RADIO-ACTIVE FALL-OUT—WHAT ABOUT IT?

BY

COMMANDER J. C. HALLIFAX, R.N., A.M.I.MECH.E.

Apology

The purpose of this article is to try to give a general outline of certain problems arising from the radio-active fall-out from nuclear explosions which affect particularly (and in some cases solely) the Engineering Departments of H.M. ships, and are not, therefore, dealt with in more general publications.

What follows is a condensed and 'bowdlerized' form of an E.-in-C. Technical Publication, intended to assist engineer officers in evaluating the risks likely to be present in their own ships. Unfortunately, the bowdlerizing has involved the removal of all the figures, so that I cannot offer much relief from dull going. My excuse for this offering of gruel must be that in this age of 'tactical' atomic weapons, their effects must be considered a normal part of everyone's ship defence knowledge.

Introduction

The majority of the effects of neclear weapons are not unfamiliar, although they occur on a quite unprecedented scale, being caused in one way or another by blast and radiant heat. The one major novelty in weapon effects is the ionizing radiation which is emitted both at the time of burst and later.

As far as radiations emitted at the time of burst are concerned, there is little or nothing that ships staffs can do to minimize the effects, except to ensure that at any state of readiness no more men than are essential are stationed high up in the ship or towards the sides (i.e. with relatively little protection). In this respect the Engineering Department is subject to exactly the same problems as everyone else, but is in general better off than most.

In respect of radiation risks after a burst, however, the Engineering Department has problems which are not quite the same as those of others, and may in some cases be very serious. This article is, therefore, concerned with outlining these problems and what can be done about them.

A general introduction to the sort of problems confronting us was given by Commander Norman and Mr. Chambers in an article in Vol. 8, No. 1 of the *Journal*. To a certain extent this present article is a follow-up of that but, unfortunately, development of weapons (and of knowledge of their effects) in the last few years had been so rapid that it is necessary to re-cover a good deal of the ground covered before.

This is not to say that what follows is the law of the Medes and Persians, or anything like it. It is not quite so subject to change as the weather (though very nearly so), but one can say that the basis is now reasonably proved, though the details may well be out-of-date in a few years.

FALL-OUT AND RESIDUAL RADIATIONS

What is Fall-out?

The so-called 'fall-out' from nuclear weapons, whether small or large, consists of a wide variety of radio-active material in the form of fission products

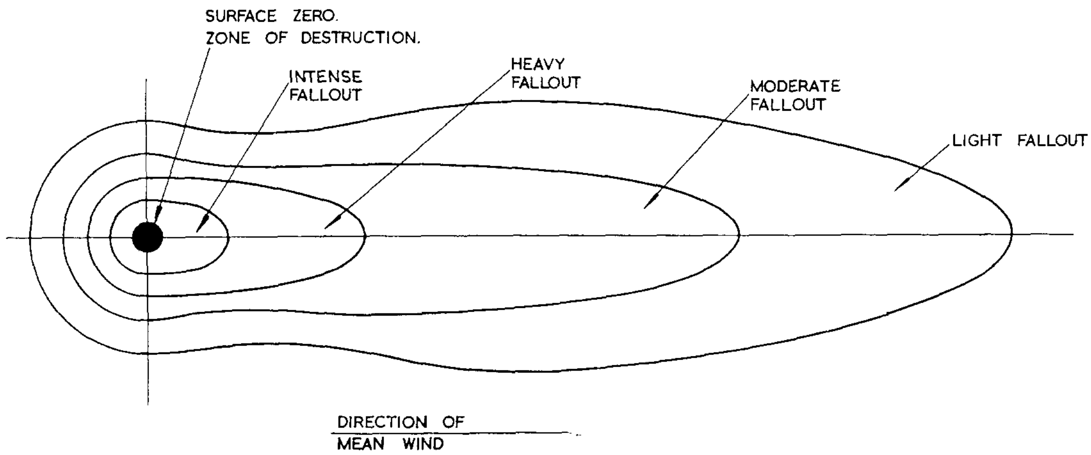


FIG. 1—IDEALIZED FALL-OUT PATTERN

from the explosion and unfissioned bomb material, usually attached in various ways to components of the surface below the explosion, which has been drawn up with the fireball and rising cloud to a considerable height before descending under gravity in a down-wind pattern depending mainly on the prevailing weather, the position of burst and, of course, the size of the weapon (see FIG. 1). The essential point is that fall-out does not 'make things radio-active' but merely covers them with a layer of radio-active dirt. This dirt cannot be made inactive, and therefore removal is the only means of decontamination although, if the activity is very low, sealing in the dirt to prevent its spread may be acceptable as a temporary measure.

In the immediate vicinity of 'surface zero' (the position on the surface immediately below or above the burst) the fall-out is augmented by the fact that the neutrons emitted from the burst itself can make many of the elements of the surface itself artificially radio-active. This, however, we need not consider as a separate problem here, but merely as a slight addition to the fall-out pattern.

A major factor in determining the extent and intensity of fall-out from a given weapon is the position at detonation. If this is sufficiently high for the fireball to form clear of the surface there will, for practical purposes, be no fall-out. If, on the other hand, the fireball touches the surface, militarily significant fall-out will occur, increasing as the height of burst decreases until, for a burst at or relatively near the surface, the fall-out is at a maximum.

If the detonation is below the surface, the extent of fall-out will be reduced by the retention of fission products in the surface zero area, but the intensity where it does occur may be increased sharply.

The fall-out from a burst over or on land can be fairly confidently predicted to be mainly dry material, while the fall-out from a burst over a water surface is likely to be water-borne, either in the form of rain or mist, at short and medium ranges. At long ranges it will probably be dry. Under certain circumstances, an underwater burst can create the phenomenon known as 'base surge', a rolling mist which can carry the very intense short-range fall-out to much greater ranges, thereby causing a considerable hazard at otherwise relatively safe distances.

Although it was the base surge formed by the underwater explosion at the Bikini tests, in 1946, which may be said to have 'triggered' investigations into the hazards presented on board ship by fall-out, it is fairly generally accepted today that a base surge can only occur with a combination of circumstances which is relatively unlikely in operations. On the other hand, the intense and widespread fall-out from the very large weapons developed recently can easily present hazards of the same order of magnitude as the Bikini base surge, over a far greater area. Even a small weapon burst on the surface can produce hazards of this order over a small area without necessarily forming a base surge.

It is therefore reasonable, when outlining the fall-out hazard in operational terms, to consider fall-out in general, without reference to specific phenomena such as base surges.

General Characteristics

Referring then to fall-out in general, it is likely that long-range fall-out will be mainly dry, and of such small particle size as to be mainly invisible. At close ranges, characteristics are likely to differ according to the material at surface zero. A land burst is likely to produce fairly large and relatively heavy particles, which may appear like a snow or dust storm, reducing visibility considerably in the inner zones. A burst at sea is likely to produce smaller particles, mainly wet, in the form of a mist or fine rain, which may or may not be visible. A very large proportion of the close-range fall-out from a burst at sea, a somewhat lesser proportion of that from a land burst and virtually all the medium and long-range fall-out from any burst, is likely to be drawn in to any intakes where the indraught is great, such as machinery air systems, or machinery space ventilation systems where the fans are running. Unfortunately, it is virtually certain that of the fall-out which may enter the ship in this way, only a negligible amount at the most will leave by the exhausts.

On arrival at the sea surface, some of the fall-out will dissolve, some will sink at once and some will remain in suspension in the water. As far as we are concerned here, the net result will be a patch of sea-water contaminated down to below keel depth, lingering for a considerable time (several days) while dispersing slowly and being moved as a whole by winds and currents.

Before leaving the more general considerations to discuss individually the duration, intensity, etc., of fall-out, it is as well to point out that, except in a very few cases, the factor which determines the magnitude of the hazards produced is the intensity. Discounting the cross-wind variation of intensity and considering only the variation along the centre-line of the fall-out track, the intensity decreases sharply as the distance from surface zero increases. As a result the degree of hazard can be very roughly related to the range from surface zero (or rather an equivalent figure measured down the track centre-line) at which fall-out is met. In practice, this means that the degree of hazard produced by steaming up-wind towards a burst will be much greater than that produced by steaming down-wind away from it, even though in the latter case fall-out may last much longer. In fact, of course, the hazard will be minimized by steaming in such a direction as to get away from the fall-out track as quickly as possible.

Time of Arrival and Duration

Owing to the number of variables, and the wide range possible in weapon size and weather, only the most sketchy information can be given here. Fortunately, only a very rough outline is necessary to this article.

The time of arrival of the fall-out is dependent almost entirely on the mean wind affecting the smoke column and cloud from the explosion, and will thus vary from almost immediately after the burst in the close-range region to several hours after the burst in the more distant areas.

The duration of fall-out similarly may widely vary. In the close-range region the variation may be from a few minutes to an hour or two, though fall-out from the larger weapons is unlikely to be over in much less than an hour. As the range lengthens, the duration of fall-out will also lengthen, up to, say, five or six hours at moderate ranges, or even longer at extreme ranges.

An unfortunate consequence of this is that it is almost impossible to say ' this is an extreme case ', as it is quite reasonable to suppose that a ship could be forced by circumstances to steam towards surface zero after a burst, and should this course happen to be up the fall-out track she would be involved in fall-out corresponding to a much shorter range than her actual range when the burst occurred. On the other hand, with good meteorological information, ships at moderate to long ranges have a fair chance of avoiding fall-out almost entirely.

Range and Intensity of Fall-out

Here also it is not possible, owing to the extent of variation of weapon size and weather, to go into detail, but none the less, some idea of the situation can be obtained by relating expressions of fall-out or contamination intensity to the damage radius of the burst, thus indicating roughly the effect of weapon size. This must, however, be regarded as only the most approximate illustration.

Throughout this article, therefore, expressions of fall-out intensity have been graduated roughly according to the following scale, related to the maximum radius at which severe damage to ships (e.g. temporary immobilization) is expected : such expressions as ' intense ' or ' very severe ' imply fall-out at ranges up to two or three times the severe damage radius ; ' severe ' or ' heavy ' is used for ranges up to about seven times the same radius ; ' moderate ' up to about thirty times ; and ' light ' for significant fall-out at all longer ranges. The first two categories relate to positions in any direction from surface zero, the latter two applying only to positions down-wind, as determined by the mean wind to a great height, and not that at the surface.

Causes of Hazards in Ships

The most obvious causes of hazards from fall-out are the radiation from the contaminated atmosphere during fall-out, the contamination deposited on weather surfaces and the radiation from the contaminated sea-water. These, however, apply to all personnel in the ship to some extent, and are dealt with in general doctrine. This article is not concerned with the general aspects, but only with those peculiar to engineering departments, and will not, therefore, deal any further with these hazards.

The causes of hazard arising particularly in machinery and machinery spaces, with which this article is concerned, can be listed according to their origin, as follows :—

- (*a*) Intake of fall-out to the air-using machinery, such as boilers, Diesel engines, gas turbines, etc.
- (*b*) Intake of fall-out to ventilation systems which cannot be closed down during the event
- (*c*) Deposition of contamination from sea-water in pipe systems and heat exchangers
- (*d*) Radiation from contaminated sea-water passing through pipe systems, etc. (this arises from the possibility of passage through highly contaminated water in the surface zero area after fall-out is over)

(*e*) Carry-over of contamination in evaporators, if running, resulting in contaminated drinking water.

It is convenient for discussion to separate these effects, but it must be remembered that they will not, in practice, occur singly. Before discussing them, however, it is necessary to examine more closely the effects of radiation on human beings.

RADIATION HAZARDS TO PERSONNEL

In general, the hazards from radio-active material fall into two main categories: external and internal.

(*a*) *The External Hazard*—from general irradiation of the body by material outside it. This hazard can be further subdivided into that from gamma radiation (electro-magnetic radiation similar to X-rays) which is highly penetrating, and that from beta particles (high-speed electrons), which cannot penetrate more than a small thickness of metal, are to some extent slowed down by clothing and only penetrate the outer layers of skin. The latter form of hazard is, therefore, only present when working in a contaminated space.

(*b*) *The Internal Hazard*—from inhalation or ingestion (by swallowing, transfer from hands to mouth, or through cuts and wounds) of the radio-active material itself. This hazard can, of course, only arise from working in a contaminated space or from contaminated food, water or clothing, and is sometimes referred to as ‘ radio-active poisoning ’.

It is desirable to point out at this stage that although the internal hazard is of comparatively little importance above decks, where the contaminant is mainly underfoot and the air (except during fall-out) clean, it is of far greater importance in enclosed compartments where the contaminant may be on all surfaces which are liable to be handled or rubbed against by any part of the body or clothes, and is likely to be present in large quantities in the ventilation supply system. Furthermore, the ventilation systems of machinery compartments being of exceptionally high capacity may cause very high concentrations of contaminant to build up.

In very broad terms it may be said that the external hazard is mainly immediate in its effects, but requires the presence of relatively large quantities of active material, whereas the internal hazard may not show its effects for years, but may arise from quite small quantities of material. It follows, therefore, that whereas the external hazard is only likely to be serious at comparatively short ranges from surface zero, the internal hazard may be dangerous at far greater distances. In order to discuss the effects of a given situation, however, it is necessary to examine these hazards in more detail.

The External Hazard

For the present purpose, the effects of external irradiation can be regarded as immediate, or at any rate short-term. The long-term effects, such as liability to cataract, blood diseases or cancer, are not well defined and in any case are obviously of secondary importance in war.

The probable effects of both gamma and beta radiation are shown in TABLES I and II in terms of the ‘ dose ’ units commonly employed. The dose unit for gamma radiation, the roentgen, is probably familiar by name to most people by now and its exact significance is quite irrelevant to this article. The unit used for beta radiation, the rad, is probably not so familiar, but in most of the problems facing the Engineering Department the beta dose to an individual, in rad, is likely to be between eight and fifteen times the gamma dose in roentgens except where the contaminant is shielded from the man, as for instance by being contained within the machinery, in which case only gamma radiation will reach him.

TABLE I—EFFECTS OF GAMMA IRRADIATION

ALL RADIATION IS HARMFUL

Dose (Roentgens)	*Likely effects*
0–150	Little or no acute effect. Long term hazard may be serious, particularly over about 50R. Probably some cases of nausea above 50R.
150–250	Nausea and vomiting within 24 hours. Recovery in about 2 days.
250–350	Nausea, etc., in under 4 hours. Some deaths in 2–4 weeks.
350–600	Nausea, etc., in under 2 hours. Deaths certain in 2–4 weeks.
600 and over	Nausea, etc., almost immediate. Death in about 1 week.

TABLE II—EFFECTS OF EXTERNAL BETA IRRADIATION

ALL RADIATION IS HARMFUL

Dose (Rad)	*Effect*
0–600	Probably none.
600–1000	Reddening of skin as by sunburn, possibly severe and followed by dermatitis and in severe cases, persistent ulceration.
1000 and over	As above, with probably skin cancers later.

Notes: (1) The above are averages for young, fit men. Ill-health or age will increase the effects, and in any case it must be expected that some individuals will react much more, and others less, than the TABLES indicate.

(2) The TABLES refer to total doses received over a period of about a fortnight or less. Within this period, no allowance for partial recovery between repeated doses should be made.

The extent to which the beta dose affects the response of the individual to gamma radiation is not fully known, but at the dose levels considered below, the effects can be considered independent.

Owing to the wide range of doses which can temporarily incapacitate, without any very serious likelihood of death, the operational problem is likely to be to minimize early incapacities, not deaths. From the machinery space point of view, this is complicated by the fact that men may be expected to receive a significant dose of radiation at times other than when they are on watch.

Although no official figures for what may be called ‘ tolerance doses ’ have yet been agreed, the basis on which the severity of risk has been assessed in the cases discussed later is that no man should normally be expected to receive from his engine-room duties alone, a radiation dose exceeding 50R (gamma) or 500 rad (beta) in the first two days after any one contaminating incident.

The Internal Hazard

The effects of the internal hazard are much more difficult to assess. In the first place they are all delayed effects, such as cancers, which may not appear in the victim for years. In the second, detailed estimates of the risks are extremely scanty, though it is known that minute quantities of active material can have the most unpleasant consequences. Furthermore, the risk is largely dependent on the particular materials and their degree of attachment to the surface in any particular case.

It is not possible here to discuss this type of hazard in any detail. Control of it is straightforward, though an operational nuisance of a high order, and consists of the use of protective clothing, with proper facilities for dressing, undressing, personal cleansing and monitoring, combined with a high degree of personal hygiene. The type of protective clothing required will be well closed (double flap) overalls, sealed at the wrists and ankles to gloves and over-shoes or boots, a cap covering the hair and in cases of severe contamination, particularly of the ventilation system, a face mask of some sort, or a respirator. All external clothing may have to be decontaminated (by laundering in segregation) or, if this is impracticable or insufficient, discarded after use.

If peace-time standards of risk as applied for instance in weapon trials were to be applied to this hazard, the controls outlined above would have to be applied whenever the surface contamination at any place is sufficient to be just discernible when the probe of a Service pattern ‘ contamination meter ’ is placed close to the surface. Since, however, these standards incorporate a very large safety margin, it is probable that unless the meter referred to reads on the amber or even, in more urgent cases, on the red portion of the scale, the risk of omitting controls would not be excessive when judged by war-time standards. In the extreme, of course, any risk from the internal hazard would be acceptable—it would be ridiculous if a ship were to drift alone because a few of her company might get cancer in thirty years time !

If in any particular case the internal hazard were to be serious, and proper clothing was not available, very strict personal hygiene would probably reduce the risk to reasonable proportions. The hazard from inhalation is never very great as long as the nose and not the mouth is used for breathing and, provided cuts, etc., are properly covered, the real danger is reduced to fouling of the mouth by transference, for instance when smoking. The obvious measures would, therefore, be to keep the mouth away from surfaces while on duty, not to smoke or eat or wipe the face until after coming off watch, to strip carefully and wash thoroughly the face and body, particularly the hands and hair, immediately after coming off watch and before entering radiologically ‘ clean ’ parts of the ship.

INDIVIDUAL EFFECTS OF FALL-OUT

Having now briefly discussed the effects of radiation on personnel, it is appropriate to turn back to consider the ways in which fall-out can cause hazards in machinery spaces and machinery.

Contamination of Trunked-air Machinery Systems

Even where the fall-out consists of relatively large particles, the indraught of machinery at high power is likely to suck in a very high proportion of the contaminant concentration in the outside air, whether or not a pre-wetting system is in use. Indeed, the pre-wetting water, if itself heavily contaminated, may add considerably to the total contaminant drawn in. Of the contaminant drawn in in this way, only a negligible amount will leave the ship via the exhausts.

Deposits of active material will, therefore, form in the air and gas passages of boilers, Diesel engines, gas turbines, etc. Since the air flow is great, these deposits are liable to be much greater than those on the weather surfaces of the ship, even if no pre-wetting were used on the latter.

Deposition will be heaviest at places where the gas flow changes direction, on horizontal rather than vertical surfaces, on porous or dirty surfaces, and in sooty deposits, since in the combustion chambers the active material appears to attach itself to particles of soot. Furnace brickwork is also likely to be heavily contaminated.

The relative importance of the deposits is likely to follow the same order as their positions in the course of the gas flow. For instance, in a boiler system with trunked air the greatest deposits would be in the intakes, followed by the blower rooms, furnaces and tube nests, in that order. A similar state of things can easily be drawn up for any other system, but it is noteworthy that intakes always present the most serious problems.

The deposits thus formed will present two entirely separate problems. Firstly, the gamma (penetrating) radiation will be a hazard to watchkeepers near the machinery. This will in some cases be appreciably reduced by the shielding afforded by the machinery itself. Secondly, both internal and external hazards will be present when the machinery is opened for inspection or maintenance. (The latter includes, for example, entry to the blower rooms of a trunked-air boiler.)

The hazard to watchkeepers will depend largely on the distance they can get away from the machinery, and the machinery air consumption. In the case of Diesel engines of propulsion size, provided the watchkeeper remains at the normal control position distance of, say, that in a type 41 frigate, normal watchkeeping could probably be resumed very shortly after fall-out had ceased even in severe cases (assuming for the moment that the engine air supply was trunked to the engines). Steam-driven vessels would probably have to wait for up to four or five hours after the bomb-burst before the (open) stoke-holds could be manned on a three-watch basis, if caught in intense fall-out. Of gas-turbine driven vessels, all that can be said at present is that they will be in a somewhat worse position than steamships, owing to the higher air consumption. Anywhere near the intakes of major gas-turbine plants is likely to require strict control of access for anything up to about twenty hours after bomb-burst.

Of the hazards presented by maintenance and inspection, it can safely be assumed that as some time will have elapsed since the burst, during which the activity will have decayed, the external hazard will not be very serious. The internal hazard will remain, however, and will require the use of protective clothing by maintenance staff, and very careful arrangements will have to be made to prevent contamination spreading from inside the machinery to the working space.

Full decontamination of the machinery will probably be impossible without complete dismantling, but a limited measure of decontamination can be achieved by thorough cleaning using normal methods, such as scrubbing, removal of carbon deposits, soot-blowing or water-washing of boilers, etc. Any porous material such as lagging (if not covered with aluminium coated cloth), acoustic insulation, or boiler brickwork will have to be removed and discarded, as the contaminant is likely to penetrate such material to a considerable depth. Great care will be needed in cleaning to avoid spreading the contamination, and such methods of soot-blowing of boilers will require specially careful control. In general, however, contamination will be a job for a base.

A very brief summary of the effects described above is given in TABLE III.

TABLE III—CONTAMINATION OF MACHINERY TRUNKED-AIR SYSTEMS

SUMMARY OF EFFECTS

External Hazard	Serious to watchkeepers at short times after heavy or intense fall-out. Directly dependent on machinery air consumption. Most serious in vicinity of intakes. Gas turbine installations are the worst case, owing to high air rate.
Internal Hazard	None to watchkeepers but will require use of protective clothing by maintainers, and controls to prevent spread of contamination.
Decontamination	Full decontamination impossible without base assistance. Limited amount can be done by any normal cleaning methods. Porous materials will have to be discarded.

Contamination of Ventilation Systems, and Machinery Systems Without Trunked Air

The previous remarks concerning the formation and location of deposits in general terms apply here, though the relative importance of deposits is slightly different. In this case the deposits in the machinery space will be the most important, although those in the intake systems will probably be of as great or greater magnitude, the reason being that the intake system deposits will in general be further away from, and at least slightly shielded from the watchkeeper. Deposits in the exhaust system will in general be of minor importance.

It is convenient to consider such installations as closed stoke-hold boiler rooms, and other spaces where the machinery air is not trunked direct to the machine, as part of this section, as the machinery acts to all intents and purposes as the ventilation exhaust system.

In all these situations the risks arising can be considered in three groups.

Firstly, the contaminant in the supply trunking and fan(s) may cause an appreciable external (gamma) hazard in spaces adjacent to them, particularly in the neighbourhood of the first two or three bends in the intakes. The exhaust system is unlikely to be sufficiently contaminated to present any serious problem of this type. Since decontamination of these systems is unlikely to be possible until return to base, it may be necessary after passage through heavy fall-out to control time spent in the vicinity of these components for about a day or so.

Secondly, the contaminant in the compartment itself will cause a serious external hazard in the compartment, both from gamma radiation and beta particles. The latter will be slightly reduced by the protective clothing which will in any case be necessary, but the net effect after heavy fall-out may be to restrict watchkeeping very seriously. It is likely that even if the allowable gamma dose is raised, the restrictions would be almost unchanged owing to the casualty risk from beta particles. The hazard will be particularly serious in closed stoke-holds, where the compartment itself forms the diffuser for the fans, and the (wet) contaminant is likely to coalesce in the fan flat and drip down into the working space below.

Thirdly, again from the contaminant in the compartment itself, the internal hazard will be serious. Full protective clothing will be required, and owing to the high rate of air flow and the contamination of the supply trunking, respirators will also be necessary after any heavy fall-out. This will involve a very serious nuisance in control of entry and exit to prevent spreading the contamination to other parts of the ship, such as living spaces, etc.

A minor result is likely to be the slight contamination of any tanks, W.T.C. etc., having vents or filling funnels within the contaminated compartment. In most cases, this can be neglected, but any of these tanks, whose purity is vital, should have the vents covered during fall-out to avoid this risk.

The net result in terms of operation is likely to be that normal watchkeeping will have to be suspended for a very considerable time after heavy fall-out. The time when a three-watch cycle can be resumed is likely to be up to five or six hours after burst in a steam-driven ship's engine room, and about sixteen to twenty hours after burst in a closed stoke-hold boiler room. The engine room of a Diesel-driven ship, taking a type 41 frigate as typical, would correspond to about midway between the examples quoted.

Watchkeepers will be required to use protective clothing, of course. Local decontamination by ordinary cleaning methods can be expected to reduce all hazards considerably, but will take some time and involve a number of extra men whose radiation exposure will subsequently have to be carefully controlled. Unfortunately, it is not to be expected that local decontamination will suffice to eliminate the need for protective measures against the internal hazard, unless outside circumstances require unusual risks to be accepted.

Proper decontamination, while not technically difficult, is likely to be so laborious as to require a major operation at a base. On most surfaces, any really thorough cleaning methods will probably suffice, especially if a detergent, or better still, a complexing agent such as citric acid, is used. Extreme measures such as complete paint stripping or grit blasting will probably only be needed on old crazed paint or in positions where the airstream impinges heavily on the surface concerned. To this statement, porous surfaces such as uncoated lagging, acoustic insulation and brickwork must be considered exceptions. In these cases decontamination will in general be impossible, and the material will have to be discarded.

Summarizing, the operational results are likely to be a considerable external hazard in the contaminated compartment, requiring control of time spent in it, a similar though slightly reduced hazard in the neighbourhood of intakes and supply fans, and a serious internal hazard in the compartment, requiring the use of protective clothing and extreme care in control of entry and exit to prevent spread of contamination. The first two results are only likely to be serious for a day or so, even in extreme cases, but the third will continue to be a major nuisance until the ship can eventually be decontaminated at a base, even after relatively long-range fall-out.

It is worth noting here that control over protective clothing, etc., will be particularly important in that care taken over this will reflect in reduced water consumption for personal cleansing at a time when the water supply situation in the ship is likely to be critical.

A very brief summary of the effects described above is shown in TABLE IV.

External Hazard from Contamination of Pipe Systems, etc.

The cause of this hazard has been described earlier. Effectively, the result will be that from very shortly after the start of fall-out (or from immediately after burst, in the surface zero area) a large area of sea-water, contaminated down to below keel depth and to an intensity roughly corresponding with the fall-out pattern, will exist. The activity will decay with time, but will remain considerable in the heavy fall-out region for some days after burst. This patch of contaminated water will move and change shape under the influence of winds, currents, etc.

TABLE IV—CONTAMINATION OF VENTILATION SYSTEMS AND NON-TRUNKED-AIR MACHINERY

SUMMARY OF EFFECTS

External Hazard	Considerably more serious than for trunked-air machinery (TABLE III). Beta particles, causing immediate ineffectives, may be more restrictive than gamma radiation.
Internal Hazard	Very serious. Watchkeepers will require protective clothing, with proper control of same, for extended periods. Maintainers likewise.
Decontamination	Full scale decontamination will require base assistance. Local cleaning can reduce all hazards considerably, but probably not to such an extent as to allow protective clothing to be discarded.

The contaminated water will, of course, be drawn in to all the sea-water systems of a ship passing through it. Should there exist any leaks, it will also enter the tanks or compartments concerned, but except for cases of previous action damage, the amount entering is unlikely to cause any serious hazard in terms of war-time risk. Some will enter through the stern glands but, provided the bilges of the gland compartments are flushed with ' clean ' sea-water as soon as possible, any hazard remaining when the compartments are next thoroughly cleaned should be easily dealt with.

While the systems are actually full of contaminated water, some degree of external (gamma) hazard will, of course, exist in positions near the pipework, heat exchangers, pumps, etc. It is, however, most unlikely that this will be at all serious except near the vicinity of very large units such as condensers of steam-driven ships, and then only if passage across the actual surface zero area must be made within an hour or so after bomb-burst. As a guide, it is most probable that if steam-driven ships not fitted with remote control can avoid the area of severe damage for about two hours after burst, any extra dosage given to watchkeepers will not be serious, unless the watchkeepers' position is very close to the condenser. Ships with other systems of propulsion need not be restricted.

Although it is arguable that this restriction might hamper rescue operations, it is probable that in view of the limited amount of rescue likely to be practicable, the hampering would be more apparent than real.

Internal Hazard from Contaminated Pipe Systems, etc.

To what extent deposition of suspended contaminant is likely in the affected systems is not properly known, though deposition is known to occur. It is most unlikely to present an appreciable gamma hazard outside the systems concerned. The internal hazard to maintenance workers might, however, be serious, and will probably require the use of protective clothing whenever a system is opened for any purpose until full decontamination can be carried out at a base. Face masks will not be required provided the exposed parts of the system can be kept wet throughout (except possibly for bodily entry to the systems, as in condensers), but care in disposal of waste would be required to avoid spread of contamination.

The sites of the heaviest deposits will obviously be strainers, pump casings, dead ends, parts of valve castings, bends, and any part of the systems where scale or marine growth has gained a foothold.

Decontamination is likely to require chemical cleaning of the whole system and possibly shot-blasting of such parts as pump casings, where severe impingement occurs. This is obviously impracticable until after return to base. A measure of immediate decontamination could be achieved for any ' hot spot ' by flushing the system concerned with clean sea-water at as high a rate and for as long as possible. This is most unlikely, however, to reduce the maintenance hazard to a level at which precautions can be neglected.

After any particularly heavy contamination of this kind, it is possible that the use of water from the contaminated system for such purposes as potato peeling or dish-washing might be a health risk. Medical advice should be obtained on this point in any particular case.

Contamination of Evaporators

In many respects, the results of running evaporators in contaminated sea-water will be the same as those considered above, and will require the same precautions and treatment. There are, however, two points requiring special mention.

Taking the simplest first, it is that the scale in the evaporator is certain to be relatively heavily contaminated. As a result, protective clothing (though probably not masks) will be needed when descaling after blowing down, and great care will be needed in disposing of the scale. The descaling process will, of course, partially decontaminate the surfaces concerned, so that after some time (probably several days) it should be possible to at least partially relax the precautions.

The second and more important point is that some carry-over of contaminant to the distillate, though very small, may be present. The tolerance likely to be imposed, even in war-time, on drinking water is very low indeed, even if contaminated water is drunk for only a few days.

It is not possible here to discuss this in detail but it appears from current estimates that, after a big burst, distilling to ship's tanks would not be permissible for about six hours in the zone of destruction, for about three hours in the severe damage zone and need not be restricted beyond about four times the radius of severe damage (assuming, of course, a weapon burst on or near the surface). At greater distances, distilling could be carried out normally, but it is worth noting that this would require very thorough monitoring and might entail decontamination of the entire fresh-water systems of the ship as soon as possible. This work could only be done at a base, particularly as a much higher standard of decontamination will probably be required than for any other part of the ship.

Decontamination of evaporators will require base assistance, and will probably be very difficult indeed, though not technically complicated. Basically, it will require scale removal by acid pickling, followed by washing with various chemicals.

Summarizing, then, distilling in water contaminated by fall-out will not in general be dangerous, but will involve a very difficult decontamination task, which must be carried out as soon as possible. Unfortunately, the areas of sea involved may be large, and it may well be impossible to avoid this problem by stopping the plants. In the immediate vicinity of surface zero, it will probably be necessary to stop distilling for drinking water for a few hours after a very big burst but, as this restriction need not apply to feed water, it should not prove very serious.

Development of monitoring equipment to deal with this situation is proceeding.

OPERATIONAL SITUATIONS

Up to this point the various risks arising from fall-out have been considered individually, without relation to one another. Before discussing counter-measures, it is desirable to outline the two most likely situations in which these hazards may arise so that the way in which the individual risks may combine can be seen more clearly.

Direct Passage Through Fall-out

The first case is a straightforward passage through the fall-out zone. In this case all the hazards discussed above will be present. Air-borne contamination of machinery and spaces, unless closed down, may be very heavy, particularly if for some reason the ship's course is along the track of the fall-out. If the course is at right angles to the track, the hazards will, of course, be reduced. Machinery contamination will probably cause the most restrictive external hazard, particularly if, as is likely, the passage is at high power to minimize the time in fall-out. Direct radiation from sea-water systems will only be of importance if the surface zero area has to be crossed within an hour or so of the explosion. In this case, engine-room watchkeepers in steam ships without remote control should keep as far as possible from the condensers. Even so, some watchkeepers might exceed the suggested dose standard. Ships with remote control would not be affected. Evaporator contamination might be serious, either from direct carry-over, or by the consequent decontamination, but could probably be eliminated by stopping evaporators for a short time, particularly in crossing the fall-out track.

In assessing the risk due to contamination of machinery, it must be remembered that this will be proportional to the air consumption, and thus in most cases to the power developed. It is probable that the command will require high power, to minimize the time spent in fall-out, but in some cases, particularly in ships with closed stoke-holds or other 'non-trunked-air' main machinery, it may be a net advantage to use maximum power on part of the machinery only (the 'crash-shut-down' doctrine).

It must always be remembered that, although in an article such as this the results of heavy fall-out tend to be emphasized, the internal hazards as discussed above may remain operationally serious, due to the nuisance value of the precautions required, even in very light fall-out, at ranges where the external radiation hazards are negligible.

Passage Through Contaminated Water After Fall-out

The hazards from this second case obviously can greatly vary. The least will be the internal hazard in maintenance of contaminated sea-water systems. Even this will require a big task of decontamination on return to base, particularly if, as might happen if it should not be possible to stop distilling for the whole time in contaminated water, the evaporators and fresh-water systems also require decontamination.

External hazard from water in the systems will only produce a serious hazard if an immediate passage across the surface zero area has to be made. Even then, only steam-driven ships without remote control are likely to be affected.

Hazard from carry-over in evaporators is not likely to be serious except in three cases : distilling in the surface zero area very shortly after burst, distilling for very long periods from relatively less contaminated water, or failure to decontaminate the systems within a reasonable time (say, a fortnight) of serious contamination. Of these three, only the first is at all likely operationally, the second is most unlikely, and the third is unlikely to be serious, as the lower the carry-over the longer the time which can safely be allowed before decontamination.

Probably the most serious result of passage through contaminated sea-water would be if the ship's pre-wetting system were in use. In this case all the effects of airborne fall-out would be found, due to pre-wetting spray entering the intakes, though probably only to the extent of slight fall-out.

It follows, therefore, that care in the use of pre-wetting is desirable, in that it should never be used unless the machinery spaces are as fully closed down as possible, and that one should try to avoid being misled by contamination in the sea into starting pre-wetting before airborne fall-out actually arrives. This could easily happen through over-reliance on fall-out prediction as, for instance, arriving in a predicted fall-out zone after it had in fact ceased, leaving a patch of contaminated water, and then starting pre-wetting at the first sign of activity. The result would be quite unnecessary and perhaps heavy contamination of machinery and, possibly, machinery spaces.

COUNTERMEASURES

The foregoing will probably have induced a certain amount of gloom among readers. The following is intended to slightly relieve the gloom, or at least cut the picture to size, by providing some, if not all, of the answers to the inevitable question 'what do we do about it ? '.

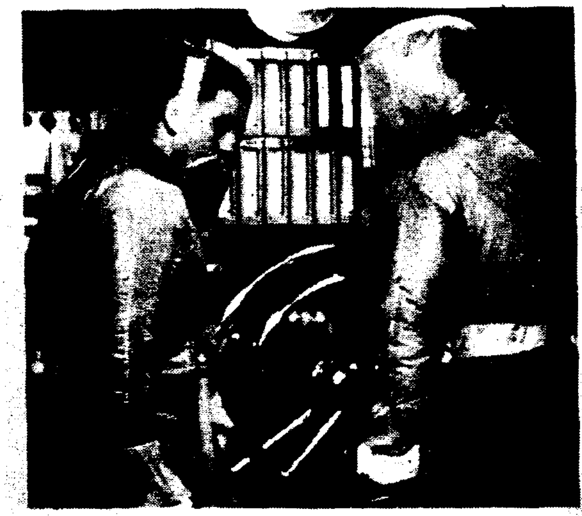
Radiac instruments and decontamination are considered outside the scope of this article, for reasons of space. (The benefits likely from, and methods of, local decontamination on board have, in fact, been reasonably covered already). Further, it is assumed that reference to protective clothing implies also full control of dressing, undressing, monitoring, etc., at the boundary of the contaminated area.

Airborne Contamination—Spaces

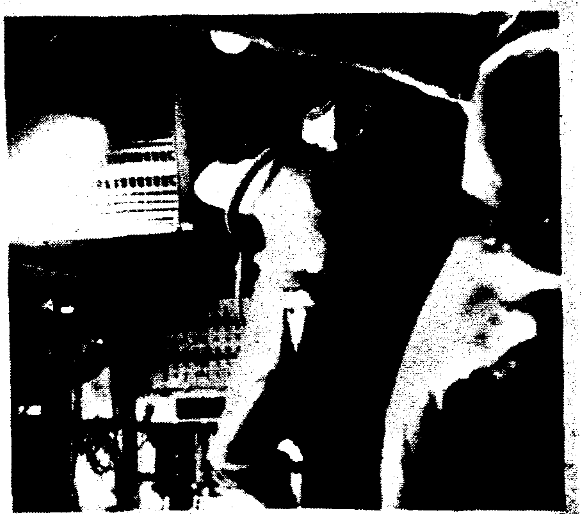
The first and most obvious countermeasure is to prevent entry of the contaminant. Total filtration of machinery air and space ventilation is not at present feasible, but the possibility of doing this in the future is by no means being neglected. It is therefore essential that, wherever possible, machinery intakes and machinery space ventilation should be fully closed down during fall-out. To assist in this, intake closures are being improved as much as possible (subject to new and practicable ideas being forthcoming) and two major points of policy are being implemented. These are the trunking of air supplies to boilers and other essential machinery direct from the open air, and the fitting of sufficient remote controls to machinery to enable full control to be exercised from a position effectively within the citadel for several hours; the machinery space ventilation meanwhile being fully closed down. Complete remote control of all functions does not appear justified at present. Ships thus fully equipped should be capable of accepting any hazards from airborne fall-out, provided the necessary precautions can be taken when machinery requires maintenance or inspection. This may be a nuisance, but should not interfere with the ship's operational function. It is, of course, necessary that all trunked-air machinery must be gas-tight, and maintained in that condition, and that no parts of the system (such as boiler blower rooms) require to be opened for inspection or any other purpose during routine operating.

It will obviously not be practicable to fit both these arrangements to all existing ships in conversions. The situations in these cases fall into three categories :—

ENTERING SPACE USING HAND-BELLOWS FOR AIR SUPPLY.



COMPLETE ENGINE-ROOM WATCH



THIS WAY OUT!

FIG. 2—EXPERIMENTAL AIR VENTILATED PROTECTIVE SUITS

(i) Where remote controls cannot be fitted, but machinery air can be trunked, the spaces can be closed down, but normal watchkeeping will be impossible because of the temperature rise. To overcome this, a special air-ventilated suit is being developed which, coupled to a compressor in the compartment, will supply the wearer with filtered, cooled air, and so enable him to keep a watch of reasonable length under the most severe conditions likely of temperature and humidity. By keeping the number of watchkeepers to a minimum, and arranging shortened watches (necessary in any severe case to control radiation dosage), ships not fitted with remote control should be able to continue operating without intolerable difficulty. After fall-out, of course (or from a few hours after it has ceased) they will be in no worse a situation than fully equipped ships.

This air-ventilated suit will also be supplied to fully converted ships, so as to allow for brief visits to evacuated machinery spaces for adjustments, etc. An early experimental form of the suit is shown, more for amusement than information, in FIG. 2. This type, while not by any means satisfactory, did serve to show the possibilities, and to indicate most of the practical requirements.

(ii) Where machinery air cannot be trunked, but remote controls can be fitted, the situation while actually in fall-out presents no difficulty. As many compartments as possible should, of course, be closed down, and whenever the risk either operationally or to machinery allows, as much as possible of the machinery should be stopped and its air intakes shut. The remaining machinery can be

operated by remote control, and closed-down spaces visited if necessar
using the ventilated suits described above.

After fall-out, however, these vessels have a much more seriou problem. Although immediate decontamination, especially in th vicinity of the normal control position, will considerably reduce hazards and therefore must be undertaken as soon as possible by washing o any other cleaning methods, it cannot be expected to reduce the interna hazard to anywhere near an acceptable level after heavy fall-out. Remote control steaming, to minimize the number of men required to visi contaminated spaces, and protective clothing for the latter, with all it attendant control nuisance, will therefore be necessary until full decon tamination can be undertaken at a base. A form of lightweight protectiv coverall, which can be worn with either a respirator or an industrial-typ filter mask, is being produced for use in these circumstances and fo work on contaminated machinery. It cannot be said that watchkeepin under these conditions is comfortable, but even under tropical condition and wearing a respirator it is not intolerable.

(iii) In the very few (it is to be hoped) cases where neither trunked-air no remote-control conversions can be arranged, the situation is somewha similar to, though much more serious than, that when only remot control can be fitted. During fall-out and for some time after, watche in the ' open ' spaces will have to be kept short if the fall-out is mor than light, and if possible the machinery should be left unattende except for short visits. The light protective coverall referred to above worn with a respirator, will provide protection against personal con tamination during fall-out, though watchkeepers should keep awa from the direct blast from fans, and it may be necessary to discard thei outer clothing and respirator filters on coming off watch. After fall-out the situation will be as in (ii) above, but the increased use of protectiv clothing, due to lack of remote controls, will probably seriously reduc the effective endurance of the ship if proper protection is to b maintained.

Airborne Contamination—Machinery

If and when a suitable total air intake filter can be found, this problem wil vanish. Meanwhile, the results must be accepted, though they can be minimize by shutting down all non-essential machinery, and by using a few primar units as possible to meet the power requirements of the Command. In th particular case of boilers, soot-blowing can remove a lot of the loose contam inant, but its effect in reducing the hazard to watchkeepers may not be ver great, as the tube-nest deposits are by no means the most serious from thi point of view, A particular point in this connection is that, unless carried ou with great care as to wind conditions, soot-blowing could seriously recontam inate the upper deck, and therefore add fresh leaves to its wreath of unpopu larity with first lieutenants !

Water-borne Contamination

At present, no special material measures (apart from monitoring) to counte water-borne contamination are planned. It is obviously not practicable t prevent it entering the systems, which would really be the only effective counter measure.

In fact, the hazards from this cause seem unlikely to be serious. Direc radiation from water in the systems is likely to be a considerable risk only o very rare occasions. It is not possible to prevent deposition in the systems but provided suitable clothing is used and care taken in maintenance, the only serious problem will be the final base decontamination. The same remarks apply to internal contamination of evaporators, scale, etc.

Carry-over in evaporators is most unlikely to cause a serious risk except very close to surface zero, and then only for a very few hours. On the other hand it may well present a very serious decontamination problem on return to base.

Summary

A tabular summary of the material countermeasures possible or planned is shown in TABLE V.

TABLE V—SUMMARY OF MATERIAL COUNTERMEASURES
(other than instrumentation or decontamination measures)

Total Air Filtration	May or may not be practicable, but remains eventual pious hope! Would provide complete answer to problems of airborne contamination.
Trunking of Machinery Air	Most useful single countermeasure. Planned for all new construction and as many as possible modernizations.
Remote Control of Machinery	Will allow spaces to be closed down in spite of temperature rise, and avoids awkward periods of shortened watches during and immediately after fall-out. Planned as for trunked air.
Air-ventilated Suit	Will allow watches to be carried on in closed-down spaces, in spite of heat, where remote controls cannot be fitted. Where remote controls are fitted, will allow visits to machinery for adjustments, etc.
Lightweight Protective Coverall	Will allow watches to be carried out on, or visits made to (depending on dose-rate) spaces open during fall-out, and will be used for watchkeeping in contaminated spaces or maintaining contaminated machinery after fall-out has ceased.

CONCLUSIONS

As a general conclusion, it seems fair, without being complacent (one can only be that when schemes do not cost anything or are already universally accepted and fitted !) to say that the material countermeasures now planned should enable ships to continue operating during and after fall-out from a nuclear explosion without insuperable difficulty and without unnecessary casualties. (It would, of course, be possible to provide complete protection, but not in a warship). Maintenance of contaminated machinery will be made difficult and base decontamination will be a very serious problem but need not seriously interfere with a given operation.

There are bound to be cases among existing ships where the planned measures cannot be fully implemented, but I hope that this article may help those who find themselves in these ships to improvise a little more effectively.

Lastly, I hope that those who have borne with me to this stage feel they have a slightly better picture of what the risks are, and are not. That is after all the main purpose of this article. There can be no rules in this field of ' collective protection ' until we have had experience of it (Heaven forbid), and therefore the better one's understanding of the risks the better are one's chances of coming out on top.