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IVY – MIKE

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Prologue

On 1 November 1952 at 0714:59.4 , MIKE was detonated on the surface of Eluklab Island in the Pacific Proving Ground at Enewetok Atoll. This was the first thermonuclear explosion ever, and yielded 10.4 megatons. Eluklab was evaporated, leaving a crater 200 ft deep and 1 mile in diameter. Three Scripps oceanographers were concerned about the possibility of triggering a submarine landslide generating a tsunami. They persuaded Task Force 132 to evacuate the Proving Ground and perform the test by remote control.

The following paper is adapted from a talk given by Walter Munk at the ONR Southwestern Regional Review at the Scripps Institution of Oceanography, 20 January 2004.

For nearly fifty years, my wife Judith and I have had the pleasure of your company at our home (named SEICHE) during site visits at the Scripps Institution. I want to trace the beginnings of this tradition. It all started with the Bikini Nuclear Bomb Tests in 1946. In preparation for the test, Bill von Arx of Woods Hole and I shared the responsibility of measuring the lagoon circulation (Munk, et. al, 1949). We inferred a flushing time of order one week, but the Admiral could eat the lagoon fish in two days if the skin was carefully removed.

Bikini atoll is an oval basin 30 fathoms deep, rimmed with coral islets and made of limestone a mile thick. It sits on a steep basaltic seamount rising two miles from the three-mile deep sea floor. Surveys of the north rim of Bikini showed evidence of old sub-marine landslides down the 23^0 slopes (Fairbridge, 1950). There was some concern that the nuclear explosions might trigger a slide, this being a region of low seismic activity. The first test, Bikini ABLE, was an air-dropped device (which missed the target by a quarter mile); the second test, BAKER, an underwater explosion. The yield was about 20 kilotons for both tests, roughly equivalent to a magnitude 3.8 earthquake. There was no slide.

In August 1949, three years after Bikini, the Soviet Union exploded their first nuclear device. This gave an urgent impetus to U.S. efforts to develop the BIG ONE. Studies led by Edward Teller (figure 1) for the development of a thermonuclear device had been underway well before Bikini, but with no clear ideas of how to make one work. Finally in early 1951 the program converged on a geometry where the radiative implosion of a fission primary would serve to ignite the thermonuclear reaction. This "Teller-Ulam" configuration (translated into a design by Richard Garwin and Marshall Rosenbluth) was to be tested only a year later at the Enewetok Proving Grounds in operation IVY-MIKE.

The explosion exceeded expectation. Disturbances were detected over the entire Pacific Ocean. Air pressure waves varied from 106 mb at Enewetok Island (12 nautical miles from ground zero) to 0.3 mb at La Jolla (4500 nautical miles). The water wave was recorded at Enewetok, Bikini, Kwajalein, Wake and Hawaii; it varied from 1m amplitude and 1 minute period at Enewetok Island (12 nautical miles) to 10 cm and 6 minutes at Hawaii (2500 nautical miles). The water wave was not a direct result of the explosion, but generated by the traveling air pressure wave, a type of coupled air-water phase discovered by Ewing and Press (uncoupled velocities are comparable, 319 m/s and 206 m/s). Meanwhile in Berkeley, Edward Teller (Bolt, 1976; Rhodes, 1995), who had resigned in a huff when Marshall Holloway of the Los Alamos Scientific Laboratory (LASL) was put in charge of the thermonuclear effort, had gone to the basement of Haviland Hall to watch the seismographs. The p-waves arrived at zero + 12 minutes (on 31 October local date). Teller wired Marshall Rosenbluth, "It's a boy," claiming paternity.

A year earlier Cdr. C.N.G. "Monk" Hendrix had come to Scripps to meet with Revelle, Isaacs and Munk. He had read the Bikini report and inquired how a Marshall Island coral atoll would withstand a Magnitude 7 earthquake. Not yet knowing anything about IVY-MIKE and having in mind the low regional seismicity, I remarked that the probability of such an event must be nearly zero. Monk Hendrix answered: "the probability is nearly ONE."

Hendrix (figure 2) was attached to the Hydrographic Office in Suitland, Maryland but at the request of the Scripps Institution of Oceanography he received new orders in June 1952 to report to the Office of Naval Research Branch Office at Pasadena for duty as research and liaison officer at Scripps Institution of Oceanography. He was also to report to the Commander, Task Group 132.1 LASL for additional duty with the Joint Task Force 132. C.N.G. (for Charles Nelson Grant) Hendrix was a 1939 graduate of the Naval Academy where he was a champion athlete. During the war he served 12 patrols on submarines in the Pacific and received two silver stars and several navy commendations. Lt. Hendrix was aboard the USS S-39 in 1942 when she struck a reef off the southeast coast of New Ireland. With twenty foot waves breaking over the hull, and the ship listing 60 degrees, Hendrix swam to the reef to establish a riding line for the crew. Thirty-two men reached the reef via the line. Hendrix studied oceanography at Scripps and received a master's degree in oceanography in 1951. His association with the ocean community was to extend through his entire career.

IVY-MIKE (for Mega) was the first thermonuclear explosion, ever, with an expected yield of 5 to 10 MT. (The actual yield turned out to be 10.4 MT, equivalent to a whopping magnitude 6.7 earthquake, three magnitudes above Bikini.) The explosion was to be at the surface of Eluklab Island of Enewetok Atoll (figure 3). A submarine landslide can be an effective tsunami generator. Revelle, Isaacs and Munk expressed concern. (Revelle, et. al memorandum 1952) Here is the wording in the TF132 official report declassified in 1982 (Defense Nuclear Agency, 1982):

> At a meeting attended by LASL (Los Alamos Scientific Laboratory) and Scripps representatives it was decided that the present test shot, if it caused a (submarine) landslide, could cause a destructive tidal wave. The chance for such a landslide is considered very small, but not so small as not to warrant certain safety precautions.

A "just in case" plan was adopted. The mean elevation of Enewetok is ten feet above sea level. The decision was to perform the test by remote control. The test plan provided for (i) evacuation of all military personnel from Enewetok Atoll[1] (previous plans had been for the MIKE firing party to remain ashore at Enewetok Island.) (ii) evacuation of the people of Ujelang Atoll and their domestic animals[2], (iii) contingency plans for emergency evacuation of IVY-MIKE test personnel from Bikini and Kwajalein. The signal for executing the emergency evacuation was to be provided by the Scripps Institution under contract with the Office of Naval Research.

Scripps was already planning a major geophysical exploration of the South Pacific for fall 1952. This expedition provided a convenient disguise for the classified task, and the IVY-MIKE work performed during the first month paid $ 210,000 (Revelle, memorandum, 1952), which covered the cost of the geophysical expedition in the next four months under Roger Revelle's leadership.

So in October 1952 we were at it again, making our way via Military Air Transport Service to meet the Scripps vessel *R/V Horizon* at Enewetok. MATS schedules were stochastic, but we were fortified by our experience that no one had ever embarked in MATS without eventually being ejected at the destination. When we arrived, we were issued identification badges, goggles and the official observers pamphlet which described the facilities and assured us that "All personnel of the Task Force will be well outside of the range of all hazard at the time of detonation…" (Operation Ivy, 1952).

The IVY-MIKE test was performed by Task Force 132 comprising 25 Navy vessels and auxiliary craft, plus the lonely *Horizon* (figure 4). The Scripps task was led by Willard Bascom, with Cdr. Hendrix providing liaison with

[1] This differs from a published task Force account: (TF132, p503). " ..estimates of Mike's yield ranged so wide that the entire land task force had to be evacuated from the atoll onto ships …"

[2] This is not a happy story. Just prior to the 1946 test the native Bikinians had been evacuated on short notice to Rongerik Atoll. They were found to suffer from malnutrition and were moved to Kwajalein in 1948. The people from Enewetok were evacuated in 1947 to Ujeland Atoll. (MARSHALL ISLANDS, A CHRONOLOGY: 1944-85, Maka'ainana Media, Honolulu, 1978).

TF132. Bascom was John Isaacs' colleague and a member of the Engineering Department at the University of California in Berkeley. Bascom had broad experience in coastal processes. The previous year he had been diagnosed with an inoperable cancer and treated with a powerful radiation dose to alleviate his condition. He was not expected to survive. Roger Revelle wrote to University of California President Sproul (Revelle, letter, 1952): "… partly in order to help him from thinking too much, and partly because he was the best man I knew of for the job, I asked him to take responsibility for measuring the waves produced by one of the great explosions."

Bascom performed his assignment in an incredible two weeks, starting 16 October when the *Horizon* became available. In a letter from the ONR Research and Liaison Officer to Commander Task Group 132.1, Cdr. Hendrix described Bascom's many assignments, (Hendrix, letter, 1952) among them:

> (1c) make detailed bathymetric survey of Seamount 26 in the deep ocean area north of Enewetok Atoll;
>
> (1d) perform same work for Seamount 72, … ;
>
> (1g) anchor two wood rafts above seamount #26 and #72 and attach pressure instruments on piano wires at precise depths above the anchor. Install instruments in rafts a certain number of hours prior to test time.
>
> (2b) … (lay) the armored submarine cable off Enewetok Island….. Mr. Bascom performed all diving operations himself and on several occasions had to cease operations due to presence of sharks…. . In the opinion of the Project Officer this should have been a full 2 day's job. It was accomplished in 10 hours.
>
> (2d) the sharks became so numerous and were so large and inquisitive that it became necessary to establish 'shark watches' with rifles…".

During his "free time", Bascom volunteered to search for a missing airplane and pilot that had crashed off Enewetok Island.

Some months later, RADM C.M Bolster, Chief of Naval Research, wrote to Revelle (Bolter, letter, 1953):

> The response of your group in undertaking the difficult and sometimes dangerous job …has been most gratifying…. The manner in which your organization was able to aid the Department of Defense …. is a fine example of the team work between the Department of Defense activities and research institutions. This Office feels such cooperation is a major value received from the sponsorship of basic research by the Navy Department. ….
>
> Cdr. Hendrix has especially commended the work of Mr. Willard Bascom. Therefore, I would appreciate it if you will present the enclosed letter of commendation to Mr. Bascom with my congratulations.

These were the very early days of free aqualung diving, and sharks were indeed a problem. During Capricorn we dove almost daily throughout the South Pacific, always in the company of sharks, but felt secure on the basis of the existing Navy policy: shark attacks occur only when (i) the diver is at the surface, and (ii) he is bleeding. These two situations were avoided. It was not until our return that we learned that the Navy policy had been extended to other situations.

Bascom was an accomplished diver and a pioneer in underwater photography. Knowing that he had only a short time to live he took many chances. We operated under the "buddy system," always dive in pairs. Bascom dove alone. And he told us to stay out of sight when he was taking underwater pictures. It went something like this: "I don't want my tropical marine compositions jarred by your figures dangling down from face plates."

Bascom, had been tasked by Revelle to measure the MIKE water and air pressure waves at a variety of sites (Bascom letter, 1952). He designed a differential pressure meter with peak intensity at two-minute period (intermediary between swell and tides) to provide the tsunami warning (figure 5). The recording was on a primitive Esterline-Angus pen and ink curvilinear paper tape, with 10 m water pressure at full scale and 0.5 m sensitivity. I recall that the evacuation signal was set at 3m amplitude.

The evacuation warning signal was to be provided from observations near (but not too near) Ground Zero. Offshore depths are typically 18,000 feet, but there were two seamounts reaching within 4500 ft of the surface at distances of 26 and 72 nautical miles northerly from Ground Zero. The former was within the evacuation range limits and could not be tended; for seamount 72, computed travel times from Ground Zero were 7 minutes for

the air pressure wave and 11 minutes for the water wave. The latter would allow for 20 minutes of tsunami warning for Bikini Island at 200 nautical miles.

Four moorings (two for each seamount) were set by *Horizon* during the three days preceding the MIKE shot. A taut piano wire led from the anchor on top of the seamount to a buoyant raft at the surface. For anchor Bascom had clamped together some old San Diego trolley car wheels (perhaps the first example of what was to become a standard practice for the resting place of used railroad wheels). The wave recorder was attached to the raft, with leads down to the pressure transducer clamped to the mooring line at 130 feet beneath the mean surface. A tsunami crest would raise the surface and increase the recorded pressure. Flotation for the raft was provided by four truck inner tubes.

Bascom and I tended identical moorings separated by about 2 miles on "Seamount 72". *Horizon* was between and within sight of the two observers who were standing on 3x3' rafts (figure 6) , ready to relay prearranged visual signals to the flagship *Estes* which in turn had open communication links to the island evacuation sites (Proposed Tidal Wave Warning Plan, 1952). The signals were

> ABLE ABLE ABLE Destructive Tidal Wave Pacific Ocean
> BRAVO BRAVO BRAVO Destructive Tidal wave Marshall Islands
> CHARLIE CHARLIE CHARLIE minor tidal wave
> DOG DOG DOG No tidal wave at all.

As M-Hour approached, 1952 November 1 0715 h Enewetok local time before dawn, wet and cold, I put on my high-density goggles. An instant heat blast signaled the explosion (a momentary power failure aboard the *Estes* had thrown off the timing sequence by half a second); at 0721 a 5 mb air shock arrived, a sharp report followed by angry rumbling. After that, nothing.

By then Eluklab Island was no more, leaving a crater two hundred feet deep and one mile across (figure 7). The burning mushroom cloud had reached 100,000 feet elevation (figure 8). My memory is faulty after fifty years, but I will not forget the boiling sky overhead. (None of the photographs I have seen captured this impression). The *Horizon* was barely visible over the horizon. I felt lonely on my little raft, and kept attaching 5-minute ticks to

the straight line drawn by the wave recorder. At 0745 the *Horizon* came by the rafts to pick up Bascom and me; she had been ordered to get underway on course 045T at flank speed (11.5 knots in this case) to avoid radioactive fallout.

The order came from Task Group 132.4, which was responsible for weather prediction and had been tasked to avoid times when radioactive fallout might be carried in the direction of known human habitation.

It was noon and the *Horizon* was now hove-to (as ordered) at 46 nautical miles northeast of seamount 72, about 100 nautical miles northward of Ground Zero. I was on the open bridge talking to Capt. Noel Ferris when it started to drizzle. The radiation safety officer Captain Rogers, USA came by to perform his half-hourly check as assigned by his Task Unit 132.1.7: to hold his Geiger-Mueller radiation probe from 1 to 6 inches of the surface to be examined: "Here I am again, sorry" said the Captain, sticking the counter towards my stomach. It gave a noticeable acoustic signal: brrrr. "What's wrong with the damned thing," said Captain Rogers, gently tapping the sensor against the bulkhead for instant repair. By now it had started to rain. He tried again: BRRRRR . The reading was 30 mR/hr. The permissible outdoor rate for boats was 7 mR/hr.

It was 1240; we immediately initiated the procedure should fallout be detected. Our clothes were thrown overboard. All topside openings were closed and the ventilation system was shut down. All hands were kept below deck (the tropical marine climate is warm and humid).

At 1400 we received orders from Task Unit 132.4 to proceed at flank-speed, but now southward. After two hours the activity had decreased to 0.3 mR/hr, with an integrated dosage well below the allowable personnel expedition total of 3R. From 1600 to 1800 the previously installed "wash down system" was put into action (figure 9). The theory was that by covering the entire vessel with a spray of uncontaminated seawater, descending fallout particles would not lodge in topside gutters or the pores of wood or paint surfaces, and the particles would be washed overboard. But by then, as Roger Revelle put it, *Horizon* had lost her virginity. For the remaining twenty-six years of Scripps service she was unable to accommodate experiments involving low-level radiation counting.

Next morning we returned to Seamount 72 to recover our gear. I un-spooled the paper tape back to 0745 when we had abandoned the raft on the previous day. Within 90s following the final time mark was a positive pressure jump (perhaps the meter had slipped down the mooring line). The signature was too late, too large and too step-like to be consistent with our pre-test calculations, but there was the chance of a delayed landslide. There was no signal at the neighboring mooring tended by Bascom. If the rafts had still been manned, would we have signaled the ABLE ABLE ABLE code and set in motion the evacuation of several thousand people? We will never know. At the occasion of my 65th birthday I wrote (Munk, 1984): "I would have been too embarrassed to return to the United States, and would have left the ship at the next landfall in Tongatapu."

We easily recovered the second mooring on Seamount 72. By evening we had returned to Seamount 26, but were unable to find the mooring. A brief entry into the log book by Capt Ferris says "hunt for buoy unsuccessful." According to Bascom it "was last sighted drifting on three floats towards China."

We spent the next day recovering the wave recorder at Bikini Atoll. There the Scripps party had never received the DOG DOG DOG (all clear) signal, but rather a voice message at zero + 27 minutes: "Drop what you are doing and get the hell out". The stand-by boat was in the water at the expected tsunami arrival time of 0 + 31 minutes (Barr,1990.) ! By strange coincidence a real tidal wave alert was issued by the U.S. Coast and Geodetic Survey for November 4 at 1030. It fizzled.

We returned to Enewetok Island on 6 November for a final report to the Task Force Commander. Lots of things had not gone according to plan. Evacuation of Enewetok had not been popular with the participating Navy, viewed as unnecessary, expensive and even dangerous. When we made our farewell visit at the local BOQ on Parry Island, a young Lieutenant turned on his barstool and said, with a big grin, "… hope you science bastards are now satisfied."

We have never been able to reconstruct the reasoning behind the *Horizon* evacuation orders issued by Task Group 132.4.[3] Perhaps it signals a certain

[3] None of this would have happened if *Horizon* had stayed with the rest of the fleet and deployed the tsunami warning gauges on the seamounts to the south of the atoll. But the

level of acceptance for collateral damage? The exact wording was: (Defense Nuclear Agency, 1982): "The conduct of the tests went essentially as planned. The winds remained favorable, carrying the radioactive fallout northwesterly over the open ocean."

On one of the frequent pre-bomb visits to the Bikini Officers Club (figure 10), I asked a Berkeley theoretical physicist serving on TG 132.4 how they were going to predict the trajectory of radioactive fallout. I will never forget his reply: "we have found a solution to the wind problem". For the next fifty years I have responded with a lack of enthusiasm to any such offers to solve ocean/atmosphere problems.

We did not get back to San Diego until late February 1953. On the way home, under the leadership of Roger Revelle, we made some discoveries (figure 11). Russell Raitt's seismic surveys were consistent with a sedimentary layer of order 100m thickness, much thinner than expected. And Richard Von Herzen measured a traditional geothermal heat flux of order 0.1 W/m^2. These results eventually turned out to be crucial in the resolution of plate tectonics, hardly a subject of direct relevance to the Navy.

Bascom served as Principal Scientist on the Scripps vessel *R/V Spencer F. Baird* that had joined the *Horizon* in making ship-to-ship seismic transmissions. In a previously quoted letter (Revelle, 1953), Revelle wrote to President Sproul : "Just before our return to San Diego Bob Livingston, physician of the expedition, informed me that he had discovered metastises (sic) in Bill's neck and perhaps elsewhere. These do not seem to be responding to further X-ray treatment and the prognosis is bad." In fact, Bascom recovered and went on to look for diamonds off the coast of South Africa and for sunken vessels from antiquity. He died in September 2000 in La Jolla, CA, as a result of an automobile accident. Cdr. Hendrix maintained his close association with his fellow oceanographers until his death in 1976. He worked with scientists to locate *Thresher* and founded the U.S.Naval

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seamounts had not been discovered. The bathymetry in fig. 3 was generated by David Sandwell from a combination of satellite altimetry and multibeam cruises which became available in the 1990's.

Academy's oceanography program It was typical of the post-war period that navy officers and oceanographers worked together informally and effectively as they rose through their ranks.

There has always been a problem of balancing assistance to Navy operational problems with support for basic ocean research. I have had my foot in both camps, and found the combination exhilarating, with either activity helping to do a better job on the other.

Back in San Diego I terminated my failing first marriage, and proposed to Judith. We started building our house in 1954 and roofed the SEICHE living room in 1956. Soon thereafter it became a habit for ONR Site visitors to come up to SEICHE for a drink. Judith says we live “on top of the store”.

Acknowledgement

We thank Breck Betts for his help in preparing this paper.

FIGURES

Figure 1. Edward Teller, left, and Roger Revelle on television during what was probably testimony at a hearing on science and the environment, circa 1958. Teller was responsible for the development of the H-bomb, but did not participate in IVY-MIKE. Revelle was the Scientific Leader of the Capricorn Expedition.

Figure 2. Cdr. C.N.G. “Monk” Hendrix, Marshall Islands, 1952. Monk served as Scripps Liason Officer with the Navy Task Group. Photo by Alan Jones.

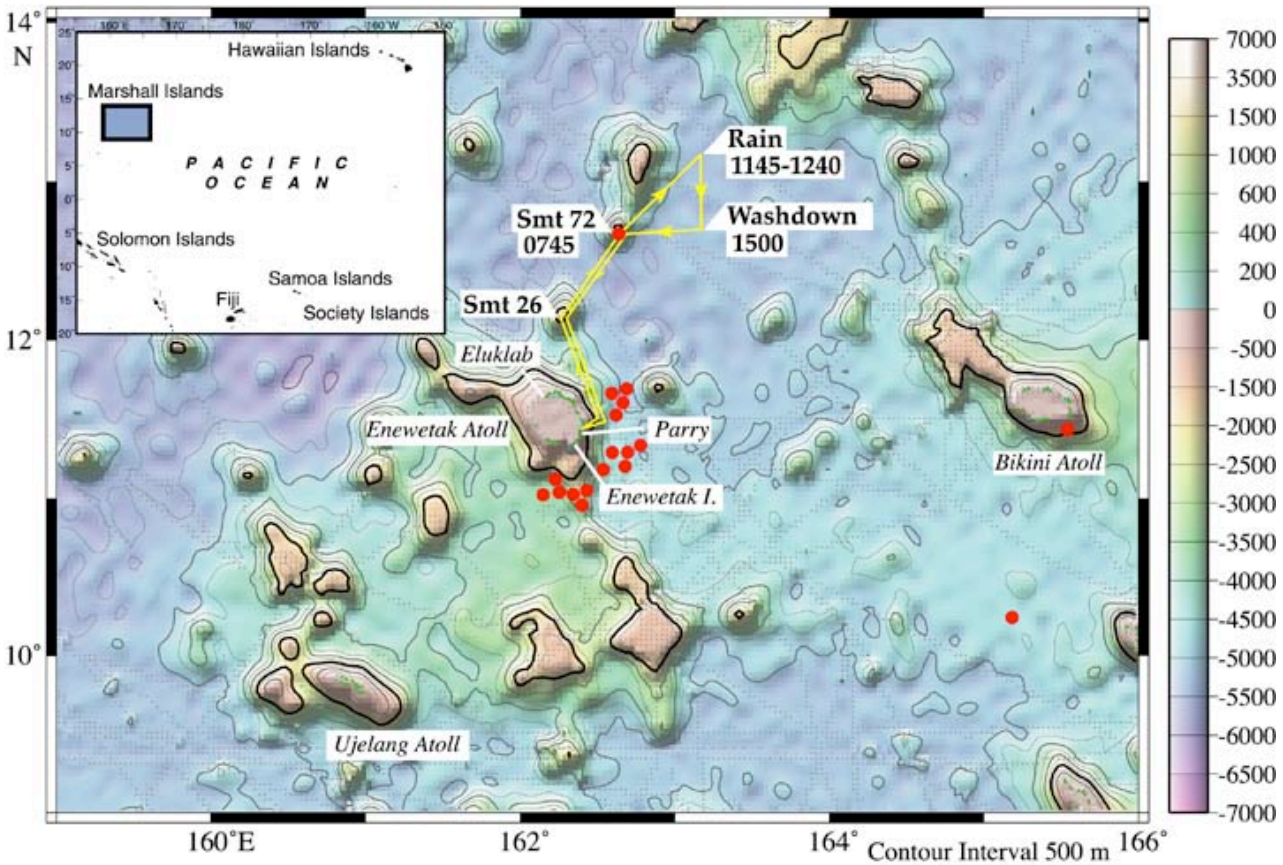

Figure 3. The Pacific Proving Grounds. Ground Zero was at Eluklab Island at the northern end of Enewetak Atoll, with Headquarters at Enewetak and Parry Islands to the south. Red circles indicate location of vessels of Joint Task Force 132 on 1 November 1952, at 0715 local (zero) time. Scripps vessel R/V *Horizon* (the only civilian vessel) is to the north of Ground Zero over Seamount 72 to relay a possible tsunami warning. At 0745, Horizon was ordered to proceed on course 45°T at flank speed in an effort (unsuccessful) to escape the radioactive fallout.

Figure 4. The R/V *HORIZON* on Capricorn Expedition, c1952. The converted Navy tug had a long career with Scripps. Photo by E.S. Barr.

Figure 5. Readying instrument raft on R/V *Horizon*, 1952. Willard Bascom is standing on the raft, Walter Munk is by the railing to the left, and John Isaacs has his back to the camera.

Figure 6. Willard Bascom on instrument raft, John Isaacs and Monk Hendrix in the rowboat. Four truck inner tubes are used for floatation of the plywood raft, which was anchored to the 4500 ft deep seamount by San Diego trolley car wheels.

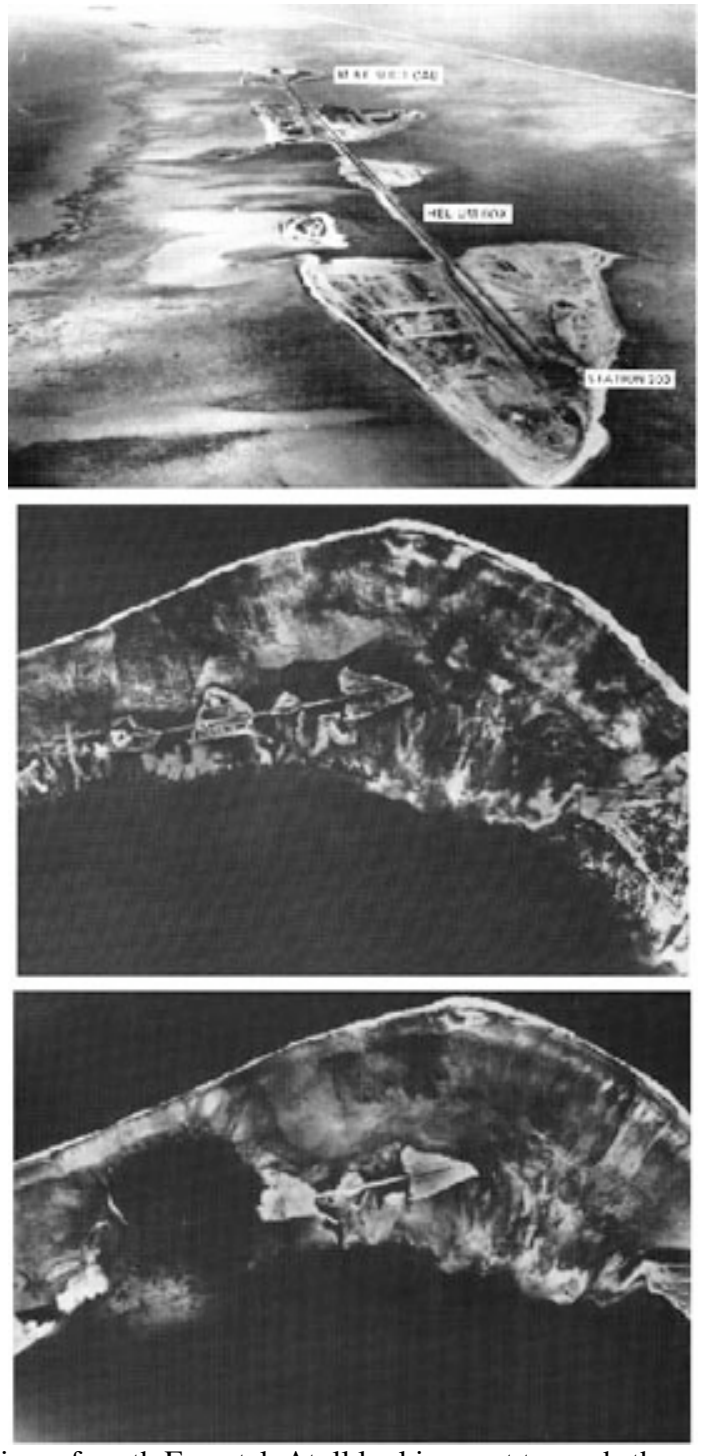

Figure 7. Top: View of north Enewtak Atoll looking east towards the arrow-point of Bogon Island, then Bogeirik Island, Lidilbut Island, and Elugelab Island with the Mike shot cab. It was exactly 2 statute miles from the western tip of Bogon Island to the eastern edge of Elugelab Island. Middle: Aerial view of north Enewetak Atoll before the Mike shot. Bottom: On 1 November 1952 at 0714:59.4 Elugelab Island was evaporated by Mike, the 10.4 megaton thermonluclear explosion, leaving a crater 200 ft deep and 1 mile in diameter.


FIRST HYDROGEN BLAST PICTURES

More Photos
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U.S. Releases Details of First Hydrogen Fury

Public Is Entitled To Facts, Declares Civil Defense Unit

McCarthy Hearing

EVENING TRIBUNE

HOME

Figure 8. San Diego Evening Tribune headline November 2, 1952. Courtesy of Union Tribune Publishing Company.

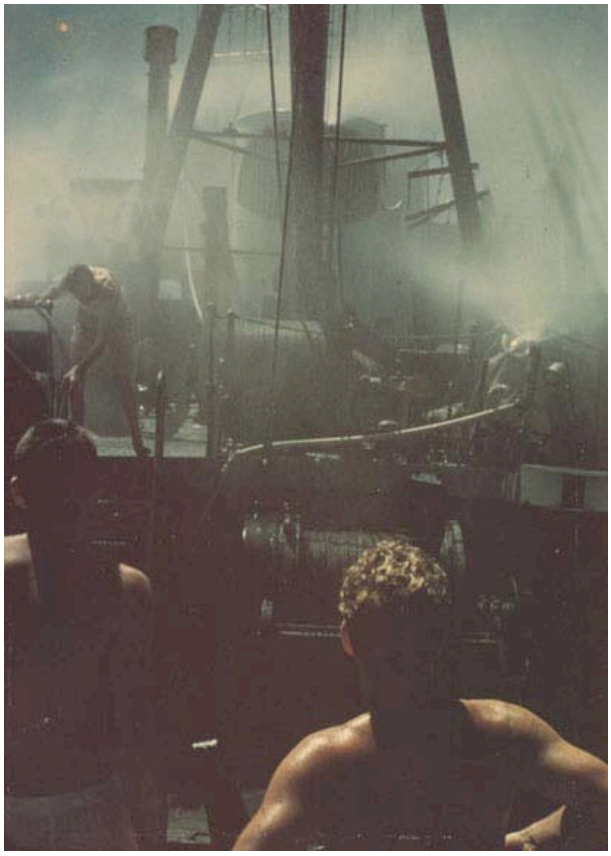

Figure 9. Atomic wash down system, R/V *HORIZON*, Winter Horton and Bernard Darsey in foreground, October 1952.

Figure 10. Beer Blast and Movie at the "Back 'N Atom" Club, Bikini, November 4, 1952. Willard Bascom, barefoot and shirtless is on the front left, Walter Munk is in profile on the right. Martin Johnson in glasses and a cap is center left.

Figure 11. Scientists and crew aboard R/V *Horizon*, Capricorn Expedition, c1952. R, ; V, ; H, ; O, ; R, : I, ; Z, ; O, ; N, ; S, ; I, ; O, ; La Jolla, ; Cal UCLA. Walter Munk, seated, is "La Jolla".

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