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A REPORT
TO
THE NATIONAL ACADEMY OF SCIENCES -
NATIONAL RESEARCH COUNCIL
COMMITTEE ON OCEANOGRAPHY
FROM
A SUB-COMMITTEE OF THE COMMITTEE
ON EFFECTS OF ATOMIC RADIATION
ON OCEANOGRAPHY AND FISHERIES
CONCERNING
THE FEASIBILITY OF THE DISPOSAL OF LOW LEVEL
RADIOACTIVE WASTES INTO THE INSHORE WATERS
OF THE ATLANTIC AND GULF COASTS
OF THE UNITED STATES

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I. CHAIRMAN'S PREFACE

The deliberations of this committee were undertaken at a time when active debate was going on concerning the extent of the hazard to man being created by the introduction of radioactive materials into man's environment. Both sides of this debate have been pressed by people in all sections of American society: scientists, politicians, and laymen. Although this debate has centered primarily around the effects of activity produced during bomb testing, since this is now the main source of radioactive wastes, the results are much more pertinent to the situation that will exist when nuclear power production reaches its expected levels. At that time the quantity of activity in existence will be many thousands of times greater than that which now must be considered. It has been estimated, for example, that the equilibrium quantity of activity in about the year 2000 will be approximately 30 million megacuries. To be sure, most of this will be contained in such a way, and in such locations, that its hazard will be negligible, just as the "high level wastes" from present pile operations are now treated. Nevertheless, it is inevitable that as the rate of production of radioactive materials increases, so the quantity of "low level wastes" will increase. These large volume, low activity wastes result from the processing of spent reactor fuels and from an increased production and use of radioisotopes by industry, hospitals, and research institutions.

A significant feature of the present debate is centered around the issues of "pathological effects" and "genetic effects" of radiation. Relatively speaking, the levels of radiation that will produce defined pathological effects are rather well established. Our experience with X rays, early radium work, and more recently with the entire spectrum of fission product problems provides the information for an assessment of these levels. It is these considerations that form the basis for the recommendations of the International Commission on Radiological Protection, and the establishment of maximum permissible concentrations for various radioisotopes in air and drinking water, and the maximum permissible amounts in the human body.

The "genetic effects" problem, however, is not so sharply defined. Our experience has been gained over much too short a time to be able to assess what effects rather small increases in radiation levels in man's environment will produce in the next several generations. The Committee on Genetic Effects of the National Academy of Sciences - National Research Council (1) summarized the situation (in part) as follows:

"The basic fact is - and no competent persons doubt this - that radiations produce mutations and that mutations are in general harmful. It is difficult, at the present state of knowledge of genetics, to estimate just how much of what kind of harm will appear in each future generation after mutant genes are induced by radiations. Different geneticists prefer differing ways of describing this

situation: But they all come out with the unanimous conclusion that the potential danger is great.

"This report recommends that the general public of the United States be protected, by whatever controls may prove necessary, from receiving a total reproductive lifetime dose (conception to age 30) of more than 10 roentgens of man-made radiation to the reproductive cells. Of this reasonable (not harmless, mind you, but reasonable) quota of 10 roentgens over and beyond the inevitable background of radiation from natural causes, we are now using on the average some 3 or 4 roentgens for medical X rays. This is roughly the same as the unavoidable dose received from background radiation."

Furthermore, it is significant that suggested changes for present MPC values would make them smaller. For example, Looney (2) shows that the present MPC for radium, from which the MPC for other radioisotopes is calculated (in part), may be significantly too high. He states in summary:

"It cannot be concluded from the present information on the effects of radium in man that the present MPC of 0.1 microgram of radium is permissible. The effects of radium deposited in man in concentrations at or near the present MPC for a period greater than 40 years is not known. Extrapolation of the present results to cover a normal life-time indicates that 'appreciable bodily injury' may occur at or below the present MPC. It would seem advisable to consider lowering of the present MPC of radium until information becomes available on the effects of radium in man over a normal lifetime."

From the point of view of a committee that must make recommendations concerning the release of radioactive substances to the

human environment, these considerations are extremely troublesome. On the one hand, the recommendations must be based upon an evaluation of how rates of release of activity can combine with the containment and dispersal properties of the environment to produce a return of activity to man at levels that will not be hazardous, a procedure that must have as its base line a definition of hazard. On the other hand, it is plain that there is not unanimous agreement as to where this base line should be placed.

We realize that at our present state of development this situation is probably inevitable. However, the realization is not a substitute for the missing information.

Three courses of action appear to be open to us. We might attempt to evaluate the evidence regarding the pathological and genetic effects of radiation, and so establish a firm base line. However, having no competence in these fields we feel unqualified to do this. We might refuse to make recommendations, stating that it is impossible to do so until better agreement as to what constitutes a hazard can be reached by those who have competence in such matters. This course we believe to be both unnecessary and dangerous. It would be dangerous because low-level radioactive wastes are now being introduced into shallow, coastal waters, and our refusal to make recommendations concerning permissible quantities and suitable locations certainly

would not stop the practice. It is unnecessary because there is an effective course of action open to us, which is to make as careful an assessment of the situation as possible, noting in detail the areas in which more information is needed. We can then recommend procedures that correspond to the conservative, or safe, side of the large band of uncertainty that must surround the predicted behavior of the system we are considering. We may rely upon the results of the recommended studies to furnish the basis for revision of our conclusions.

II. SUMMARY

The feasibility of establishing areas in the Atlantic and Gulf coastal waters of the United States into which packaged low level radioactive wastes may be disposed has been studied in an attempt to learn at what rate of disposal the practice will create a hazard to the marine environment and to man in his uses of the marine environment and marine resources.

These studies are a continuation of the work of the National Academy of Sciences - National Research Council Committees on the Biological Effects of Atomic Radiation. In particular they supply a part of the information considered by the Committee on Effects of Atomic Radiation on Oceanography and Fisheries to be necessary before the disposal of radioactive wastes into onshore waters should be authorized.

Two mechanisms have been considered which appear to be the most likely avenues by which radioactivity deposited in onshore waters could become a hazard to man or to the marine environment. They are: (1) diffusion from containers, followed by transport to the immediate shoreline, thereby creating a potential hazard primarily to man's recreational uses of the areas; and (2) diffusion from containers, followed by inclusion in the various trophic levels of the marine biota, and final return to man via the commercially important marine fish and

shellfish, thereby creating a potential hazard to man in his food supply.

Approximately twenty locations along the Atlantic and Gulf coasts of the United States are suggested as possible disposal areas. On the basis of information presently available it has been concluded that any one of these locations could have received the radioactive isotopes (measured at the time of shipment, omitting sealed sources) shipped to licenced non-governmental activities in the area east of the Mississippi River, plus the states of Texas and Louisiana, during the period January 1956 to September 1957, under the condition that the rate of disposal with immediate release to the water was equal to the rate of shipment from Oak Ridge. This conclusion appears to be valid for rates of production that have been estimated for the next five years.

Hazard level is based upon the recommendations of the National Committee on Radiation Protection (4).

Maximum permissible concentrations of various isotopes in sea water have been calculated. These are the concentrations that will supply to man, by the ingestion of marine fish or shellfish, the same quantity of activity that he would receive by drinking water having presently accepted MPC quantities. The maximum permissible sea water concentrations (PSC) also provide a measure of the extent to which any quantity of a given radioisotope must be diluted with sea water in order that it be a non-hazardous habitat for fish or shellfish

that are to be food for man.

That no shore line hazard will be created by the stated quantities of activity in the suggested locations was concluded after estimating the maximum concentration of activity that could result at various distances from the disposal site as a result of mixing and dilution of the waste by turbulent diffusion processes and transport by ocean currents.

The conclusion that fish will not become contaminated to hazardous levels is based upon an estimate of the quantity of activity that would be received by man, assuming that fish is his sole source of protein for about thirty years, and that the fish remain for at least one month within one kilometer (about 5/8 mile) of the center of the disposal area, and always on the downstream side. Even under these unlikely conditions, the total quantity of radioactivity that would be ingested by man is below hazardous levels, for present levels of production of low level wastes.

The calculations of the extent of mixing and dilution due to turbulent diffusion provide conservative estimates of the concentration that would be observed in the natural system. That is, the calculated concentrations are higher than the actual ones.

Completely omitted from these considerations is the process of sorption of the wastes on naturally occurring sediment components in suspension and on the ocean floor. It was found impossible to make a

reliable estimate of the extent to which this would occur. Neglecting this factor provides an additional factor of safety in the estimates of maximum concentration that would be realized in nature, as the process is known to be effective in removing many dissolved and suspended substances from solution.

It should be noted that evaluation of the hazard level using only those factors that can be dealt with in a quantitative or semi-quantitative manner leads to the conclusion that present production rates of the radioactive substances that will get into civilian disposal routes are approaching rates that might create a hazard. If production levels were to be increased by three, and possibly only two, orders of magnitude, it is conceivable that the resulting wastes might create a hazard if disposed into some of the suggested locations.

Under conditions of a constant rate of disposal of packaged wastes, the build-up of activity in the water and in the marine biota surrounding the disposal site to steady state will require from ten to twenty years.

Because of the many uncertainties in the estimates that form the basis for these conclusions, the recommendation of a pre-survey of all areas that are chosen as disposal sites, followed by surveys at intervals after disposal is started, is thought to be an essential part of the disposal problem.

Specific recommendations of the committee include:

1) The quantity of activity that is deposited into any one disposal area in any one year should be limited to 250 curies.

2) The quantity of activity that is deposited in any one area during any given month should be limited to 100 curies.

3) Adjacent disposal areas should be separated by at least 75 miles.

4) No 300 mile section of coast line should contain more than three disposal areas unless permanent currents, both bottom and surface, indicate that no exchange between areas is possible.

5) The waste container should be of such construction that no part of it or its contents will float to the surface should the container be broken. The practice of using steel drums as containers is recommended as giving appreciable holding time in the disposal area.

6) A survey should be conducted prior to disposal operations to learn pertinent biological and physical properties of the specific location, and periodic surveys be conducted after the start of disposal to learn to what extent the practice has altered the area.

III. BACKGROUND

The problems associated with the disposal of radioactive wastes are not only continuing, they are increasing in both magnitude and complexity. The use of the oceans as a disposal area has always been attractive, probably because for most purposes the oceans appear "limitless", and therefore offer a reservoir of "infinite" storage or dilution capacity. All except the very surface of the oceans is considered (by the uninformed) to be useless so far as human activities are concerned.

Obviously, the main concern in the radioactive waste disposal problem is to prevent the wastes from entering man's environment at levels that will be hazardous. Two basic concepts have developed for achieving this end, and as a result radioactive wastes are divided into two categories. Radioactive wastes may be contained, as is now done in the case of "high level" wastes, or they may be dispersed, as is frequently done in the case of "low level" wastes. The present study is concerned with low level wastes and, so far as present practices are concerned, with a combination of containment in, and dispersion by, shallow, inshore areas of the Atlantic and Gulf coasts of the United States.

The first recognition of the problems associated with ocean disposal of radioactive wastes appears to have been a study that produced

NBS Handbook 58 (4). This was published at a time when relatively little detailed information was available outside of the classified literature (and probably little within it) concerning the behavior of quantities of activity above "tracer levels", when contained in systems comparable to natural aquatic environments. The definition of high level waste has changed since publication of the handbook. Hundreds of curies were then considered high level, whereas present day operations are at the hundreds of megacurie level, and reasonable estimates of quantities to be expected in the near future are in the megamega curie range. The situation has changed so drastically since the publication of Handbook 58 that the quantities of activity then considered to be high level are now in the low end of the low level range.

At the time Handbook 58 was being prepared the marine environment was not as well understood as it now is. Studies of large scale eddy diffusion processes, and the development of theories to generalize the results, were not well enough advanced to permit an evaluation of the dispersal and dilution of material from a disposal site. Also, very little was known concerning the extent to which marine organisms can concentrate dissolved and suspended substances from their environment. It is not surprising, therefore, that Handbook 58 is primarily an enumeration of the factors thought at that time to be pertinent to the containment and dispersal capacity of the oceans. A review of the

disposal problem was recommended as new information became available.

In 1956 the National Academy of Sciences - National Research Council organized six committees to examine the biological aspects of atomic radiation. One of these committees was the Committee on the Effects of Atomic Radiation on Oceanography and Fisheries. Detailed results of the studies of this committee were published in 1957 as Publication 551 of the NAS-NRC (3), and a summary of these results was included in a summary report of the studies of all six committees (1).

Publication 551 gives a detailed accounting of the state of knowledge of the physical, chemical, biological and geological factors involved in the interaction of radioactive wastes, especially fission product elements, with the marine environment. It also points out areas where additional studies are needed to furnish the information needed before reliable predictions can be made of hazards resulting from the disposal of radioactive wastes into the oceans. While much of this study is concerned with the deep oceans and the massive quantities of materials that will be produced as a result of nuclear power production, it is, nevertheless, a useful guide in the attempted solution of all problems concerned with radioactive wastes and the marine environment.

Following the 1956 meetings of the Committee on the Effects of Atomic Radiation on Oceanography and Fisheries, but before Publication

551 was completed, a meeting of several scientists from the United States and the United Kingdom was held, with liberal exchange of information concerning the problems of the disposal of radioactive wastes to the oceans. At that meeting it was learned that the British Atomic Energy Authority plant at Windscale, on the Irish Sea, was discharging low level liquid wastes through a three mile long pipeline, directly into the Irish Sea. The British Atomic Energy Authority was at that time authorized to discharge at the rate of 1000 curies per month. The basis for authorization was a series of studies which included (1) the detailed circulation of the Irish Sea area immediately seaward from the Windscale plant; (2) the uptake of activity by migratory fish that pass through the area; (3) the contamination of an edible seaweed that is harvested in an adjoining area, estimated from the circulation study and uptake experiments; and (4) the level of contamination of local beaches, estimated from the circulation study.

It is now believed that as a result of monitoring studies made during the build-up to the 1000 curie per month discharge level, and a reassessment of the "safety factors" that were included in the original studies and recommendations, authorization has been given to discharge at the rate of 10,000 curies per month.

A summary of the discussions at the meeting has been distributed under the title, "Report of a Meeting of United Kingdom and United

States Scientists on Biological Effects of Radiation in Oceanography and Fisheries", National Academy of Sciences - National Research Council, October 31, 1956 (5). A portion of that report is quoted below, as it has direct bearing on the studies of the present committee.

"Disposal into Coastal Waters

"Maximum quantities and rates of disposal of radioactive substances into coastal waters are set, in all cases, by two considerations. The first is the transfer of these substances back to man and his surroundings. The second is the effect upon the marine resources and environment.

"Bulk Liquids

In coastal waters it will, in general, be possible, in proper circumstances, to dispose of wastes in dilute liquid form, but the permissible quantities of radioactivity in such wastes may be expected to vary considerably from one area to another because of the diverse nature of coastal situations.

"A careful study is required to determine the safe quantity of each isotope in each situation, including the details of the physical, chemical, and biological factors, and the habits of the human population potentially affected.

"Continuing studies are required at each disposal locality to insure safety, to determine ultimate steady state conditions, and to detect possible long term variations arising from variability of the environment.

"Such investigations have been carried out over a number of years in the Irish Sea and the results indicate that fission products can be safely released in that area at an average rate of several hundred curies a day; it appears likely, therefore, that similar quantities of waste could be safely liberated in some other areas.

"In selecting locations for nuclear installations the waste disposal problems should be taken into account. Because of the additive effects of wastes independently discharged into the same water mass, the proximity of other facilities is an important consideration.

"Packaged Wastes

Packaged liquids and sludges in containers which can rupture and thus liberate their contents to the sea, and solid materials of density greater than sea water may also

be safely disposed of in coastal waters if proper precautions are observed. The amount of activity which is dissolved in the sea water, or taken up by organisms, from such materials is subject to the same limitations as for bulk liquid wastes.

"Precautions must be taken to guard against recovery by fishing or salvage operations, or transport to areas where the material could constitute a hazard. Disposal areas for such wastes should be in designated locations, and all disposals should be adequately recorded and controlled."

IV. THE PRESENT PROBLEM

The National Academy of Sciences has been requested by the Atomic Energy Commission to examine the feasibility of establishing disposal locations in the inshore regions of the Atlantic and Gulf coasts of the United States, up to twenty-five miles from the shore, into which low level radioactive wastes may be deposited by authorized civilian waste disposal companies.

The scope of the problem as seen by the Atomic Energy Commission and some background information are given in Appendix I and Appendix II of this report. Several pertinent points can be noted here:

1) Limited amounts of low level radioactive wastes have been deposited in shallow waters (50 fathoms), approximately 12 to 15 miles from shore, for the past several years. This has been done under authorization from the Atomic Energy Commission. They consider that no hazard is produced at the present level of disposal, but as the rate of disposal becomes larger their concern increases because of (a) public relations aspects, (b) increasing possibility of contaminating shellfish and filter feeders, and (c) physical obstructions of fishing and trawling areas by the containers holding the wastes. A popular and somewhat misleading account of the operations of one of the disposal companies appeared in the Saturday Evening Post on January 25, 1958, under the title, "Gangway for the Atomic Garbage Man!"

2) The radioactive materials that may be involved in civilian disposal operations are those that are produced by the Oak Ridge National Laboratory and distributed to licensed facilities, such as university laboratories, hospitals, and industry. In contrast to these, the low level wastes that arise from AEC implant operations are now either contained in land burial areas or carried to the deep sea disposal areas, the latter under an arrangement with the U. S. Navy. The regulations regarding packaging, shielding, allowable limits, etc., for the material given deep sea disposal are contained in Appendix III. Non-AEC government operations such as the Bureau of Standards, National Institute of Health, Fish and Wildlife Service, etc., have no uniform method of disposal of low level wastes. Each has its own regulations and disposal means. Presumably the wastes from these operations may become a part of the load of the authorized civilian disposal companies.

3) The total quantity of activity shipped by Oak Ridge to contractors east of the Mississippi River plus Louisiana and Texas that could enter commercial disposal operations on the east coast and Gulf, during the period January 1956 to September 1957, amounted to approximately 50,000 curies, at the time of shipment. The isotopes and quantities are listed in Table 4, Appendix II. Of this total, the isotopes of strontium, cobalt, cesium, iron, and zinc, these being the

most hazardous from the standpoint of half life, concentration by organisms, and energy of radiations, amounted to 21,141 curies. Most of this (21,020 curies) was shipped as "sealed sources": metallic cobalt bars used as radiation sources, strontium or cesium samples used as primary radiation sources for calibration of counting equipment, etc. The argument has been made that these "sealed source" activities very likely will not find their way into commercial disposal routes. The remainder, 121 curies, constitutes the major fraction of the activities (at the time of shipment) that is likely to appear at the dockside for disposal to inshore waters.

An estimate of the quantities of low level wastes that have been introduced into the oceans is difficult to obtain. The results of an AEC survey of both government agencies and private companies is contained in Appendix II, Tables 3 and 4. The total quantity of activity reported as introduced to the sea (most of it approximately 200 miles offshore) amounts to less than 25 curies. Ten curies of this was Co 60.

If the 121 curies of "hazardous isotopes" noted above is a fair estimate of the potential supply, then the approximately 25 curies that has been given to sea disposal suggests that approximately 20% of the shipments from Oak Ridge will eventually appear as wastes for sea disposal.

V. BASIS FOR EVALUATING THE POTENTIAL HAZARD

The request from the Atomic Energy Commission to the National Academy of Sciences asks for recommendations concerning the disposal of radioactive materials that are specified as to kind and within limits as to quantity and rates of production. The environment into which the activity may be introduced was specified as the coastal waters, meaning the area from the shore line seaward for some fifteen to twenty-five miles along the Atlantic and Gulf coasts of the United States.

The approach that has been taken by the committee is that of attempting to solve several rather general problems that appeared to be essential parts of the specific request, but at first with little regard for actual quantities, specific locations etc. It was felt that the solution to the general problem would provide the solution for the specific one, would provide a basis for evaluating other similar problems, and would form a firm basis for evaluation of the conclusions of this committee with respect to the specific request from the Atomic Energy Commission.

Our approach to the problems is rather simple, at least so far as outlining the parts and stating what our original demands for the solutions were to be. First, we noted that the potential hazards of radioactivity to man can be eliminated, or at least reduced, by one of two

procedures. The material can be contained, thereby essentially removing it from man's environment until the natural radioactive decay process brings it to non-hazardous levels. Under conditions of complete containment the hazard can be eliminated for all except those who process the material for containment. Or the material may be dispersed to such an extent that the concentration of radioactivity in man's environment is below levels that previous experience has established as hazardous.

The manner in which radioactive wastes are now prepared for sea disposal suggests that it is the intent to use the sea both for containment and for dispersal. The containers are fabricated in an attempt to have them withstand long submersion without releasing the activity to the environment, thereby achieving a holding period during which decay may take place. Once the containers do corrode and rupture the remaining activity is pictured as being dispersed to non-hazardous levels (if holding has not already achieved this condition) by the large dilution that is available in the oceans.

Serious difficulties stand in the way of making quantitative estimates of the extent to which either containment or dispersal in the oceans will achieve the desired end. If containment alone is to be successful, it must be known that the container will remain intact until the activity (which must be known as to kind and quantity) has suffi-

ciently decayed. This implies that the corrosion, erosion or leaching rates for containers can be readily determined. Actually, this is not so. Properties of this kind can be set only within wide limits. Attempts to measure the "holding property" of containers designed for disposal into depths up to 1,000 fathoms indicated considerably more rupturing and breakup than expected. On the other hand, if dispersal and dilution of the waste is to be successful, it must be possible to calculate the reduction in concentration by turbulent diffusion processes for any given rate of introduction into any ocean area. Again, the uncertainties are rather large.

Our basic approach to these problems is as follows. We considered first the mechanisms that might bring radioactivity from the disposal site back to man. There appear to be two such mechanisms. They are:

A. A combination of diffusion and transport mechanisms whereby the radioactivity would be carried from the disposal area shoreward so as to create a hazard to man's industrial or recreational use of the immediate shore line area.

B. Uptake of the wastes by the marine biota in the disposal area and in the areas through which the wastes are carried, followed by transfer of the wastes to fish or shellfish that become food for man.

In evaluating the amount of radioactivity that could be returned to

man via these two mechanisms, we have examined the following processes and where possible made quantitative estimates of the contribution of each to the mechanisms noted above.

1. Diffusion processes. An attempt has been made to describe the distribution of the waste throughout the environment by turbulent diffusion processes, under assumed conditions of depth, current velocity, container characteristics, etc., that appear to be applicable to actual disposal conditions. In the solution of these problems, given in detail by R. O. Reid in Appendix IV, certain simplifying assumptions have been made. In all cases the simplifications tend to produce a conservative result. That is, the predicted concentration of activity will always be greater than the concentrations that will be found under actual conditions.

2. Transport by permanent or semi-permanent circulation features.

The circulation along the Atlantic coast is described by B. H. Ketchum and D. F. Bumpus in Appendix V. Special attention was given to features that would carry wastes to the coast line, thereby increasing the chances of creating a hazard in man's uses of the immediate shore, and to features that might carry the waste into areas of known fishing potential, thereby increasing the chances of creating a hazard in man's uses of marine food resources.

3. Concentration of radioactive isotopes by marine organisms.

The extent to which the various isotopes supplied by Oak Ridge are concentrated in the edible parts of marine organisms has been summarized by W. A. Chipman and B. H. Ketchum in Appendix VI. Maximum permissible concentrations of the various isotopes in sea water have been calculated by combining these concentration factors with an estimate of the intake of marine foods by man to obtain the quantity of each isotope ingested. The maximum permissible concentration in sea water is the concentration that will give to man through ingestion of marine fish or shellfish a quantity of activity equal to the amount received by drinking water containing maximum permissible concentrations.

It should be noted that ingestion of water at MPC levels and ingestion of food at MPC levels would present twice the permissible quantities of radioisotopes to an individual.

4. Sorption of radioactive elements by suspended sediments and bottom deposits.

Inorganic sediment components are known to be effective in removing dissolved and suspended radioactive waste components. Although these sorption reactions have been studied in the laboratory and have been observed in natural aquatic systems, at the present time there appears to be no way to interpret them in a quantitative manner that

will permit an estimate of the extent to which the reaction will occur in the kind of system we have considered.

Calculations in which concentrations produced by various loadings into disposal areas have been compared with the maximum permissible concentrations in sea water, mentioned above, do not include this reaction. These calculations are, therefore, always conservative estimates. That is, the concentrations of wastes observed in the natural systems will always be smaller than the calculated values. The effect of neglecting sorption reactions will depend primarily on the kind of bottom in the disposal area. In regions of highly turbid waters with muddy bottoms it is reasonable to assume that a large fraction of the activity will be sorbed onto the suspended solids and carried to the bottom as sedimentation occurs. On the other hand, in relatively clear waters with hard sandy bottoms, the sorption reaction may be relatively insignificant.

In selection of possible disposal areas, in addition to the considerations outlined above, the following factors were evaluated:

1. The intensity of fishing in the area. The disposal of wastes in fishing areas is objectionable not only because of the possibility of contamination of the fish, but also because an accumulation of containers on the bottom creates a hazard to fishing equipment. Trawl gear undoubtedly would become damaged and possibly lost if dragged

against a concrete disposal container. Furthermore, there is the possibility that a disposal container might be retrieved by some of the heavier equipment, thereby exposing the fishermen to a possible hazard. Mr. Howard Eckles of the U. S. Fish and Wildlife Service prepared a summary of regions in which fishing activity is known to take place along the Atlantic and Gulf coasts. A portion of that information is given in Appendix VII.

2. The distribution of submarine cables. Cable areas often are dragged in attempts to retrieve broken or otherwise disabled cables in order that repairs may be made. The deposition of containers of radioactive wastes in cable areas is undesirable because of the possibility that the containers might be retrieved by cable operations, as well as possible rupture of the cable during disposal of the containers. Appendix VIII, prepared by B. C. Heezen, shows the location of cables along the Atlantic coast of the United States.

VI. DISCUSSION

Of the many problems that were discussed by the committee, three stand out as being especially important in the return of radioactivity from the disposal area to man. They are: (a) turbulent diffusion processes, (b) transport by ocean currents, and (c) accumulation of radioactive materials in the marine biota, especially the species that are commercially important and are a source of food for man.

The turbulent diffusion problem is discussed in Appendix IV. Several simplifying assumptions have been made in order that the final results focus attention on a few important variables, and also to reduce the bulk of purely mathematical manipulations. In several cases the effects of these simplifying assumptions can be removed by modification of the final results. In cases where this is not practical or possible it is shown that the net effect of the simplifications is to make the calculated concentrations of radioactivity higher than would be observed in the natural system. This amounts to a built-in factor of safety in the conclusions that are based upon these calculations.

The spread of activity by turbulent diffusion processes has been examined for three different conditions, each being analogous to events that might happen in nature. They are:

Diffusion from a sustained gross source. The theoretical model is comparable to the entire disposal area. With the assumption that at

steady state the rate at which activity becomes available for diffusion is equal to the rate of disposal (no containment), and within certain restrictions as to the relative dimensions of the disposal area, water depth, and distance from the disposal area for which the theory is valid, a relationship is presented that permits calculation of the maximum concentration that will be found at various distances downstream from the disposal area. A specific case is cited in which the rate of supply is 100 curies per year, the water depth 30 meters, the diffusivity $1 \text{ cm}^2/\text{sec}$, and the current velocity 5 n.mi./day. The maximum concentrations at 1, 10, and 100 km downstream from the source will be 2.1×10^{-7} , 0.7×10^{-7} , and 0.2×10^{-7} uc/ml respectively. These concentrations are approaching the MPC values for drinking water, and as will be shown later, also the maximum permissible concentrations in sea water. However, it should be emphasized that these figures are most certainly on the conservative side. No allowance has been made for "cooling" in the disposal container, which would modify the assumption that diffusion rate is equal to disposal rate; and it is assumed that no removal takes place by processes such as association with bottom deposits and suspended sediments, or through the marine biota.

Diffusion from individual sources. The analogues of the theoretical model are the disposal containers. Two cases are considered. In the first, the waste is available for diffusion upon contact with the bottom;

that is, there is no containment. In the second, the waste leaches from the container at a rate determined by various properties of the container.

In the first case, a specific example is cited in which 0.01 curie is contained in 50 gallons, the concentration then being 5.4×10^{-2} uc/ml. Ten hours after introduction, the peak concentration, in the absence of a mean current to aid in dispersal, will be approximately 6×10^{-5} uc/ml. The relationship that has been developed is such that the maximum concentration can be calculated as a function either of time after introduction, or of distance from the disposal site. For the latter case, the peak concentrations at 10, 100 and 1000 meters from the 50 gallon - 0.01 curie uncontained source will be 1.5×10^{-6} , 3×10^{-9} , and 4×10^{-11} uc/ml respectively. Again, these are conservative figures, for essentially the same reasons as noted above. They suggest that although initially the contamination at the location of the disposal container may be high, it dies away rapidly in space and time.

The second case, that of controlled leaching, more nearly describes the situation that would exist for the disposal of wastes in metal containers, in which the wastes were mixed with the concrete at the time of packaging. The analysis of this situation is in some ways similar to the "gross source" noted above. The controlled leaching situation presents a semi-continuous source for diffusion and although the initial peak concentration will be lower than in the case of free diffusion, the concen-

trations that can be achieved at large distances from the leaching source will be greater than for free diffusion.

If the behavior noted immediately above is taken as the basis for choosing between containers that will immediately release the wastes to the environment and ones that will permit a slow release, the choice should be in favor of the latter. In the specific example cited, the leaching container reduces the initial peak concentration by a factor of nearly 10^4 , compared to immediate release, yet the peak concentration occurring at 10 km from such a source is less than 10 times greater than from the immediate release container. Furthermore, containment is desirable as it allows natural radioactive decay to reduce the quantity of activity that will ultimately be presented to the environment.

Information concerning the rate of corrosion of steel containers, comparable to those now used in the preparation of wastes for sea disposal, and the leaching rate of radioactive substances from concrete, is presented in Appendix X. Corrosion rates of steel in sea water suggest that with the presently used kind and thickness of container material, containment of the concrete-waste mixture will last for approximately 10 years. The only leaching rate studies cited were carried on for relatively short periods of time. While not sufficient to provide an indication of long-term leaching behavior, they do suggest that liberation to the environment from concrete mixtures will be

considerably slower than predicted for free diffusion.

Transport by ocean currents along the Atlantic coast of the United States is reviewed in Appendix V. Our present knowledge concerning the details of bottom circulation in shallow inshore regions of the Atlantic coast is practically nil. In some areas we have fairly detailed information concerning the surface circulation, and we have rather broad hints as to the behavior of the bottom waters, but there is little information detailed enough to permit a reliable, quantitative prediction of the rate of flow shoreward and of the quantities of materials that will be transported from a given disposal area.

In general, disposal sites have been placed in areas in which the predominant circulation, estimated from known or extrapolated surface circulation, appears to parallel the coast, thereby making direct transport to the immediate coast line improbable.

Of special interest are the following features: (a) landward flow of bottom water at the mouths of estuaries; (b) a general stagnation of bottom water in a region south of Nantucket Shoals, during the approximately six months of the year in which these waters are stratified; (c) suggestion of a general shoreward movement of bottom water, in the area from Virginia to New Jersey, during the summer months, and a seaward flow during the winter; (d) a counterclockwise eddy in the Gulf of Maine that may produce longshore non-tidal drifts of up to 6

miles per day; (e) longshore non-tidal drifts in the area from Cape Hatteras to Georgia that may reach 12 miles per day; (f) a southerly drift from Georgia to Daytona Beach; and (g) a northerly drift along the coastal area south of Daytona Beach.

The lack of detailed knowledge of circulation in the areas that have been selected as disposal areas makes necessary the recommendation that detailed studies be conducted in these areas before disposal is started.

More information concerning the extent to which marine organisms can concentrate radioactive substances from sea water is available now than at the time Publication 551 was conceived. This information is summarized in Appendix VI, Table I, where it provides a necessary piece of information for the calculation of maximum permissible concentration of the various radioisotopes in sea water. This is defined as the concentration in sea water that will contaminate the edible parts of fish or shellfish to such an extent that should these fish be the sole source of protein for an individual, he would receive an amount of activity equal to that received by drinking fresh water at MPC levels. The consumption levels used in these calculations are 15 liters of water and 1.5 kilograms of fish per week. Also listed are the volumes of sea water necessary to dilute to MPC levels the quantities of non-sealed source isotopes that have been produced by Oak Ridge during

the period January 1956 to September 1957.

It is noted that at present production rates phosphorus and iodine require the greatest dilution to reduce them to non-hazardous levels. However, these elements unquestionably are not now a hazard since their short half lives insure that during the time from production to release to the environment most of the activity will have been destroyed.

Strontium 90 appears as the most likely source of hazard, followed by copper 64, cesium 137, and iron 59.

The selection of possible disposal sites was guided by two features in addition to those discussed above. They are the fishing intensity in the various areas, and the location of submarine cables. The locations of submarine cables are shown in Appendix VIII. A detailed summary of fishing intensity has been prepared only for the coastal area from Hudson Canyon to Roseway. This information is given in Appendix VII.

Monitoring of disposal areas is an essential and somewhat difficult part of the disposal problem. A discussion of this part of the problem is given in Appendix VI. The monitoring consists of two steps, the first of which is a pre-survey of any selected site. This survey has three objects: to firmly establish background levels of radioactivity in the area; to obtain rather detailed measurements of the bottom circulation; and to obtain a census of bottom organisms that live in the general region. The census will provide data concerning not only the

kind and abundance of species present, but also the current level of gross radioactivity in each, and the isotopic composition of the radioactive elements. Special attention will be given to elements that are a part of the low level wastes that will enter the disposal area. In this latter regard it seems essential that it be possible to distinguish, during future stages of monitoring, between activity introduced by disposal operations and that brought to the region by other means, for example fallout. This information can be obtained by a continuing comparison between the disposal area and an adjacent control area outside of the influence of the disposal area. During the pre-survey the pattern of fishing activity in the region should be determined and an estimate made of the extent to which migratory fish inhabit the region.

The second aspect of the monitoring problem has to do with the surveillance of the area after disposal has started. Two difficulties should be noted. First, the levels of activity that may constitute a hazard are low. Therefore the analytical problems connected with getting and measuring a representative sample from the area are large, counting levels will be low, and the chances of contamination of the samples high. Second, it should be emphasized that the establishment of a steady state condition, with respect to the distribution and levels of contaminant, will require ten to twenty years at present production levels. Because of the lag between disposal and possible appearance

of the activity in the environment, there is the likelihood that low levels during the lag period may be interpreted as an overall measure of the hazard level.

Because many marine organisms have the ability to concentrate within themselves substances that appear in their environment, they stand out as the part of the marine system best suited as an indicator of radioactive contamination. This appears to be especially true of bottom organisms. There is merit in the suggestion that bottom organisms, oysters or clams for example, be introduced into an area and then used as indicators of contamination levels.

The results of a recent survey of the Pacific coast disposal areas (5), in which dumping has gone on for about ten years, suggest first that no gross contamination of the environment is now evident, and second, that in bottom deposits low level contamination by fission products is difficult to detect and measure against the background of radium and its daughter products.

Our recommendations concerning the quantities of activity, rates of disposal, separation of disposal areas, and package characteristics can be criticized as being extremely conservative, especially when compared with existing British practices and in the light of preliminary studies of the disposal areas of the U. S. Pacific coast. We justify these conclusions, first of all, on the grounds that disposal practices

should be well below hazard levels, and that in view of the large uncertainties obvious in many of our quantitative estimates, we feel that conservatism is essential. Secondly, these recommendations provide adequate capacity for the disposal of quantities of activity much greater than the currently estimated production level during the next five years.

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APPENDIX 1

Memorandum to Richard C. Vetter, Executive Secretary,
Committee on Oceanography, from Arnold Joseph, The U.S. Atomic
Energy Commission

APPENDIX I

MEMORANDUM TO RICHARD C. VETTER, EXECUTIVE SECRETARY, COMMITTEE ON OCEANOGRAPHY

The Atomic Energy Commission is faced with a problem of whether or not to establish sea disposal locations in Atlantic Ocean waters (for low-level radioactive wastes) closer to shore than the present designated areas now 100 and more miles out. Would the Committee on Oceanography consider setting up a special working sub-committee to look into this matter to give us the benefit of their deliberations and their recommendations. Time is of the essence, it is most desirable to have definite conclusions as to the feasibility of establishing such disposal areas and if feasible to actually establish these areas by the end of May 1958.

BACKGROUND

For several years, a commercial concern has been disposing of a limited amount of low-level radioactive wastes in shallow (50 fathoms) waters approximately 12 to 15 miles from shore. In recent years, this operation's size has multiplied (the total amount of activity and number of containers disposed are yet a great deal less than the amount disposed by the Atomic Energy Commission) and the indications are that it will become larger still in the future. The Atomic Energy Commission has not strenuously objected to this shallow water disposal in the past because the amounts of radioactivity so disposed were not large (equivalent roughly to what is allowed to be discharged into sewers) and because there was no real or valid reason for disallowing it. As the operation becomes larger, however, Atomic Energy Commission's concern increases because of (a) public relations aspects, (b) increasing possibility of contaminating shellfish and filter feeders, and (c) physical obstruction of fishing and trawling areas by the containers holding the wastes.

Compounding this concern is the strong possibility that this kind of operation may become larger still. Within the past year, Atomic Energy Commission has received two more applications for licenses from would-be commercial radioactive waste disposers who would like to initiate similar operations.

On the other hand, sea disposal operations as conducted in cooperation with the Navy causes very little concern for the Atomic Energy

APPENDIX I (Continued)

Commission. These operations generally follow the recommendations of the National Committee on Radiation Protection (Handbook 58). The wastes, in weighted containers, are taken out to disposal areas designated by the Navy as ammunition and hazardous chemical disposal areas.

The Atomic Energy Commission has recommended to the commercial waste disposers that they dispose of their radioactive wastes in the designated areas used by the Navy. There are no strong scientific reasons for requiring them to do so. The commercial operations balk at going out so far because it would cost them more money - money for ocean-going vessels and money for the additional time involved. The additional expense would in turn be reflected in higher charge for their services. Naturally, they would like their costs to be as low as possible so that they cannot only compete with each other, but also with other methods of radioactive waste disposal (such as burial on land).

There exists this seeming conflict of interests - the Atomic Energy Commission would prefer all radioactive wastes be disposed in the Navy designated areas whereas the commercial waste disposers would like to dispose their radioactive wastes as close to shore as possible. Hence, the Atomic Energy Commission is desirous of examining the feasibility of establishing designated areas suitable for the disposal of radioactive wastes closer to the Atlantic Coast line than the disposal areas now located 100 miles and more from shore in water at least 1000 fathoms deep.

OBJECTIVES OF STUDY

If it can be concluded that it is feasible to dispose of low-level radioactive wastes in certain areas of the Atlantic Ocean not as distant from shore as the existing designated areas, then steps can be taken to establish these areas, and regulations written which will govern their proper use.

Certain criteria which can be enumerated at this time set the pattern for the establishment of these disposal locations. Atomic Energy Commission feels that as many as 4 or 5 disposal areas can be established along the Atlantic Seaboard. These areas should be convenient to port facilities not necessarily in the most densely populated cities but which are accessible by rail or truck by disposers of radioactivity.

APPENDIX I (Continued)

These areas should be large enough in extent so as not to require the most precise navigation to attain them. Location buoys may be helpful.

They should be so located as not to interfere with sport fishing or commercial fishing (trawling and shellfishing). Perhaps they can be located around underwater obstructions. If possible, they should not be so far out at sea as to require ocean-going vessels.

The study group considering establishing these disposal areas will almost certainly have to consider how such areas can be operated safely and without adverse effects on the resources of the sea. Special requirements may need to be delineated as to the levels of radioactivity which may be disposed; the kinds of material, i. e. special treatments of liquids and solids; and the kinds of containers or packaging methods best suited to such disposal.

In this latter regard, it should be understood that those closer-in disposal areas are intended for use principally by commercial waste disposers or by private organizations. It is not anticipated that Atomic Energy Commission sea disposal operation will change, at least not in the foreseeable future. Insofar as other Government agencies may use commercial services in the future their waste dumpings may switch from the present designated areas to the closer-in areas if they are established.

Will the Committee on Oceanography consider sponsoring a detailed study of this problem? If so it is suggested that a special study group comprised of scientists and oceanographers familiar with the Atlantic Coast and of the Government agency people most concerned with radioactive waste disposal be formed. The following persons are suggested as a nucleus for this group:

Dayton Carritt	Chesapeake Bay Institute
Bostwick Ketchum	Woods Hole Institution
Dean Bumpus	" " "
Howard Eckles	Fish & Wildlife Service
Walter Chipman	" " "
Arnold Joseph	Atomic Energy Commission

Arnold Joseph/ for the
Coordinating Committee on Oceanography

APPENDIX 11

A Special Report on Disposal of Radioactivity

into Atlantic Ocean Waters

Past, Present, and Predicted

Division of Reactor Development, U.S. Atomic Energy Commission

Washington 25, D.C.

November 1957

APPENDIX II

A SPECIAL REPORT ON
DISPOSAL OF RADIOACTIVITY INTO
ATLANTIC OCEAN WATERS
- PAST, PRESENT, AND PREDICTED -

November, 1957

Division of Reactor Development
U. S. Atomic Energy Commission
Washington 25, D. C.

A SPECIAL REPORT ON
DISPOSAL OF RADIOACTIVITY INTO
ATLANTIC OCEAN WATERS
- PAST, PRESENT, AND PREDICTED -

Purpose

This is a special report summarizing sea disposal operations of agencies of the Federal Government and of private organizations. The reasons for this report are: (a) to inform interested and concerned officials and scientists of amounts and kinds of radioactive materials that have been and will in the near future be disposed of into Atlantic Ocean waters. (b) To supply quantitative information for a study of the advisability and feasibility of establishing sea disposal areas closer to the coast line than existing, designated disposal areas.

Summary of Information Available

Table 1 indicates the size and scope of the Navy-AEC cooperative Atlantic sea disposal operation. Almost all of these wastes originate in AEC contractor operations.

Table 1 - PAST AND PROJECTED AMOUNTS OF RADIOACTIVE MATERIALS

DISPOSED BY U. S. NAVY IN ATLANTIC AT

APPROXIMATELY 38°30'N - 72°06'W

<u>Category of Waste</u>	<u>Numbers of 55 Gallon Drums</u>			
	<u>'51-'52</u>	<u>'53-'56</u>	<u>FY '58</u>	<u>Est. FY's '59-'60</u>
Combustible solids	0	1005		
Other contaminated solids	159	1376		
Reactor irradiated materials	0	4311		
Solidified liquids	0	1581		
Other packages	0	100		
<hr/>				
Total number of drums	159	8373	1708	4478
Estimated curie content at time of packaging	20	5850		

AEC wastes which are dumped at sea are heterogeneous in character and as a rule contain quantities of activity normally associated with laboratory experimentation and with decontamination operations. For the most part, they consist of solid materials such as paper wipes, rags, maps, ashes, animal carcasses and contaminated laboratory paraphernalia. Some liquids containing radioactivity in the concentration range of microcuries per liter have been incorporated in cement mixtures or with chemical gelling materials prior to packaging and dumping. Because the wastes and their contaminating radioisotopes are heterogeneous in character, it is difficult to determine accurately the total quantities of radioactivity involved. Since the material is of no value very little analytical work is warranted

to determine these quantities. The operational objective is to dispose of the materials as efficiently and conveniently as possible so as to eliminate the nuisance and possible hazard associated with large waste accumulations.

Table 1 summarizes the currently available information on radioactive wastes dumped in the Atlantic Ocean by the U. S. Navy. The information supplied appears to be detailed, but the only numbers which can be authenticated are the total numbers of drums dumped annually. All of the other numbers are judgmental estimates. The categorized numbers of drums are probably close to actuality whereas the estimated curie content could be off as much as a factor of 10.

Packaging AEC Wastes for Sea Disposal: The great bulk of AEC wastes deposited in the sea is contained in 55 gallon drums. Several different methods of utilizing these drums for waste packaging are used, depending on the radioactivity of the waste; some of the most common are illustrated in plate 1. Second hand drums, reconditioned in some cases, are used throughout. Many of the drums are without tops.

All packages are weighted with concrete or other materials so that the average package density is sufficiently greater than sea water to assure sinking. Minimum AEC packaging requirements are as stipulated in the appended memo from the New York, AEC Operations Office.

AEC Atlantic Ocean Waste Dumpings: The wastes were categorized as in Table 1 because these groupings lump together wastes which are more or less of a kind and also uniform in concentration and amount of radioactivity. A brief description of the measure of radioactivity in these categories of packages follows.

Bale of compressed combustibles

Mixture of waste materials and concrete

30 gallon drum of ashes or solidified liquids

Preformed concentric cylindrical space for more radioactive wastes

Lead shielded space for irradiated and more radioactive wastes

Plate 1 Cut Away Isometric Views Showing Modifications of 55 Gallon drums for Pakaging Radioactive Wastes Which are Dumped in

The Atlantic Ocean

The category of combustible solids includes materials which are usually contaminated with mixed fission products or other beta-gamma emitters having half lives greater than one year. Dose rates up to 500 milliroentgens per hour at the surface of any package containing these wastes have been measured. The amount of radioactivity contained in the drum packages ranges from 0 to 1000 millicuries; the average is estimated to be nearer 50.

The category of other contaminated equipment includes such things as laboratory equipment and used air filters. Contamination is by beta-gamma emitters with half lives greater than one year. The amount of contamination ranges somewhat higher than the combustibles - as high as 30 curies per drum. The median figure, however, is probably closer to 200 millicuries per drum. These packaged wastes can register as high as one roentgen per hour at the package surface.

The category of irradiated materials includes reactor fuel samples and other reactor experiment materials and byproducts of isotope production.

These materials have fairly high specific activities. Containing packages, as can be seen in plate 1, have limited preformed spaces for wastes with lead and concrete shielding taking up most of the volume of the 55 gallon drums. The amount of radioactivity is usually limited to approximately 10 curies per package. Emitted radiation at the surface of a drum may be as much as one roentgen per hour.

The category of solidified liquids includes only low level liquid wastes. No other liquid wastes are disposed of at sea by the U. S. The radioactivity may be as concentrated to as much as one microcurie per milliliter and a drum package may contain as many as 100 millicuries. Some drums of solidified liquids read as high as one roentgen per hour at the surface of the drum.

Radioactive wastes from AEC operations are deposited in two areas of the Atlantic Ocean that have been previously designated by the Navy as "explosives dumping areas." Toxic chemical wastes and defunct munitions were dumped in these areas for several years before addition of radioactive wastes. Each of these areas is a 15 mile square, theoretically. The northernmost area is centered at 41°33' N Latitude, 65°30' W Longitude. Very few drums of wastes are dumped there - possibly twenty 30 gallon drum packages, or less, per year since 1951. The dump area which received the wastes listed in Table 1 is centered at 38°30' N Latitude, 72°06' W Longitude.

Both of these areas are located at the edge of the continental shelf where the water is about 1000 fathoms deep.

Non-AEC Government Operations: Table 2 summarizes sea disposal operations by other government agency laboratories. Except for the U. S. Fish and Wildlife Service's field installation at Beaufort, North Carolina, these laboratories are in the Washington, D. C. area.

The waste materials themselves are very much like those from AEC installations, but the radioactivity is unquestionably of a lower average magnitude than the radioactivity of the AEC wastes. A wide spectrum of isotopes is represented. The amounts of radioactivity noted as being disposed were recorded at the time of packaging, not at time of disposal.

Packaging varies among the agencies. The USF&WS disposes of their tracer experimentation wastes and residues directly to the sea without packaging - reportedly wastes which normally could be diluted and flushed into their sewerage system. The National Bureau of Standards and the

Naval Ordnance Laboratory package their wastes in much the same fashion as the AEC installations, i.e., with concrete inside 55 gallon drums. The National Institutes of Health and the Naval Research Laboratory uniquely package their wastes with concrete inside small size pre-cast-concrete burial vaults.

The USF&WS disposes of their wastes in an area 8 miles off shore from their installation at approximately $34^{\circ}32'N - 76^{\circ}40'W$. Wastes from the other agencies are disposed of by the U. S. Coast Guard in a (Navy) designated ammunition disposal area off Norfolk, Va., centered at approximately $36^{\circ}30'N - 74^{\circ}18'W$.

Private Operations: Table 3 summarizes waste disposal operations by private companies including the Crossroads Marine Disposal Company which is in the business of disposing of radioactive waste materials for others. The other firms listed dispose of their own wastes. In comparison with the operations of the AEC and the other agencies, these private waste disposal operations appear to be very small, radioactivity-wise.

The disposal locations used by these private companies are as varied as the listing of firms. It appears that the oil tankers dispose of their companies' wastes while enroute to foreign ports. Woods Hole Oceanographic Institute disposes of their radioactive wastes 2 miles off shore, while Crossroads Marine disposes the wastes it receives in Massachusetts Bay.

Upper Limit to Sea Disposal Operations

Table 4 is a listing of isotopes shipped from Oak Ridge to users east of the Mississippi River, but including Texas and Louisiana. This listing does not indicate the wastes which are disposed of in the sea, but it does

Table 2 - PAST AND PROJECTED AMOUNTS OF
RADIOACTIVE MATERIALS DISPOSED AT SEA
BY GOVERNMENT AGENCIES

Origin of Wastes	Activity Disposed 9/55-11/57	In Number & Kind of Packages	Activity to be disposed next 5 yrs.
USF&WS Beaufort, N.C.	0.235c(1)	none	0.4 curies short-lived
Nat. Bu Stds. Wash. D.C.	<84mc(2)	84 (55g. drums)	1.250c(3)
Nav. Ord. Lab. Silver Spring, Md.	none	55 g. drums	39.11c(4)
Nav. Res. Lab. Wash. D.C.	2.836c(5)(6)	29 vaults 2 (55g. drums)	435.55c(7)
Nat. Inst. Health Bethesda, Md.	1.15c(8)	29 vaults 5 (55g. drums)	56.05c(9)

- (1) 0.02c MFP, .015c Zn65, .08c Cs-137, .02c Ce-141, .025c Ca-45, .075c Sr89
- (2) less than 1 mc per package of mixture of C-14, S-35, Ca-45, Fe-55-59, Co-58, Sr-90 and Po-210.
- (3) 250 mc/yr of mixture of 33 isotopes from H3 to Ra-226 including Sr-90 and Cs-137.
- (4) 10c Co-58, 20c Sr-90, 5c Ir-192, 10mc I-131, 1c Tm-170, 2c Cs-137, 1c Fe-55-59, 1c Ra-226
- (5) 2.836 c of mixed activities
- (6) 4.2 curies of mixed activities sent to Crossroads Marine Disposal Co. Boston, Mass. in 59 containers
- (7) Plus or minus a factor of 2 of .15c Sr-90, 30c Co-60, 5c Cs-137, 0.2c Po-210-214, 0.2c Ra-226, 400c others
- (8) 0.1 mc to 400 mc per package of C-14, Na-22, S-35, Cl-36, Cr-51, Fe-55-59, Ra-226
- (9) 0.5c C-14, .05c Na-22, 50c H3, 5c S-35, 5mc Cl-36, 0.1c Cr-51, 0.1c Fe-55-59, 5mc Co-58, 0.1c Co-60, 0.05c Ca-45, 0.05c Sr-89, 0.1c Ra-226

indicate the isotopes which have been sold and (some of) which will end up as wastes. It does indicate an upper limit to the amount of waste which can be expected to be disposed for the period indicated no matter what the fashion; e.g., if one estimated, conservatively, that 10% of these isotopes would end up as wastes to be disposed of in the sea, the total number of curies would be relatively small. The sealed sources remain sealed, so their effect would be one of external radiation, principally gamma. Most of the isotopes listed have relatively short half lives so much of the activity would be decayed by the time it reached the sea.

Table 3 - PAST AND PROJECTED AMOUNTS OF RADIOACTIVE MATERIALS DISPOSED AT SEA
BY PRIVATE COMPANIES

Origin of Wastes	9/55-11/57	Amounts Disposed Next 5 yrs	Packaging	Location of Disposal (Depth)	Remarks
Atlantic Refining Co. Philadelphia, Pa.	3 drums 137 mc Fe55,59	50-250 mc of Sb 125, Co60	55g drum-concreted	32°30'N-75°45'W (1700.f) 2 30.mi Gulf of Mexico	180 mi off shore
Socony Mobil Oil Co. Paulsboro, N. J.	78 (55g drums) ea. with .01 mc Fe59 &.009 mc Fe55	1 to 2c each of Fe59, H3, C14, I131, P32 plus others		various (1)	200 lbs of sand per drum
Woods Hole Oc. Inst. Woods Hole, Mass.	?	?	Weighted, sealed cans	2 mi off shore	Licensed for 1489 total mc of C14, P32, S35, Na24, Cs45, K42, I131, Co60, Zn65, Fe59, Cu64
Magnolia Petroleum Co. Dallas, Texas	one 55g w/10c Co60	10c Co60 5c misc.	55g drum concreted	27°14'N-89°33'W (1200 f)	250 mi off shore
Crossroads Marine Disp. Co. Boston, Mass.	40 (55g drums) 1024 (30g drums) 170 (5g drums)		4" concrete surrounding 30 gal drum(s)	42°25.5'N-70°35'W (312 ft) 12 mi off shore	Licensed to possess 3c of Mass Nos 3-83
Johns Hopkins University Baltimore, Md.	4 (30g drums) 0.1mc Ag 110	5mc Sr89 5mc Cs134 5mc Ru106	Solid contam lab appar. surrounded by concrete within 30 gal drums	38°50' to 46°23'N (150 ft)	1 mi west of Kent Island

(1) 31°10'N-76°31'W; 31°53'N-76°28'W; 32°50'N-75°20'W; 25°10'N-85°17'W; 31°35'N-76°12'W; 29°38'N-77°27'W; 32°52'N-75°52'W;
31°02'N-76°48'W; 32°33'N-75°54'W

Table 4 - RADIOISOTOPES SHIPPED TO LICENSEES EAST OF
MISSISSIPPI RIVER PLUS TEXAS AND LOUISIANA

- January 1956 to September 1957 -

Iodine 131 - 1050 curies
Phosphorus 32 - 244.8 curies
Carbon 14 - 17 curies
H 3 - 247.5 curies in sealed sources
6219 curies as other material
Strontium 89-90 - 38.4 curies as sealed sources
1.93 curies as other material
Cobalt 60 - 17196 curies as sealed sources
2.97 curies as other material
Cesium 137 - 3786 curies as sealed sources
114 curies as other material
Iridium 192 - 9189.7 curies as sealed sources
20.5 curies as other material
Calcium 45 - 4.37 curies
Chromium 51 - 7.1 curies
Iron 59 - .98 curies
K 42 - 5.5 curies
Na 24 - 3.5 curies
S 35 - 21.5 curies
Zn 65 - 1.2 curies
Kr 85 - 361.3 curies as sealed sources
65.5 curies as other material
Copper 64 - 13 curies other isotopes
77.0 curies as sealed sources
270.5 curies other

The sealed versus the other are based on licensed quantities rather than shipped quantity.

APPENDIX III

Packaging of Contaminated (Radioactive) Scrap for Disposal

U.S. Atomic Energy Commission, NYOO
Health and Safety Laboratory
70 Columbus Avenue
New York 23, N. Y.

Appendix III

U.S. ATOMIC ENERGY COMMISSION
NEW YORK OPERATIONS OFFICE
HEALTH AND SAFETY LABORATORY
70 COLUMBUS AVENUE
NEW YORK 23, NEW YORK

PACKAGING OF CONTAMINATED (RADIOACTIVE) SCRAP FOR DISPOSAL

The New York Operations Office has arranged to assist local AEC contractors in disposing of limited quantities of incombustible waste contaminated by radioactive materials. It is important that any wastes which can be stored and permitted to decay to a suitable level for local disposition be handled in this manner. Incombustible waste may include any material that can be packed in accordance with I.C.C. regulations for labeled packages. Wherever practical, combustibles should be burned on site. This office should be consulted in case of question.

Combustible waste should include such materials as papers and rags, and may also include small amounts of broken glassware. Since it is generally incinerated without inspection, it should not include any materials which are explosive, either by nature or by virtue of the method of packing (such as liquid in a sealed container).

Packing - General

All waste should be packed to comply with the instructions set forth in the Manual pertaining to the Transportation of Radioactive Materials and Other Dangerous Materials. The radiation limits are 200 mr at the surface of the package and 10 mr per hour at one meter from the source. This is intended to cover only penetrating gamma radiation, but for our purpose should include beta plus gamma. There should be no detectable surface contamination on the outside of the package. A standard I.C.C. red label properly executed should be affixed if the radiation level exceeds 10 mr per 24 hours at any surface.

No accountable materials should be included. Such (Source and Fissionable) materials include normal uranium, thorium, enriched uranium or plutonium. Any waste or scrap involving these materials must be accounted for through the S.F. Accountability Branch, Technical Liaison Division.

Each package of incombustible waste should have affixed a green "Incombustible Contaminated (Radioactive) Waste" label signed by the person responsible or the shipment with the name of the shipper given.

1. Material shall be sealed in covered steel drums
2. Standard drums of 5 gallons, 30 gallons, and 55 gallons capacity shall be used.
3. Each drum shall be weighed before shipment, and clearly and permanently marked with its weight.
4. No drum shall be shipped unless its weight exceed the following:
 - 5 gallons - 50 pounds
 - 30 gallons - 300 pounds
 - 55 gallons - 550 pounds
5. No individual drum shall exceed 750 pounds
6. Any single unit too large to be inserted in a 55 gallon drum shall be packaged adequately for shipment and handling, and the package shall be marked as specified in Item 3, but shall state the lbs/cu.ft. of the final package.
7. Specific notice shall be given when any individual package exceeds 750 pounds.

Incombustible Waste

Materials which cannot be readily reduced in volume by incineration should be packed in a manner suitable for sea immersion. In general, this covers metal, glassware, or liquids. The material should be placed in a steel drum of either 5 or 30 gallon capacity and the drum filled with poured concrete to give a minimum density of 75 pounds per cubic foot. (This is approximately 10 pounds per gallon capacity). The drum should be made of 19 gauge (.0437") steel and the concrete at the top of the drum should be reinforced with steel wire screen or rods. If the radioactivity of the contents requires it, the material should be kept at the center of the container by means of a second inner container in order to utilize the outer layer of concrete as a radiation shield. Low level radioactive liquids may be introduced into a drum by using the liquid instead of water in preparing the concrete. Care should be taken, however, to keep the surface radiation within the prescribed limits.

If such incombustible package is to be sent by common carrier*, it should either have a top welded on in compliance with I.C.C. Specification 17X or be packed in an outer wooden container I.C.C. Specification 15A. In any event, the drum should be lidded in such a way as to enclose the concrete completely.

* See Shipping

Shipping

Arrangements for disposal of wastes in this manner should be made prior to preparation through the Administration Operations Division, Property Branch, NYOO. Specific instructions will then be given for shipment, including information as to whether common carrier is to be used.

At the time of each shipment NY Form 78 (Shipment Monitoring Record) should be filled out and forwarded to this office, attention Property Branch. Form 78 provides for a record of the nature of the material and an estimate of the activity. Please avoid use of the term "less than" in describing activity or radiation.

Materials and packages other than those meeting these specifications may be disposed of by special arrangements. Shipments not conforming to these specifications, for which no special arrangements has been made, will be refused unloading at the disposal site.

Necessary labels and forms may be obtained from this office.

APPENDIX 1V

An Analysis of Dispersal of Radioactivity from Local Sources on the
Sea Bed

R. O. Reid

APPENDIX IV

AN ANALYSIS OF DISPERSAL OF RADIOACTIVITY FROM LOCAL SOURCES ON THE SEA BED *

R. O. Reid

INTRODUCTION

The purpose of the following analysis is to establish upper limits on the concentrations of radioactivity which might occur in sea water under certain prescribed conditions of sources on the bottom in the relatively shallow water regions of the continental shelf. A number of assumptions must be made in regard to the diffusive properties of the water, the currents and the character of the sources. In all cases the assumptions utilized are deliberately taken to err in favor of large concentrations. In other words, the intent of the present analysis is not to give an accurate description of the diffusion processes but to give some limiting values of concentrations in the sea under the most extreme conditions which can be visualized.

The following stipulations apply throughout the present analysis :

- (a) The radioactivity of the sea water is not depleted by adsorption of the radio isotopes on the bottom.
- (b) The natural decay of the isotopes is neglected (i.e., the radioactive half life of the isotopes is considered infinite).
- (c) The diffusion process is considered to be Fickian (i.e., the diffusivity coefficient is isotropic and uniform throughout the sea water).

* Contribution from the Department of Oceanography and Meteorology of the Agricultural and Mechanical College of Texas, Oceanography and Meteorology Series No. _____.

(d) The ocean is considered to be of uniform depth, equal to the depth at the source and no flux of radioactivity is presumed to occur across the upper or lower boundaries (however, the special case of infinite depth is considered in part of the analysis).

The assumption of Fickian diffusion implies that the decay of activity concentration with distance from the source region is much slower than is known to occur under actual conditions in the presence of turbulence [Sutton (1953), p. 279] . The assumption of no adsorption on the sea bed and no natural radioactive decay obviously leads to an overestimate of activity concentrations within the sea water.

The problem is treated from both a gross source standpoint and an individual source point of view. In the gross source problem, we visualize that a specified amount of radioactivity is deposited continuously within a certain confined area of the sea bed per unit time and that this material is in a form which is subject to dispersal from the source area by diffusion and currents. Actually the material deposited is in the form of packages which may contain the material long enough that natural decay renders it harmless. On the other hand, the contents of packages may, conceivably, be subject to dispersal due to destruction of the container by impact or erosion or to dispersal through a continuous leaching action. This we presume occurs on the average at a rate equal to the average rate of addition of the packages. In other words, we visualize that the radioactive material is effectively flowing into the source area on the sea bed in solution form at a steady uniform rate and dispersing into the environment at the same rate. For all practical purposes the lateral extent of the environment (hence its capacity) can be considered infinite, and

the distribution of concentration steady.

Since the source area is actually a collection of discrete small sources, the question of micro-scale distribution of concentration arises. In this case the individual packages are treated as small but finite box sources of known volume and surface area. We consider two different problems in order to establish certain limits of activity concentration: (a) If the complete contents of the box are suddenly allowed to disperse into the environment we have the case of an instantaneous source and the resulting distribution of concentration in the environment is time dependent. (b) If the radioactive material is subject to a uniform rate of leaching through the walls of the box we have the case of a continuous source where a steady state of distribution of concentration is attained in the vicinity of the source. In both cases our interest focuses on the maximum concentration which may result at different distances from the source. For case (a) we are also interested in evaluating the time for which the activity concentration is above a prescribed value.

I. SUSTAINED GROSS SOURCE

We consider a source area on the sea bed with horizontal dimensions $L \times L$ in a depth of water D . Furthermore, we consider a uniform current of speed U parallel to shore. For large distances from the center of the source area, particularly if $D \ll L$, the source is essentially equivalent to a vertical line source contained between two parallel planes. If Q_1 represents the rate of supply of radioactivity of a given isotope to the source region (and also the rate of dispersal as well), then the concentration of radioactivity, C_1 , due to

isotope i at a distance x from the center of the source (in the direction of the current) is approximately

$$C_i = \frac{Q_i}{2D\sqrt{2\pi K U x}} \exp\left(-\frac{U y^2}{4K x}\right) \quad (1)$$

where K is the diffusivity coefficient (under turbulent conditions) and y is the transverse distance measured from the axis of the dispersed material (see Fig. 1). Eq. (1) applies for Fickian type diffusion and since it is restricted to distances x which are large relative to L , the formula cannot be used for concentrations within the source region. The equation is an adaptation of the formula given by Sutton (p. 137, Eq. 4.43) for a continuous line source across wind.* In the present case the plume is taken with a vertical plane of symmetry with the material from the source dispersing equally on each side; consequently we take half the source strength given by Sutton's formula (where the dispersal is confined to one side of the plane of symmetry only). However, if the source were very close to shore then Sutton's formula would apply directly. Thus the influence of the proximity of the shore can at the very most, increase the concentrations by a factor of two over those indicated by Eq. (1). This is small considering the fact that other safety factors involved in our present computations tend to give concentrations which are overestimated by at least one or even two orders of magnitude.

The maximum concentration for isotope i at distance x from the source is simply

$$(C_i)_{\max} = \frac{Q_i}{2D\sqrt{2\pi K U x}} \quad (2)$$

* Note that in Sutton's formula 4.44, U is omitted in the term $\sqrt{2\pi K U x}$; apparently this is a typographical error.

FIGURE 1
SCHEMATIC OF DISPERSAL FROM GROSS SOURCE

provided that $x \gg L$. This is the concentration along the axis of the plume (i.e., the x axis). In contrast with Eq. (2), Sutton (p. 276-7) indicates that the empirical results of smoke plume experiments indicates that the concentration is inversely proportional to the wind speed to the first power and also drops inversely as $x^{0.9}$ instead of as $x^{0.5}$, for a uniform line source. The formula based upon the Fickian diffusion therefore gives an upper limit of possible concentration at a given distance x and also overestimates the concentration in the presence of a moderate or strong current.

As numerical example, consider the following conditions:

$$Q_i = 100 \text{ curies per year for } \text{Cs}^{137}$$

$$D = 30 \text{ meters}$$

$$K = 1 \text{ cm}^2/\text{sec} \text{ (for stable stratification with weak currents)}$$

$$U = 10 \text{ cm/sec (approx. 5 n.mi/day)}.$$

Then

$$(C_i)_{\max} = 0.21 / \sqrt{x} \quad (3)$$

where $(C_i)_{\max}$ is in $\mu\text{C}/\text{m}^3$ and x is in kilometers. The estimate of K given above is really applicable for vertical mixing. Measurements of horizontal diffusion in the surface layers indicate values of K in excess of $10^3 \text{ cm}^2/\text{sec}$ (Ketchum and Ford, 1952 and Moon, et.al., 1957). Thus the values of concentration indicated by (3) are probably overestimated by at least one order of magnitude. However, since we know very little about the horizontal mixing near the sea bed, the very low value of K is taken as a factor of safety. Values of C_i as obtained from (3) for different distances from the center of the source are listed in Table I.

These are expressed in terms of activity per unit mass as well as volume of sea water.

TABLE I
 $Q_i = 100$ curies per year
 (C_s^{137})

x (km)	C_i	
	$\mu\text{c}/\text{m}^3$	$\mu\text{c}/\text{kg}$
1	0.21	.00021
2	0.15	.00015
4	0.10	.00010
10	0.07	.00007
20	0.05	.00005
40	0.03	.00003
100	0.02	.00002

II. ANALYSIS OF INDIVIDUAL SOURCES

A. Instantaneous Source

For an instantaneous point source in an infinite, isotropic medium in the absence of any mean current

$$C_i = \frac{M_i}{8(\pi K t)^{3/2}} \exp\left(-\frac{r^2}{4 K t}\right) \quad (4)$$

where t is the elapsed time from the instant of introduction of the isotope i of total radioactivity M_i , and C_i is the concentration of radioactivity due to this isotope at the distance r from the point of introduction (Sutton, p. 134). Here it is considered that the amount of radioactivity M_i occupies an infinitely small volume at $r = 0$ when $t = 0$, so that C_i is infinite at the source and $C_i = 0$ everywhere else initially. For a finite box source of dimensions $2a, 2b,$

h resting on a plane surface in a semi-infinite medium (see Fig. 2) we have for the total amount of radioactivity $M_i = 4abhc_{oi}$, where c_{oi} is the finite initial concentration of radioactivity in the source. The dispersion from the finite box source can be formulated from relation (4) by considering all sources within the finite box at positions x' , y' , z' and of strength $c_{oi} dx' dy' dz'$ thus :

$$C_i = \frac{C_{oi}}{8(\pi Kt)^{3/2}} \int_{-a}^a dx' \int_{-b}^b dy' \int_{-h}^h \exp \left[-\frac{(x-x')^2 + (y-y')^2 + (z+z')^2}{4Kt} \right] dz' \quad (5)$$

where c_{oi} is presumed uniform throughout the box source. The integration is extended over an image source below the surface in order to satisfy the boundary condition of zero flux through the horizontal plane at $z = 0$, and assures the continuity condition that the total amount of radioactivity of isotope i above the plane $z = 0$ is equal to M_i at all times.

Carrying out the integrations indicated in Eq. (5) gives

$$C_i = C_{oi} \left[\phi\left(\frac{x+a}{m}\right) - \phi\left(\frac{x-a}{m}\right) \right] \left[\phi\left(\frac{y+b}{m}\right) - \phi\left(\frac{y-b}{m}\right) \right] \\ \times \left[\phi\left(\frac{z+h}{m}\right) - \phi\left(\frac{z-h}{m}\right) \right] , \quad (6)$$

where

$$m = \sqrt{2Kt} \quad (7)$$

and $\phi(\beta)$ is the probability integral defined by

$$\phi(\beta) = \frac{1}{\sqrt{2\pi}} \int_0^\beta e^{-s^2/2} ds \quad (8)$$

and has the properties

FIGURE 2
GEOMETRY OF SINGLE BOX SOURCE

$$\phi(-\beta) = -\phi(\beta) \quad (8a)$$

$$\phi(\infty) = 1/2 \quad (8b)$$

It may be noted that for $|x| < a$, $|y| < b$, $|z| < h$, Eq. (6) gives $C_i = C_{oi}$ at $t = 0$ in view of (8a,b); while for $|x| > a$ or $|y| > b$ or $|z| > h$, $C_i = 0$ at $t = 0$ as desired.

For simplicity we will consider the special case where $a = b = h$ and hence the volume of the source is $4a^3$. At the point $x = y = z = 0$ in the source, Eq. (6) then reduces to

$$\frac{C_i}{C_{oi}} = 8 \left[\phi\left(\frac{a}{\sqrt{2Kt}}\right) \right]^3 \quad (9)$$

Thus the relative concentration C_i / C_{oi} at the center of the source is a function of Kt/a^2 only. For sufficiently large t ($t > a^2/K$),

$$\frac{C_i}{C_{oi}} \doteq \left(\frac{a^2}{\pi Kt} \right)^{3/2} \quad (10)$$

at the center of the source; while at $t = 0$, $C_i = C_{oi}$. A plot of the general relation (9) for the decay of concentration at the center of the instantaneous box source is shown in Fig. 3. The specific time scale at the top of this graph is based upon $K = 1 \text{ cm}^2/\text{sec}$ and $a = 36 \text{ cm}$ (corresponding to a volume of 0.186 m^3 or about 50 gal). The value of C_{oi} is of course given by

$$C_{oi} = \frac{M_i}{4a^3} \quad (11)$$

Thus if $M_i = 0.01$ curie for isotope C_s^{137} in one package source, then $C_{oi} = 54 \text{ m c/m}^3$ or $54 \text{ } \mu\text{c/kg}$, which would decay to a concentration of $0.06 \text{ } \mu\text{c/kg}$ in about 10 hours even without any mean current to aid the dispersal.

($K=1 \text{ cm.}^2/\text{sec.}$, $A=36 \text{ cm.}$, $V=49 \text{ gal.}$)

FIGURE 3

DIFFUSIVE DECAY OF CONCENTRATION AT SOURCE
SOURCE ON BOTTOM
 $D=\infty$

It should be emphasized that this analysis presumes that the radioactive contents of the package are suddenly released to the environment in a form which is subject to diffusion processes. The assumption of a semi infinite medium (infinite depth) was made in this case; the effect of finite depth will be felt when the material has diffused significantly to the actual surface, which occurs only after C_i at the source has dropped by a factor of about 1000. Thus Fig. 3 should be adequate up to about 10 hours even if the depth is of the order of 30 meters.

It can be shown that for sufficiently large distances from the finite box source ($r \gg a$), Eq. (6) reduces approximately to

$$\frac{C_i}{C_{oi}} = \left(\frac{a^2}{\pi K t} \right)^{3/2} \exp \left(- \frac{r^2}{4 K t} \right). \quad (12)$$

In view of Eq. (11) this formula is the same as the point source formula (4) if the source strength is taken as $2M_i$ (to account for the boundary effect which is represented by an image source of strength M_i).

If an upper boundary is imposed at $z = D$, through which no flux can occur then we must add a succession of image sources along the z axis at intervals of $2D$ above and below the actual source in order to achieve the correct boundary conditions at both top and bottom. The resulting relation for C_i for $x, y > D$ and sufficiently large t is

$$\frac{C_i}{C_{oi}} = \frac{a}{D} \frac{a^2}{\pi K t} \exp \left[- \frac{(x^2 + y^2)}{4 K t} \right] \quad (13)$$

which corresponds to a uniform line source of strength $4a^3 C_{oi}/D$ along the

z axis between the planes $z = 0$ and $z = D$. Eq. (12) applies for small t while Eq. (13) applies for large t after the upper boundary begins to significantly effect the dispersion.

Our main interest lies in the maximum concentrations which occur at different distances from the source. It can be seen from either Eq. (12) or (13) that the exponential term increases as t increases while the term t^{-1} or $t^{-3/2}$ decreases. Hence there exists a particular time for each position at which C_i is a maximum.

The time of maximum C_i from Eq. (12) is readily found to be

$$t_m = \frac{r^2}{6K} \quad (14)$$

and that for Eq. (13) is

$$t_m = \frac{r^2}{4K} \quad (15)$$

Substituting these expressions into Eq. (12) and (13) respectively gives for the maximum concentrations of radioactivity at r :

$$\frac{C_{mi}}{C_{oi}} = \left(\frac{6}{\pi e} \right)^{3/2} \left(\frac{a}{r} \right)^3 = 0.59 \left(\frac{a}{r} \right)^3 \quad (16)$$

for $a < r < D$ and

$$\frac{C_{mi}}{C_{oi}} = \frac{4}{\pi e} \frac{a}{D} \left(\frac{a}{r} \right)^2 = 0.47 \frac{a}{D} \left(\frac{a}{r} \right)^2 \quad (17)$$

for $r > D$ where r is the radial distance from the source along the bottom. It is of interest to note that the maximum concentration at any position r is independent of the diffusivity coefficient K . However, the time at which this

maximum concentration occurs certainly depends upon K as we see from Eq.(14) and (15). As a matter of fact K is essentially a measure of the rate of spreading of the material from the source, in the sense that $d\sigma^2/dt = 2K$ where σ is the standard deviation of the distribution of C_i about the source at time t .

The maximum relative concentration of radioactivity, C_m/C_o , for a given isotope as a function of relative distance from the source is shown in Fig. 4. Curve (1) corresponds to Eq. (16) and curve (2) to Eq. (17), the latter applying to the special case of $D/a = 100$ (i.e., $D = 36\text{m}$ for $a = 36\text{ cm}$). For any r/a , the curve with the greatest C/C_o governs; thus curve (1) governs for $r/a < 100$, curve (2) for $100 < r/a < 2000$. For $r/a > 2000$ ($r > 0.5\text{ n.mi.}$) other considerations enter in establishing the maximum concentration which might occur at large distance from the individual source.

If we suppose that $M_i = 0.01$ curie for isotope Cs^{137} for a single package source ($C_{oi} = 54\text{ }\mu\text{c/kg}$), then the maximum radioactivity by this isotope is about $.0015\text{ }\mu\text{c/kg}$ at 10 m from the source, $3 \times 10^{-6}\text{ }\mu\text{c/kg}$ at 100 m and $4 \times 10^{-8}\text{ }\mu\text{c/kg}$ at 1 km. It must be remembered however, that these values apply to but one package (assuming $M_i = .01$ curie for Cs^{137}); the total concentration of radioactivity at a given position is the sum of the effects from all packages and all isotopes in the source area.

At a distance of about 1 km from an instantaneous package source C_m/C_o is about 8×10^{-10} . If the sum total of all packages for a year were

FIGURE 4

RELATIVE CONCENTRATION VERSUS DISTANCE FROM SOURCE

suddenly dispersed from a common origin simultaneously, and $M_i = 100$ curies for the total activity of C_s^{137} , then C_m would be about $.0004 \mu\text{c/kg}$ at 1 km . This is only twice that given in Table I based upon a continuous supply at the rate of 100 curies per year.

B. Continuous Source at Uniform Leaching Rate

In the preceding analysis it was considered that the total material in the package source was released instantaneously. Consider now that the walls of the container are permeable and of thickness proportional to the size a . We will make the following hypothesis: the amount of radioactivity diffusing through the permeable walls per unit time is directly proportional to the surface area of the container, directly proportional to the difference in concentrations inside and immediately outside the container and inversely proportional to the thickness of the walls. Thus if Q_i is the rate of leaching for a given isotope then it is presumed that

$$Q_i = k_i \frac{A \Delta C_i}{a} \quad (18)$$

where ΔC_i is the concentration inside the container minus that at the outer walls, A is the exposed surface area and k_i is a constant for the isotope considered.

For a box of dimensions $2a \times 2a \times a$ resting on the bottom, $A = 12a^2$ while the volume is $4a^3$. In the initial stage the concentration outside the box will be very small compared with that inside and we can take as the upper limit of ΔC_i simply $M_i / 4a^3$ (the initial concentration in the box). Thus

initially

$$Q_i = \frac{3 k_i M_i}{a^2} \quad (19)$$

For a sustained point source in an infinite medium, in the absence of a mean current, Sutton (p. 135) gives the formula

$$C_i = \frac{Q_i}{4 \pi K r} \quad (20)$$

We can apply this for moderate r ($a \ll r < D$), provided that an image source of equal strength is taken adjacent to the actual source at the bottom. In this case the concentration at moderate distances is given by

$$C_i = \frac{3}{2 \pi} \frac{k_i}{K} \frac{M_i}{a^2 r} \quad (21)$$

or in dimensionless form

$$\frac{C_i}{C_{oi}} = \frac{6}{\pi} \frac{k_i}{K} \frac{a}{r} \quad (22)$$

where $C_{oi} = M_i / 4a^3$ as before. The coefficient k_i represents an effective diffusion coefficient through the permeable walls, and may be taken as the molecular diffusivity times the porosity of the walls. If we consider the order of magnitude of k_i as $10^{-6} \text{ cm}^2/\text{sec}$ and K as $1 \text{ cm}^2/\text{sec}$ then

$$\frac{C_i}{C_{oi}} \approx 2 \times 10^{-6} \frac{a}{r} \quad (23)$$

This relation is plotted as curve (3) in Fig. 4, and as indicated corresponds to the condition of infinite depth of water.

If D is taken finite then the source can be considered as a line source distributed over a vertical column of depth D when considering the effect at very

large distances ($r > D$). However, in the case of a line source in the absence of current, a steady state of concentration is not possible; the diffusive flux is not sufficiently great at large distances, and the concentration continually builds up in the presence of a sustained source. The concept of no mean current at all is quite unrealistic, and as we have seen from the analysis of part I, a steady state of C_i is possible in the presence of a sustained source and a current U which leads to a relation of the type C_i proportional to $x^{-1/2}$.

Using relation (19) we can investigate the question: What order of magnitude of M_i is required for all packages in the disposal area in order to develop a gross Q_i for the area which is equal to the average rate of addition of activity of a given isotope to the area, assuming that the dispersal is governed by leaching (rather than by destruction or erosion of the packages)? In other words, what is the equilibrium level of activity in all packages in the disposal area considering a continued supply of packages per year?

If we consider Q_i as the average rate of addition of activity for isotope i to the disposal area, then for all packages in the disposal area

$$\sum M_i = \frac{a^2}{3k_i} Q_i \quad (24)$$

Estimating k_i as $10^{-6} \text{ cm}^2/\text{sec}$ as before and taking a as 36 cm gives

$$\sum M_i \simeq 14 Q_i \quad (25)$$

where Q_i is expressed in terms of curies per year and $\sum M_i$ in curies. Thus if our estimate of k_i is reasonable, it will take 14 years accumulation of packages in the area to maintain a steady dispersal equal to the rate of supply, assuming that leaching governs the dispersal rate. This discloses an important

point, so far neglected; for isotopes of relatively small half lives (say of the order of a year or less), the material deposited 14 years earlier will have decayed by containment to a very small level. By ignoring the natural decay, it is obvious that our considerations of the activity in the medium is far over-estimated.

One final question which might be considered is the following: Suppose a steady state has been established, with a 14 year accumulation of activity in the disposal area; then what activity concentrations could be developed in the water around the source area, if all of the packages are suddenly destroyed by an unforeseen catastrophe? To answer this we may refer to Eq. (17) and use

$$C_{oi} = \frac{\sum M_i}{4a^3} \quad (26)$$

Thus for $r > D$

$$C_{mi} = \frac{0.47}{4Dr^2} \sum M_i \quad (27)$$

If we take

$$D = 30 \text{ meters}$$

$$\sum M_i = 14 \times 100 \text{ curies}$$

for Cs^{137}

and

$$r = 1 \text{ km}$$

then

$$\begin{aligned} C_{mi} &= 5.5 \mu\text{c}/\text{m}^3 \\ &= .0055 \mu\text{c}/\text{kg} \end{aligned} \quad (28)$$

SUMMARY

A number of formulas have been given in the preceding discussion in the attempt to shed some light on the question of maximum conceivable concentrations of radioactivity which may result in the vicinity of a low level radioactive disposal area on the sea bed in relatively shallow water. The distribution at distances well outside the disposal area is reasonably illustrated by Table I which is based upon Eq. (27) for a water depth of 30 meters, a very small diffusivity ($1 \text{ cm}^2/\text{sec}$) and a relatively weak current (5 n.mi./day), and applies to the case of Cs^{137} at an estimated supply rate of 100 curies per year. Concentrations for other isotopes can be estimated by proportion (based upon their rate of supply relative to 100 curies/yr).

The maximum possible activity concentration in the water within the disposal area is simply the concentration within any individual package (C_{oi}), considering that the package is suddenly destroyed. The peak concentration as a function of time at the source, in this event, is shown in Fig. 3. The maximum relative concentration as a function of distance based upon a single source is shown in Fig. 4. This is pertinent only in consideration of the distribution of concentration within the disposal area.

An analysis of the rate of leaching of the packages indicates that an accumulation of the order of 10 to 20 years is required in order to establish an overall leaching rate which equals the rate of accumulation. This indicates that the natural decay, which is ignored in the preceding considerations will lead to concentration much less than the example computations given in Table I, if it is considered that leaching is the governing factor in regard to the supply of radioactivity to the water.

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APPENDIX V

Coastal Circulation

B. H. Ketchum and D. F. Bumpus

APPENDIX V

Coastal Circulation

By B. H. Ketchum and D. F. Bumpus
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The general features of the non-tidal circulation adjacent to the east coast of the United States are fairly well known and have been reiterated in the recent NAS-NRC Publication 551. This present memorandum will consequently be very brief.

Our knowledge of the circulation in these waters results from the studies of Bigelow, 1927; Redfield and Walford, 1951; Ketchum, Redfield and Ayres, 1951; Miller, 1952; Bumpus, 1955 and Day, in press. These studies were based on the distribution of temperature and salinity in the sea, direct current measurements at lightships, the returns from drift bottles broadcast throughout the area and more recently the observed drift of telemetering buoys in a limited area.

In the offings of estuaries we may expect a seaward flow of river effluent and a landward flow of sea water necessary to maintain the distribution of salinity in the brackish part of the estuary. Where there is a vertical density discontinuity, the inflow of sea water will be at the bottom. At times of vertical uniformity of density, the inflow of sea water may be horizontally separated from the outflow and will generally lie on the right side facing the estuary. During the seasons of the year when there is no pycnocline we might expect the non-tidal motions at depth to be quite comparable to those at the surface. During the time when the pycnocline is well developed the shear may be quite pronounced and motions at depth quite dissimilar to those at the surface.

In general the circulation in the Gulf of Maine comprises a counter clockwise eddy. The drift along the Maine - Massachusetts coast is southerly, on the order of 2 - 6 miles per day (4 - 13 cm/sec). The southerly part of the circulation, i.e. in Massachusetts Bay is comprised of two drifts, one anti-clockwise around Cape Cod Bay, and one across the mouth of Massachusetts Bay toward the outer coast of Cape Cod and thence southerly. The drift from Georges Bank is generally west during the spring and summer but more offshore and perhaps even easterly during the autumn and winter.

South of Massachusetts, Rhode Island and New York the coastal drift tends to be westerly, 3 - 5 miles per day, (6 - 11 cm/sec) and from the offing of New Jersey southward to Cape Hatteras the set is southerly with speeds varying from 5 - 15 miles per day (11 - 32 cm/sec).

From Cape Hatteras to Georgia the surface non-tidal drift tends northeasterly at speeds of 0.2 to 12 miles per day, (.4 to 26 cm/sec) with the highest concentrations of drift bottle strandings on the southern side of the Capes. From Georgia to Daytona Beach the set appears to be southerly and from Daytona Beach south the drift appears to be northerly (unpublished data).

Redfield and Walford (1951) noted that "wastes likely to be transported to beaches in the surface layers should be carried at least 10 miles to sea if contamination of beaches is to be avoided". The percentage frequency of strandings of drift bottles from areas off the U. S. coast, Figure 1, indicates the variation in what may be construed as onshore or offshore areas of drift. The contours extend farthest offshore in the Gulf of Maine and south of Nantucket. They creep in toward the mouths of the Hudson River, Delaware and Chesapeake Bays. On

the other hand, on either side of the mouths of these estuaries the frequency of returns is high. Note also the high percentage returns from bottles dropped from Georgia southward.

As to bottom water, there are three items which might be mentioned:

a. There is an area extending from south of Nantucket Shoals westward to the offing of New York from about 30 fathoms to 50 fathoms which appears to be somewhat isolated from the general circulation pattern. Following the vernal development of the pycnocline this lens of water retains its winter characteristics, remains in the same geographic location and does not become modified until the autumn overturn. There appears to be restricted interchange of some of the water seaward with slope water. In other words the portion of the continental shelf below the pycnocline tends to stagnate for about 6 months of the year.

b. Our observation posts on lightships reveal a mid-summer inshore movement of bottom water along the coast from Virginia to New Jersey and subsequent upwelling, presumably due to off-shore movement of surface waters due to wind shear. How far inshore of the lightships this intrusion occurs we do not know.

They also suggest a downwelling during the coldest parts of the winter when waters next to the coast chill to low temperatures and subsequent offshore movement when resulting densities reach below those of the adjacent offshore waters. This mechanism appears to occur in areas farthest from river mouths where the

salinity inshore is highest. This phenomenon has been observed at Nantucket Shoals where the bottom offshore movement was deduced to reach 2 miles per day (4 cm/sec) and south of Long Island where chilled coastal water contributed to the offshore lens of cold water.

c. The pycnocline develops only very weakly in the coastal areas south of Cape Hatteras, hence allowing for greater vertical mixing, compared to the pycnocline developed north of Hatteras.

Woods Hole Oceanographic Institution
19 March 1958

B. H. Ketchum
D. F. Bumpus

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Percentage frequency of stranding on North American shores of drift bottles launched in adjacent coastal waters. Stippled areas - over 50% returns.

APPENDIX VI

Permissible Sea Water Concentration- Monitoring of Disposal Areas

B.H. Ketchum & W.A. Chipman

APPENDIX VI

PERMISSIBLE SEA WATER CONCENTRATION-MONITORING OF DISPOSAL AREAS

B.H. KETCHUM and W.A. CHIPMAN

In considering permissible seawater concentrations of various radioisotopes the ultimate criterion is the hazard to man. In the absence of evidence to the contrary we have assumed that the hazard to the marine biota is probably no greater than the hazard of an equivalent body burden of the isotope to man, and some evidence indicates that the body burden of marine organisms can be greater than that in man without danger. Presumably therefore water which would be safe on its radioisotope level for man to drink would also be safe for fish and other members of the marine biota to live in.

The radioisotope hazard to man has been carefully evaluated in establishing the maximum permissible concentration (MPC) for drinking water. These values have therefore been used as the basis for our calculations. This has the additional advantage that any change in the MPC would automatically produce a comparable change in our suggested permissible concentrations for seawater.

As a first step in the evaluation of the present magnitude of the problem of low level waste disposal we have compared the total supply of radioisotopes with the maximum permissible concentration for drinking water in order to determine the volume of water necessary to achieve such a dilution. The results of this tabulation are given in Table I. The entire amount of radioisotopes (exclusive of sealed sources) shipped to licensees east of the Mississippi River plus Texas and Louisiana between January 1956 and September 1957 have been used as an index of the rate of supply (AEC, 1957).

The isotope requiring the maximum dilution in Table I is iodine 131 which would require 3.5×10^7 cubic meters. This volume would be contained under one nautical square mile of sea surface area in water that was ten meters deep. Since, however, iodine-131 has a half life of only eight days it is obvious that it would be largely decayed before disposal in the sea. For elements with longer half lives strontium is the most critical one and would require a diluting volume of 2.4×10^6 cubic meters; a volume which would be contained under a surface area of somewhat less than .1 of a square mile 10 meters deep.

All of the other radioisotopes listed in Table I would require far smaller volumes for adequate dilution to achieve the maximum permissible concentration for drinking water. It appears, therefore, that the present production of radioisotopes as listed in Table I could all be dispersed directly in a small area of coastal waters with no hazard to marine resources or to man. Actually, because of other methods of disposal, and of the

effects of storage in the containers in which they are originally dispensed, only a small portion of this activity is reaching the sea at present.

Many of these elements will be concentrated by the marine biota and it is worth considering what effect such accumulation would have upon the marine biota itself and ultimately upon the possible hazard to man. In terms of the hazard to the individual marine species there is no evidence that concentrations of elements comparable to the MPC established for drinking water would have deleterious effects on marine organisms, even if they lived their entire lifetime in such concentrations. As indicated above, a very small area of the continental shelf of the United States appears to be adequate to dilute the radioisotopes to these concentrations, and it seems highly unlikely that any species other than sedentary ones which are firmly attached to the bottom would remain in such an area for more than a small fraction of their life.

In terms of the hazard to man, it is necessary to evaluate the total potential intake from seafood as a source. It will be remembered that the MPC was derived from the total body burden on the assumption that an individual would drink about 15 liters of water weekly. The product of 15×10^3 cc and the MPC (microcuries per cc.) thus is the weekly intake permissible for the human body. It should furthermore be realized that such an intake for a period of thirty years is required to develop the permissible body burden.

In contrast to the drinking of water, man's habits in terms of the eating of seafoods are extremely variable. According to Taylor (1951) the average U. S. consumption of seafoods is approximately 10 pounds per year. Comparable figures for other countries are France, 20; Great Britain, 48; Japan, 111 pounds per year. The average consumption of seafood, however, has little significance since large proportions of the population live far from the sea coast and eat little or no fish or other marine products. When compared to meat consumption as the sources of protein a man would have to eat approximately four pounds of fish weekly in order to match the average U. S. protein consumption. It has seemed to us reasonable to take such a value as the extreme case of an individual subsisting almost entirely on fish as the source of protein in his diet.

The permissible seawater concentration (PSC) may be related to the maximum permissible concentration by the following equation:

$$MPC \times D = PSC \times f \times F$$

in which D is the amount of water (cc) drunk in a week, f is the concentration factor by marine organisms, and F is the amount of seafood ($\text{kg} \times 10^{-3}$) consumed per week. The amount of fish consumption in this equation must be expressed in terms of cubic

Table I. Supply of radioisotopes and the volume of water required to dilute them to maximum permissible concentrations. (drinking water)

Radioisotope	Supply curies	MPC $\mu\text{c/cc}$	MPC Diluting Volume m^3	Concentration factor ¹	PSC $\mu\text{c/cc}$	PSC Diluting volume m^3
Iodine 131	1050	3.10 ⁻⁵	3.5.10 ⁷	100	3.10 ⁻⁶	3.5.10 ⁸
Phosphorus 32	244.8	2.10 ⁻⁴	1.2.10 ⁶	4.10 ⁴	5.10 ⁻⁸	4.8.10 ⁹
Carbon 14	17	3.10 ⁻³	5.4.10 ³	--	--	--
Tritium	6219	.2	3.10 ⁴	--	--	--
Strontium 89-90	1.93	8.10 ⁻⁷	2.4.10 ⁶	10	8.10 ⁻⁵	2.4.10 ⁶
Cobalt 60	2.97	2.10 ⁻²	1.5.10 ²	10 ⁴ /3/	2.10 ⁻⁵	1.5.10 ⁵
Cesium 137	114	1.5.10 ⁻³	7.6.10 ⁴	50 /4/	3.10 ⁻⁴	3.8.10 ⁵
Iridium 192	20.5	9.10 ⁻⁴	2.3.10 ⁴	--	5.10 ⁻⁴	8.8.10 ³
Calcium 45	4.37	5.10 ⁻²	8.8.10 ³	10	--	--
Chromium 51	7.1	5.10 ⁻²	1.4.10 ²	--	4.10 ⁻⁶	2.5.10 ⁵
Iron 59	.98	4.10 ⁻³ *	2.5.10 ²	10 ⁴	10 ⁻²	5.5.10 ²
Potassium 42	5.5	1.10 ⁻²	5.5.10 ²	10	1.6.10 ⁻¹	2.2.10 ¹
Sodium 24	3.5	8.10 ⁻³	4.4.10 ²	0.5	1.10 ⁻²	2.2.10 ³
Sulphur 35	21.5	5.10 ⁻³	4.3.10 ³	5	1.2.10 ⁻⁴	2.2.10 ⁴
Zinc 65	1.2	6.10 ⁻²	20	5.10 ³	1.6.10 ⁻⁴	1.0.10 ⁶
Copper 64	270.5	8.10 ⁻²	3.5.10 ³	5.10 ³	1.6.10 ⁻⁴	1.8.10 ¹⁰

1. The concentration factors for the soft tissues of vertebrates or invertebrates, (whichever is higher) from Revelle and Schaeffer, (1957), Table 6.
2. Permissible sea water concentration from Equation (1) assuming a seafood consumption of 1.5 Kg/wk. - all derived from contaminated water.
3. Maximum factor reported by Ketchum & Bowen (in press) for concentration in plankton species.
4. Data for soft tissues of oysters from Chipman. Factor in Revelle and Schaeffer is 10.

* Iron 55-59 MPC.

centimeters, or for convenience as kilograms $\times 10^{-3}$ which assumes a specific gravity of one for the wet weight of fish.

The left-hand side of the above equation indicates the allowable total quantity of an element ingested by man in microcuries per week; the right-hand side indicates an identical quantity accumulated in seafood living in contaminated water. It is known that the efficiency of the assimilation of elements from solid material is less than the efficiency of the assimilation from water, but this effect is neglected in our considerations.

If we assume a fish consumption of 1.5 kilograms per week the PSC would equal the MPC in the above equation for those elements having a concentration factor of one. As the concentration factor in the marine organisms increases it is necessary to either set lower limits for the PSC or to insure that less than 1.5 kilo of seafood living in the contaminated water is caught and eaten by an individual. The PSC for the various elements are listed in Table I and the diluting volumes have been recalculated on the basis of these concentrations. Phosphorus now turns out to have the greatest required diluting volume with iodine-131 a close second. Both of these elements have half lives so short that it is likely that each would be decayed to 0.1% of the supply before reaching the environment. It does indicate, however, that assurance should be had that at least 10 half lives of decay should occur for these elements before sea disposal. Using the PSC as the basis for required dilution, strontium 90 would require a square mile of seawater 10 meters deep, copper about half a square mile, and cesium and iron less than a tenth of a square mile.

In conclusion it should be re-emphasized that several factors of safety are inherent in these computations, but it should also be emphasized that uncertainties exist concerning the concentration factors and the effects of radioisotopes on the marine biota. One factor of safety is that we have selected a rate of seafood consumption which is far greater than the national average but which is realistic in terms of the quantities eaten by the Japanese and perhaps by some coastal U. S. communities. Another factor of safety is that elements are assimilated less readily from solid food, such as fish, than they are from drinking water and we have assumed these rates of assimilation to be equal. A third and more important factor of safety is that these calculations assume that all of the fish eaten comes from the small area of the ocean which is used for the disposal of these wastes. Still another factor of safety lies in the simplified approach we have taken to compute the diluting volume. We have assumed that all of the radio elements produced in 18 months at Oak Ridge would be introduced into a single disposal area simultaneously, an assumption which is obviously fallacious. In any actual waste disposal at sea the rate of supply would be much slower than this and since currents would be washing past the location constantly the volume of water available for dilution would be enormously greater than the volume which

actually exists over the bottom at any given time.

If the quantities of radioisotopes being considered for sea disposal were sufficient so that the above calculation suggested a potential hazard it would be worth re-evaluating some of the assumptions and eliminating some of the excessive factors of safety which are included in the calculation. However, this seems unnecessary at the present time since our calculation shows that, even under the assumed conditions, which are the worst which could be postulated, the chances of hazard to human beings are negligible.

Monitoring of Disposal Areas

It is strongly recommended that a continuing system of monitoring of the disposal area should be established. Each disposal area selected should be surveyed prior to any disposal operations to establish the normal condition (except those already in use for the disposal of radioactive wastes) and should be revisited periodically after disposal operations start. For each area selected, a nearby "control" area should also be selected so that the normal fluctuation in the area can be compared with those which occur in the disposal area itself. Insofar as possible the control area should be upstream of the disposal area as indicated by the normal non-tidal drift and should be far enough away from the disposal area so that oscillating tidal currents could not be expected to carry contaminated water to a control area during any stage of the tidal cycle.

One of the important reasons for a monitoring system is that of public relations - to assure the public that the operation is in no way creating a hazard to man. An even more important purpose of the monitoring, however, is to evaluate the recommendations and conclusions of this committee. Although our conclusions have been based upon the best scientific evidence now available, the committee is acutely aware of the fact that too little is known to evaluate many of the variables which we have had to consider. The committee feels that its recommendations have been over-conservative in order to provide the maximum factor of safety against the development of a hazard to man. If the monitoring system is carefully devised to evaluate the variables as well as to describe conditions as they exist at a given time a much better foundation for later recommendations will be available. A carefully planned monitoring program will serve three purposes, that of public relations, the evaluation of the conclusions and recommendations of this committee, and the development of a fund of basic information which will be required for ultimate revision or modification of these recommendations as, if or when the quantities of radioisotopes to be disposed in the sea increase in the future.

Our conclusions have been based upon assumptions which include the worst possible combination of circumstances to assure

adequate safeguards. Thus for example we have assumed that the container will not be adequate and will allow immediate dispersion in the water, that all of the radioisotopes produced by Oak Ridge would be placed in one area in the coastal waters of the United States, that the currents and dispersion expected in the area will be the minimum to be expected along the continental shelf, that all of the seafood eaten by some unidentified man would come from this single area, and that this unidentified man would eat unusually large quantities of fish compared to the national average, enough to obtain all of his protein supply from seafood. Even by assuming all of the worst possible conditions it appears certain that there would be no hazard if the total annual output of radioisotopes by Oak Ridge were disposed and evenly dispersed in one coastal disposal area one mile square. It seemed unnecessary at the present time therefore to attempt to evaluate the numerous factors of safety in our conclusions, especially since in many cases additional data will be necessary before final evaluation can be made. As a result of these factors of safety, however, it seems highly probable to the committee that the requirements we have established could be relaxed substantially if it becomes necessary or desirable to dispose of larger quantities of radioisotopes in the sea.

Because of these factors of safety, however, the committee is well aware of the difficulties which will be presented in planning the monitoring program. Since it seems probable that the isotopes will be released from the containers at a much lower rate than we have anticipated and since the coastal non-tidal currents are substantial (as much as 5 miles per day) the detection of radioactivity from the disposed material in the seawater will be extremely difficult. It is therefore apparent that direct counts on the water, or even on crude concentrates, will be useless. The low level radioactive wastes to be dumped in the disposal areas are varied in character and their radioactivity results from an assortment of many different radioisotopes. The hazardous nature of the wastes depends on its radionuclide composition. Consequently, not only need the total radioactivity of the water be known, but the isotopes contributing the major part of the radioactivity should be identified. Measurement of radioactivity at low concentrations in seawater is difficult and identification of the radioactive components even more difficult. Large volume samples will have to be processed and analyzed by the best available techniques. The methods are not specified because it is believed that they will improve with time. The level of radioactivity which should be considered adequate should be comparable to the levels of strontium measured in Atlantic water by Bowen and Sugihara (1957) who determined 6 - 12 d/min/100 l. by a method which had a sensitivity of about 10^{-11} $\mu\text{c/cc}$ (Bowen, private communication).

Use of the biological system as a pre-concentrator of radio elements offers promise of value as a monitoring technique. Plankton appears to be one of the most sensitive indicators of radioactivity in the sea (Harley, 1956; Donaldson et al., 1956;

Seymour, et al., 1957) and the movement of plankton with water currents is particularly useful in following the movement of radioactivity in the sea. Laboratory tests employing marine phytoplankton have demonstrated the great variety of radioactive materials accumulated and may provide information allowing quantitative estimation of particular radionuclides in the water. The plankton, however, drift with the water and may not remain in the contaminated area long enough to accumulate the maximum possible concentrations of radio elements.

The fact that many bottom dwelling invertebrates are sessile or have limited migration may prove advantageous since they will be bathed constantly in the contaminated water. Many of these concentrate elements of sea water to remarkably high levels. A species of benthic foraminifera has been shown to concentrate Zr^{95} and Ru^{106} to a marked degree (Martin, 1957) and bottom dwelling pelecypods concentrate many of the minor elements, particularly trace metals, such as Zn^{65} (Chipman et al., in press) and Co^{60} (Gong et al., 1956). The calcareous shells of molluscs and the skeletal structures of fish have been suggested as a means of calculating water concentrations of Sr^{90} (Hiyama, 1957) and may be useful for estimation of water concentrations of other bone-seeking radionuclides. It is anticipated that particular organisms of a marine environment will be of special use for such bioassay procedures and exact concentration factors for many radionuclides are now being investigated.

A number of the radio elements - especially the rare earths - are very surface active and may be expected to adsorb strongly on silts and clays in the water and in the bottom sediments. Any monitoring system should include extensive analyses of the bottom sediments - especially if a method can be devised for collection of the upper few centimeters to avoid dilution with old unaffected sediments.

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APPENDIX VII

Fishing Intensity - Northeastern Coastal Waters

H.H. Eckles

APPENDIX VIII

Submarine Cable Locations

B. C. Heezen

APPENDIX IX

Disposal Areas

D. F. Bumpus and H. H. Eckles

APPENDIX IX

DISPOSAL AREAS

D. F. Bumpus and H. H. Eckles

In the process of suggesting sites for the disposal of low level radioactive wastes the following have been taken into consideration:

- Danger to man and the biota
- Nuisance to fishing interests
- Tidal and non-tidal circulation
- Storms driving material ashore
- Submarine cable locations
- Navy restricted and danger areas
- Public education.

Inasmuch as there are a number of disposal areas presently available as "explosives dumping area" or "dumping ground (by permit only)", some of which have been used heretofore for the disposal of low level radioactive wastes as well as for certain toxic chemical wastes, we have included these areas in the list of suggested sites. We have numbered the sites 1 - 12. Alternate sites have been marked with the subscript a or b indicating that they might be used as secondary disposal areas but are more inconvenient to reach than the primary disposal area.

Most of the dumping areas are large: 10 x 10 miles, 10 miles in diameter, or the like. We have indicated the centers of these areas with one exception. Additional sites listed below might be two miles in diameter centered on the positions given. Sites presently listed in

"A special report on disposal of radioactivity into Atlantic Ocean waters - Past, present, and predicted", U.S.A.E.C. Division of Reactor Development, November 1957, are marked with an *.

To serve Boston, Massachusetts:

- 1* 42° 25.5' N 70° 35' W 312' 2 miles in diameter, marked "Foul Area, Explosives" presently used by Crossroads Marine Disposal Company, 22 miles from Boston, Chart 1207

- 1a* 41° 33' N 65° 30' W 1000 fm. "Explosives Dumping Area" 10 x 10 miles square, Chart 71

To serve Providence, Rhode Island:

- 2 41° 19.7' N 71° 063' W 48-90' Rocky ledge known as "Browns Ledge" 10 miles from Sakonnet, Rhode Island, Chart 1210
- 2a 41° 14' N 71° 25' W 110-126' 2 miles in diameter marked "Danger, Unexploded Depth Charges, May 1952", 10 miles from Pt. Judith, Rhode Island, Chart 1210
- 2b 40° 45' N 70° 52' W 32 fm. "Explosives Dumping Area, Disused", 10 x 10 miles square, 45 miles from Sakonnet Point, Rhode Island. Chart 71, 1108

To serve New York - Delaware Bay:

3. 39° 26.7' N 73° 56.6' W 80' "Danger Area" 2 miles in diameter 22.5 miles from Atlantic City, Chart 1217

3a* 38° 30' N 72° 06' W 1200-1500 fms. "Explosives Dumping Area"
10 x 10 miles square, 118 miles 098° T from Five Fathom
Bank Lightship, Chart 1000

3b 38° 05' N 73° 24' W 930-1060 fms. "Explosives Dumping Area"
10 x 10 miles square, 70 miles 127° T from Five Fathom
Bank Lightship, Chart 1109

To serve Norfolk, Virginia:

4 36° 49' N 75° 27' W Wreck 9-1/4 in 11 fm. 37 miles from Little
Creek, Chart 1109

4a 37° 19' N 74° 15' W 500-800fm. "Explosives Dumping Area" 10 x
10 miles square, 73 miles 074° T from Chesapeake Light-
ship, Chart 1109

46* 36° 30' N 74° 18' W 1000-1250 fm. "Explosives Dumping Area"
10 x 10 miles square, 74 miles 113° T from Chesapeake
Lightship, Chart 1109

To serve Morehead City - Beaufort, North Carolina:

5 34° 26' N 76° 54' W 77-81' . A "tear up" area according to
"Report of North Carolina Shrimp Survey", Institute of
Fisheries Research University North Carolina, January
1951, 22 miles from Morehead City, Chart 1234

To serve Savannah Area:

- 6 32° 20' N 79° 55' W 10 fm. "Dumping Ground (by permit only)"
 8.5 miles diameter, 20 miles 136° T from mouth of
 North Edisto R. Chart 1111
- 6a 32° 00' N 80° 30' W 60' A poor bottom regards fishing. 18 miles
 from Ft. Sureven, Chart 1240
- 6b 32° 15' N 78° 40' W 20 fm. "Explosives Dumping Area", 10 miles
 diameter, 70 miles from Charleston, South Carolina,
 Chart 1111

To serve Jacksonville, Florida:

- 7 30° 33' N 81° 09.2' W 67-70' "Wreck, 42' Reported", 18 miles
 from Mayport, Chart 1243
- 7a 30° 37' N 79° 53' W 300 fm. "Explosives Dumping Area, Disused"
 83 miles from Mayport, Chart 1111

To serve the Florida peninsula:

- 8 26° 05.5' N 80° 02.5' W 600 fms. 2 miles East of Port Everglades
 Sea Buoy, Chart 1248

To serve Pensacola - Mobile Bay:

- 9 29° 48' N 87° 33' W 23 fm. "Dumping Ground" 35 miles from
 Pensacola, Chart 1115
- 9a 29° 48' N 87° 10' W 100 fm. Rough ground not suitable for trawl-
 ing, 34 miles from Pensacola, Chart 1115

9b 29° 22' N 87° 15' W 300 fm. "Explosives Dumping Area, Disused"
10 x 10 miles square. Chart 1115

To serve New Orleans, Louisiana:

10 28° 40' N 89° 51' W 100 fm. Rough ground, not suitable for trawling,
26 miles from Southwest Pass, Chart 1116

10a 28° 30' N 89° 10' W 300 fm. "Explosives Dumping Area, Disused"
10 x 10 miles square, 30 miles from South Pass,
Chart 1115

10b 28° 25' N 88° 55' W 600 fm. "Explosives Dumping Area" 10 x 10
miles square. 36 miles from South Pass, Chart 1115

To serve Galveston, Texas:

11 29° 00' N 94° 35' W 9 fm. Southernmost corner of a 5.5 x 11 mile
rectangle. "Dumping Ground (by permit only)".
21 miles from Galveston Entrance, Chart 1116

11b 29° 22' N 93° 40' W 7 fm. Rectangular 4 x 9 miles "Dumping
Ground (by permit only)" 19 miles from Sabine Pass,
Chart 1116

11c 27° 40' N 93° 30' W 250 fm. "Explosives Dumping Area, Disused"
10 x 10 miles square, 100 miles 175° T from Galveston
Entrance, Chart 1116

To serve Corpus Christi, Texas:

12a 27° 15' N 96° 00' W 250 fm. "Explosives Dumping Area, Disused"

10 x 10 miles square, 65 miles 122° T from Aransas

Pass, Chart 1117

INDEX CHART OF SUGGESTED DISPOSAL AREAS FOR LOW LEVEL RADIOACTIVE WASTES

APPENDIX X

Influence of Packaging on Rate of Dispersion of Radioactivity Disposed
in the Sea

Arnold Joseph

APPENDIX X

Influences of Packaging on Rate of Dispersion of Radioactivity Disposed in the Sea

Arnold Joseph

Release Rate of Radioactivity from Packages

The objective is to state as quantitatively as possible how much and over what period of time radioactivity within a sea disposal package can be expected to be released into a sea water environment.

Packages of radioactive wastes disposed in the sea are usually made up of 18 gauge 55 gallon drums, concrete and the waste materials. The wastes may be either intermixed with the concrete or surrounded by the concrete in the 55 gallon drum. The drum itself is likely to be second hand and perhaps reconditioned(repainted).

Corrosion of Steel by Sea Water

Reference: Uhlig, "Corrosion Handbook", John Wiley & Sons (1948), pp 383-391. "In spite of wide variations in temperature, salinity and marine organism growth from place to place, there are surprisingly small differences in the corrosion of common metals and alloys when they are exposed to corrosion by sea water at different points throughout the world... Illustrative data for steel and iron... show a surprising

uniformity of rates of attack for specimens exposed under conditions of continuous immersion.... The spread is between 0.001 and 0.0077 ipy (inches penetration per year) with an average of 0.0043. ... For a rough estimate in the absence of data applying to a particular locality or condition of exposure, it would be reasonable to use a figure of about 0.005 ipy, or about 25 mdd (milligrams per square decimeter per day), for the expected average rate of corrosion of steel or iron continuously immersed in sea water under natural conditions...."

With this average corrosion rate, i.e. 0.005 ipy, one can calculate roughly that the drum would lose its integrity in about 9.5 or 10 years ($0.0478 \div 0.005$). However, this calculation may not be too important because not all packages have welded and sealed tops and bottoms. In some cases, the drums may have open tops and the concrete would be exposed at the time it is immersed.

Leaching of Radioactivity from Concrete

In an experiment performed by Vitro Corporation of America it was determined that about 4.8% of the total MFP activity (added as the liquid component in a mortar mixture) was leached out in a period of 15 days.

In similar experiments performed by another AEC contractor, small mortar cylinders (approximately 1 inch diameter x 2 inches high) spiked with small amounts of MFP activity were leached in 2 liters of tap water. These experiments indicated that about 2% of the activity was leached out in about 40 days. About 5% of the calcium

content was leached in approximately 20 days; this Ca leach level was reached in about 10 days.

Erosion Rate of Concrete

The objective is to state quantitatively, if possible, how long a concrete parcel will remain integral when immersed in a sea water environment.

Reference: Kleinlogel, "Influences on Concrete", F. Ungar Co. (1950). "Sea Water. The free lime in concrete has a tendency to react chemically as long as it is not attached to another substance. It combines with the CO_2 to form CaCO_3 , which forms a protective crust on the surface. When sea water has access through pores or cracks to the inside of the concrete, it dissolves the gypsum and the aluminates as well as the lime. These salts combine with a large quantity of the water of crystallization to form a double salt (Ca-Al-SO_4) which has a high pressure of crystallization, expands, cracks, destroys the structure of the concrete and transforms it into a soft mass.

"In time the lime in the concrete is absorbed by the MgCl probably by forming CaCl_2 which is soluble in water. The lime is then replaced by magnesia. Consequently, the concrete becomes porous and the sea water can penetrate it."