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the diving suit on each dive; one in the shoe top, one at hip level, and one at shoulder or chest level. These badges were developed daily for the first two weeks, and then after every three dives for the remainder of all diving operations. In addition, each diver carried a pencil-type pocket dosimeter within his suit.

Gear employed in the photographic dosimetry work was as follows:

A. An Ansco-Sweet densitometer for reading the densities of films exposed in the film badges

B. Type K film badges obtained from Radiation Laboratory, San Francisco Naval Shipyard (500 badges)

C. Holders and DuPont film packets obtained from Atomic Energy Commission at Oak Ridge, Tennessee (300 holders and 5,000 packets)

The Type K film, as supplied by Naval Radiation Laboratory, has a thin lead cross upon it, which stops the beta radiation but is penetrated by the gamma radiation; the area not covered by the cross is exposed to both beta and gamma radiation. The type of badge supplied by the Atomic Energy Commission also is designed for beta and gamma radiation. It consists of a film packet in a stainless steel holder, the upper half of the packet being shielded on both sides with cadmium. This upper section is used for gamma-ray dosimetry. A window in the lower half of the steel holder permits exposure of the packet to both beta and gamma radiation. During the latter part of the resurvey operation the steel holder was not used. Film packets with cadmium shields were inserted into rubber sheaths for protection against water.

Film badges of each type were exposed to a standard radium source for calibration. Each type of film badge had an approximate sensitivity range of from 0.02 r to 2.0 r.

During the period from 15 July to 29 August 1947, a total of 572 film badges were developed, and the exposures interpreted. None of these badges was found to have been exposed to sufficient radiation to acquire computable density. From film-badge data it was determined that there were no personnel exposures in excess of the daily tolerance limit of 0.1 r, beta plus gamma. All developed badges were alphabetically filed, and will be permanently stored at the Radiation Laboratory, San Francisco Naval Shipyard, as a permanent exposure record for personnel connected with this resurvey operation.

It should be emphasized that in operations such as the Bikini Scientific Resurvey it often is necessary to protect film badges with rubber sheaths because otherwise they become water-soaked. In the initial stages of the operation many badges were completely ruined by failure to observe this precaution, even when the majority of the work was done on dry land. Frequently the badges became soaked while wearers were returning to the ships in small boats.

General precautions. Until radiological clearance was given any particular area or island, personnel entering such an area wore full suits of protective clothing.

Before the start of operations in Bikini Lagoon, a decontamination station was set up in a forward troop head. This station was secured from adjacent living spaces. Contaminated personnel entered on the starboard side, removed clothing, scrubbed and showered, were monitored, dressed in clean clothing, and left the station on the port side. Scrub brushes, soap, towels, and a bin for contaminated clothing were provided. The contaminated and clean sides of the station were

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clearly marked by appropriate signs. No contamination causing combined beta-gamma reading exceeding twice background was at any time left on the body of any personnel, and no clothing was worn which showed a combined beta-gamma reading exceeding twice background.

3.025 Summary

The principal result of the BIKINI SCIENTIFIC RESURVEY was to show that the atomic explosions caused only minor, transient disturbance to the plant and animal populations of the area, the effects of which have almost completely disappeared after one year's time. Some plants and animals in the immediate area of the underwater explosion were killed and some highly radioactive plants, fish and invertebrates of impaired vitality were found in the three weeks following test Baker. One year later, a most careful search of the islands, reefs, and lagoon by some twenty very well-qualified and well-equipped and well-supported biologists, over half of whom had made extensive studies of the same areas before the explosion, revealed no changes in population, numbers, or composition, and no physiological damage which definitely could be ascribed to the explosion. The nearest thing to a case of definite damage from the products of the explosions is furnished by some dying corals on the reef between Amen and Bikini Islands. These corals (Heliopora) were observed to be in fine condition a few weeks before test Baker. At the time of the explosion the tops of the coral clumps were about a foot under water, and the tide was rising. They may have been killed by radioactive fission products definitely known to have washed over the reef after raining down from the base surge. Other possible causes of their death are contamination by oil from the sunken ships, patches of which can still be found on almost all the reefs and beaches, or by heavy rain during one of the lowest tides. Corals are easily killed by fresh water. The question of what happened to these particular corals remains open.

Large amounts of radioactive material still exist on the lagoon bottom. Above the water, the external radiation is appreciably greater than background only on the sand spit at the northern end of Bikini Island and the adjoining reef, and near debris from the target ships cast upon various beaches. Even there, it provides no physiological hazard. In the habitable portions of the islands, any radiation from fission products is so weak as to be completely lost in the normal background. In the waters of the lagoon, the residual radioactivity from the bomb is similarly lost in the radioactivity normally present in sea water the world over. Of approximately a thousand plant and animal samples, mostly fish, which were counted or analyzed, the average radioactivity per unit weight was approximately fifty per cent more than that of the body of a man who has had no exposure to radium, fissionable material, or fission products; and in only one sample, a sponge, was the energy per unit volume being received from radioactivity as much as it would have been from the accepted tolerance of external radiation, 0.1 R/24 hours. Other than fish, no food product was found which contained more than twice the normal radioactivity of human flesh. The maximum amount of plutonium found in any part of any fish was 3×10^{-10} grams per gram of wet tissue. When it is remembered that two of the dangerous long-life fission products, strontium and cesium, are not now present at Bikini and that the fission product activity still present there will have decayed to about 30 per cent of its present value after one more year, and that from food eaten, somewhere between 1 and 10 per cent of the radioactive material is retained by the body, it becomes obvious that after a few more years these islands will constitute relatively slight radioactive hazard to any one. Nevertheless, definite predictions cannot yet be made as to whether the radioactivity will soon become sufficiently diluted to permit permanent reoccupation of the atoll.

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As Chilton (APA-38) crossed the sill of Enyu Channel, it was immediately observed that the water, instead of being marvelously clear as it had been when the first units of Joint Task Force ONE entered the lagoon, was as opaque as that off Point Loma and it was at first supposed that this decrease in transparency might reflect a major change in the biological situation. An increase in opacity had occurred during the period from March to August 1946 when the lagoon was occupied by Joint Task Force ONE. It was assumed that this was due to the increased organic activity in the water resulting from the large amounts of organic nutrient materials put into the water by the Task Force. Since the amount of phosphorus and nitrogen contributed by the Task Force was only a small fraction of that normally present in the water, it is difficult to believe that this effect alone could persist for a year in view of the continual partial flushing of the water of the lagoon. Immediately after test Baker there was a large increase in the bacterial population, probably due to nutrients from organisms killed by the explosion. It appears possible that this increase in bacterial numbers presaged a change in the biological balance which resulted in a more or less permanent increase in organic activity and corresponding decrease in transparency of water. Studies of plankton population during the Resurvey, however, showed no obvious differences from 1946, and bacteriological observations later in the summer showed that bacterial levels had resumed their pre-explosion status. The observed decrease in transparency may be a normal, seasonal effect occurring in the summertime when long swells from the South Pacific enter the lagoon through Enyu Channel and stir up the bottom sediment. These materials are below the depth that can be affected by the short, high wind-waves of winter and spring. It is quite possible that the fine materials stirred up by the test Baker explosion and redeposited on the bottom surface are more easily kept in suspension by wave action than the bottom sediment existing prior to test Baker. Essential data that would be critical in resolving this problem would be measurements of the transparency in the eastern part of the lagoon during the winter months.

On the basis of the chemists' work some detail can now be added to the phenomena of the Baker explosion. Within a tenth of a second after the explosion, some 275-day cerium 144, which is one of the more abundant and troublesome long-lived isotopes, had been formed as the end-product of a fast radioactive chain beginning with xenon 144. Under the great heat and pressure still prevailing, this was mineralized, in a way not possible in a reasonable amount of time in the laboratory, to an extremely insoluble form. Within a few minutes a large fraction of all the fission products which ultimately remained in the area were in the water of the lagoon. An exception was 53-day strontium 89, another long-lived substance, some of which was still in the form of 3-minute xenon and was carried to the outer edge of the area of precipitation. The result was that only about half of the amount of strontium 89 finally produced was deposited in the target area. After the explosion, the water in the target area was turbid for more than an hour with bottom debris, some very finely powdered. Photographs taken shortly after the cloud cleared away show an unsymmetrical patch of milky water about the size of the target array. All the fissionable material from the explosion and the following long-lived fission products: yttrium, zirconium, columbium, antimony, praseodymium, element 61 and europium, as well as many short-lived fission products, were quickly and permanently adsorbed on the suspended material and carried to the bottom, where all but an insignificant fraction still are. Thirty-three-year cesium was not adsorbed because of the large quantity of the chemically similar element sodium already present. Twenty-five-year and shorter-lived radio-strontium were not adsorbed because the relatively large amount of chemically identical neutral strontium normally present in sea water had saturated the surface of the adsorbent. Only a small fraction of the various radioactive ruthenium isotopes was carried down because of the tendency

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of this element to form complex anions with the chlorine in the sea water. After six months, more than 99 per cent of these soluble elements had been carried off to sea by the normal flushing processes occurring in the lagoon. Loss of strontium 91 by this process had the effect of diminishing the amount of its daughter, 53-day yttrium 91, which otherwise would have been a more significant contributor to the present activity of the bottom.

The radioactive materials carried down by the process just described are by no means evenly or symmetrically distributed on the bottom; the details of the distribution are so complex that only a rough, qualitative estimate of the total radioactive material on the bottom has been possible. The greater part of the material was deposited near the center of the target array, but patches of as much as forty-fold higher activity per unit weight are found further out, and the data suggested that the most active material was deposited near the outer edge of the column. Generally, the most active deposits are at the surface of the bottom, but in some places rich deposits are overlaid by poorer ones.

At the present time worms and sea cucumbers are burrowing actively in and eating the highly radioactive bottom mud. Most of this passes right through them, and some of the feces are left on top, where bacteria compost them, returning most of the active material to the mud. However, some is left available to plants, which grow on the altered material. These plants are eaten by small fish, which pass almost all the radioactive material through the gut. Small fish with the small fraction of radioactive material they have retained in their tissues are in turn eaten by large fish, which again eliminate most of the radioactivity, carrying some of it to distant parts of the lagoon and even outside. Plants remote from the explosion center get traces of radioactive material in this way, and the cycle is continued. The net tendency is to spread the material evenly over the lagoon bottom and to carry a certain amount of it out to sea.

It is time to consider the ultimate fate of the radioactive material now in or on the lagoon bottom. Fission product attrition by decay is much faster than by biological processes. Within a year, decay alone will have reduced the activity in total energy to 30 per cent of what it is now, and the flesh of the lagoon fish will not, on the average, be as radioactive as normal human flesh. In five years, only 4 per cent of the present activity will remain, and radioactivity of the fish will be completely lost in the background. In 10 years, less than 1 per cent of the present fission product activity will remain in Bikini lagoon. For plutonium, attrition by biological processes, although probably less than 1 per cent per year, no doubt will outstrip radioactive decay. The present activity from plutonium will remain substantially unchanged for many years, but the rate of transfer to foods will be so slow as to constitute little hazard.

The idea that plants and animals may concentrate radioactive material has often been expressed. By way of definition, a radioactive material may be termed concentrated when the amount of radioactive energy per second per unit weight of organic tissue exceeds the amount per unit weight of soil or water in the case of a plant, or the average for food received in the case of a fish or other animal. Concentrations of radioactivity by plants up to several hundred fold had definitely occurred in the first two weeks after test Baker. No fish collected at that time exhibited any gross concentration, though the gills, livers and spleens of some of the fish did show concentrations as high as a factor of 10 over the stomach contents. The plants collected in the lagoon a year later, after careful washing with salt water to remove the silt, were in general much less radioactive than the coral rock on which they grew. Exceptions to this statement occurred chiefly in the case of Halimeda which exhibited counting rates as high as

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three or four times background. Only one fish collected (out of approximately a thousand analyzed) in 1947 showed a higher concentration of radioactivity in the entire organism than in the feces. However, the average concentration in the liver and spleen was about 50 per cent higher than in the feces, and the average radioactivity in the kidneys and gonads was also frequently considerably higher.

The marked concentration of radioactivity by plants two weeks after test Baker and the reverse effect a year later undoubtedly reflect the different identities of preponderant radiators at the two times. In 1946 the principal fission products were strontium, barium, bromine, rubidium, ruthenium, iodine and cesium. A year later, because of radioactive decay or because of the flushing of the sea water, nearly all the radioactivity from these substances had been eliminated in the lagoon, and only the heavier elements, yttrium, cerium, zirconium and columbium, remain. As shown by Overstreet and Jacobson these are not appreciably absorbed by plants.

One of the most discussed effects of radioactivity is the possibility of producing genetic changes. At Bikini more than 1000 species of organisms have been exposed to radioactivity, and many have reproduced through at least one generation. A careful search of the area by competent biologists, including ichthyologists, botanists, invertebrate zoologists, and entomologists, in the course of which tens of thousands of specimens were examined, failed to reveal definite evidence of aberrant forms. Since it is known that mutations produced by radiation almost invariably have negative survival value, this result was not unexpected. No interference with the reproductive functions of sea-urchins taken from the most heavily irradiated portion of the reef could be detected. The only observed effect considered related to the atomic bomb explosions was an increase in catalase activity in three genera of algae taken in an area which was probably exposed to high intensities of radiation.

In using the results of the Bikini Resurvey, with other information, in planning the defense of the United States, one point needs special consideration. At Bikini, three abundant long-lived fission products, strontium, cesium and ruthenium, were not carried down by the mud because sea water contains abundant material in solution to hold them back. In fresh water and on land this will not be the case, and these elements will contribute detectible radiation in heavily contaminated areas for many years. Another point worth noting is the sharpness with which the present contaminated area is now defined. During the first few weeks after the explosion there were many fission products remaining in the water, and the boundary of the contaminated area was diffuse and variable from day to day, and it was only after these had decayed or washed out of the area that the boundaries became sharp. In fresh water or on land all fission products may be expected to become fixed in the soil or mud almost at once, and the boundaries will be sharp from the beginning. One will either be in a heavily contaminated area, or definitely out of it.

In addition to determining the long-term effects of atomic bomb detonation which might be of military interest, it was the purpose of the Resurvey to conduct researches of a purely scientific nature. Many of these had been begun or were suggested during the Crossroads Operation. During the Resurvey, information was added to the fund of knowledge concerning the geology, oceanography and biology of Bikini Atoll. Some details of these studies are included in this report.

The foregoing summary sets forth the present opinion of AFSWP staff.

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