the precise background is not static, this would be a most time-consuming and expensive operation involving the uneconomical employment of trained personnel. And even if done, it would not contribute one iota to the protection of the public.

As we know that the reactor design cannot release biologically significant fission products except under accident conditions, there would be no possibility of any background variation being caused by the reactor during normal operation.

Apart from economics it is easy to visualize how soul destroying such an unnecessary task would be for intelligent personnel!

Although we are satisfied that the mildly radio-active warm-up effluent can be discharged quite safely in harbours, we do, nevertheless, recognize that this is a deliberate discharge and as an additional measure of public re-assurance for our first operation of its kind, arrangements have been made in the Holy Loch to check radiation levels periodically over beaches and examine marine biota for signs of increased concentration of harmful isotopes.

Our planning provides for two monitoring services :—

(*a*) *Close to berth*

This is naval manned and is immediately available day or night. Its function is to provide advice to the Command as to the seriousness of any accident and to estimate boundaries of the probable hazard.

(*b*) *Back-Up Facility*

This facility is provided when an accident occurs by a nominated A.E.A. establishment and works from the outside of the hazard zone inwards.

Interpretation of Monitoring Results

Space does not permit the discussion in detail of all the problems involved in interpreting monitoring results. Some of them such as meteorological and topographical considerations are obvious. Improved instruments are constantly being developed and the art of monitoring is evolving rapidly.

Earlier it was mentioned that the limiting dosage of iodine 131 was about 0·01 curie secs/metre^3 except when a reactor was starting up or in the process of increasing power significantly. In these latter cases the shorter lived isotopes of iodine will be building up more quickly than would the iodine 131 and would thus contribute a larger fraction of the total hazard. Thus, if we are relating our hazard control measures to iodine 131 the permissible dosage must be lowered if the total radiation dose to the thyroid is not to be exceeded.

The problem is to know exactly what the reactor state was at the moment of the accident so that the correct dosage restrictions can be applied. In practice such information will probably be provided by the submarine but no monitoring organization can rely on this and so means have had to be devised to provide the information by correct interpretation of instruments.

MEDICAL ARRANGEMENTS

Medical liaison is established at Local Liaison Committee meetings and maintained through the Command Naval Medical Officer of Health, the Medical Officers of Health and the Regional Hospital Board.

Unlike the A.E.A. where its own medical officers trained in up-to-date radiological protection practices are likely to be present at any site giving rise to hazard, the submarine reactor may cause a hazard in an area where no such expertise exists. The Admiralty is endeavouring to prepare codes of practice for the more important radiological hazards based on the latest information available—for dissemination to Medical Officers of Health in areas where nuclear submarines may operate.

ACKNOWLEDGEMENT

Although the Admiralty accepts ultimate responsibility for receiving nuclear submarines in ports, tribute must be paid to the ready assistance and wise advice which has been made constantly available, virtually at any time of the day or night, through the Atomic Energy Authority Health and Safety Branch.

In addition, the assistance and guidance of the Fisheries Radiobiological Laboratory at Lowestoft of the Ministry of Agriculture and Fisheries has been of considerable help.