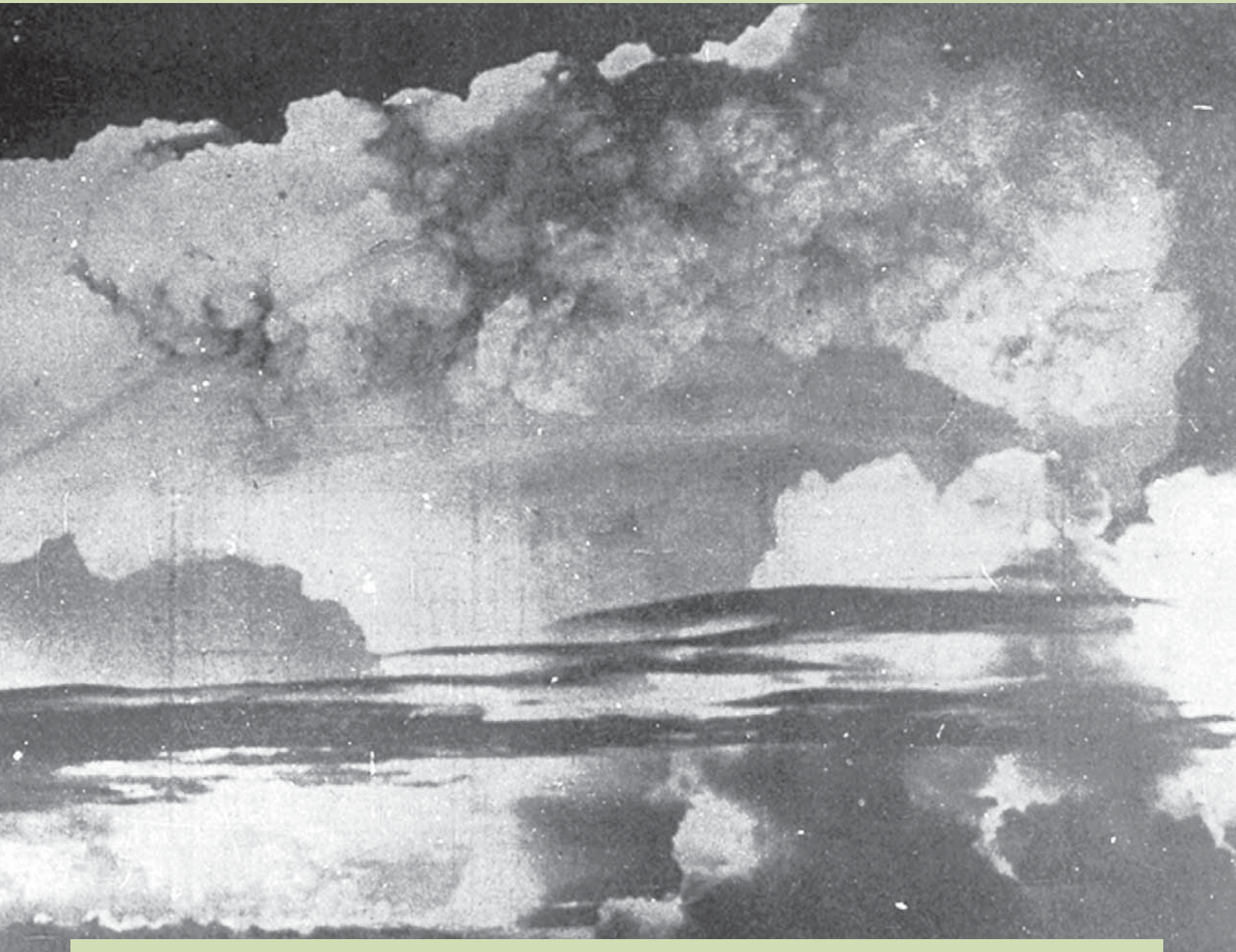
IVY-MIKE

BY WALTER MUNK AND DEBORAH DAY



On 1 November 1952 at 0714:59.4, MIKE was detonated on the surface of Eluklab Island in the Pacific Proving Ground at Enewetak Atoll. This was the first thermonuclear explosion ever, and yielded 10.4 megatons. Eluklab was evaporated, leaving a crater 200 feet deep and 1 mile in diameter. Three Scripps oceanographers were concerned about the possibility of triggering a submarine landslide and 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 on 20 January 2004 at the Scripps Institution of Oceanography to the Office of Naval Research (ONR) Southwestern Regional Review Committee.

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.

INTRODUCTION

For nearly fifty years, my wife Judith and I have had the pleasure of entertaining ONR Project Officers at our home (named *Seiche*, an oceanographic term for water undulations) during their annual site visits to the Scripps Institution. I want to trace the beginnings of this tradition.

It all started with the Bikini Nuclear Bomb Tests in 1946. The first test, Bikini ABLE, was an air-dropped device (which missed the target by a quarter mile); the second test, BAKER, was an underwater explosion. In preparation for BAKER, Jeff Holter (1946), a member of the Scripps group, nailed empty beer cans up and down the trunk of a palm tree. After the test the lower cans were found full of lagoon water, with the upper cans remaining empty, thus recording the amplitude of the lagoon seiche.

Walter Munk *(wmunk@ucsd.edu) is Secretary of the Navy, Chair in Oceanography, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA.* **Deborah Day** *(dday@ucsd.edu) is Scripps Archivist, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA.*

Bill von Arx of Woods Hole and I shared the responsibility of measuring the lagoon circulation (Munk *et al.*, 1949). We estimated that it would take a week to flush the radioactive water out of the lagoon, but that the Commodore could eat the lagoon fish in two days if the skin were 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 seafloor. Surveys of the north rim of Bikini showed evidence of old submarine landslides down the 23-degree slopes (Fairbridge, 1950). We had some concern that the nuclear explosions might trigger a slide, this being a region of low seismic activity. 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 unexpectedly exploded a 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. In early 1951 the program converged on a geometry where a fission primary provided a source of radiation for a radiative implosion of a fusion secondary. This "Teller-Ulam" configuration was translated into a design by Richard Garwin and Marshall Rosenbluth (Teller, 2001), to be tested only a year later at the Enewetak Proving Grounds.

IVY-MIKE (for Mega) was the first thermonuclear explosion, ever. It was expected to yield 5 to 10 megatons; the actual yield turned out to be 10.4 megatons, equivalent to a whopping magnitude 6.7 earthquake, three magnitudes above the Bikini tests.

Disturbances were detected over the entire Pacific Ocean. Air pressure waves varied from 106 millibars at Enewetak Island (one of the many islands that comprise Enewetak Atoll, it lies 12 nautical miles from Ground Zero) to 0.3 millibars at La Jolla (4500 nautical miles). A one-meter seiche was generated in Enewetak lagoon. The water wave was recorded at Bikini, Kwajalein, Wake, and Hawaii[1].

Meanwhile in Berkeley, Edward Teller, 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 at the time of the MIKE shot to watch the seismographs (Bolt, 1976; Rhodes, 1995). He had been alerted by Herbert York, first direction of Lawrence Livermore National Laboratory, since direct communication to the mainland had been embargoed. The p-waves arrived at zero + 12 minutes (on 31 October local date). Teller phoned York: "It's a boy," claiming paternity.

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

BEFORE THE TEST

A year earlier, Cdr. C.N.G. "Monk" Hendrix had come to Scripps to meet with Roger Revelle, John Isaacs, and Walter Munk. He had read the Bikini report and inquired whether the 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 a Magnitude 7 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 at Pasadena for duty as research and Scripps liaison officer. C.N.G. (for Charles Nelson Grant) Hendrix was a 1939 graduate of the Naval Academy where he was named All-American in lacrosse and All-Fleet shortstop in baseball. 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 (line [or heavy duty rope] usually used for hauling). Thirty-two men reached the reef via the line. Hendrix studied at Scripps and received a Master's degree in oceanography in 1951.

Operation IVY was under the command of Task Force 132 (TF132), with Task Group 132.1 (TG132.1) responsible for the LASL activities, and Task Group 132.4 for weather and safety. Cdr. Hendrix had been assigned to TG132.1 for additional duty. He informed us that IVY-MIKE was to be exploded at the surface of Eluklab Island (Figure 3). Revelle, Isaacs, and Munk expressed concern about setting off a submarine landslide, which in turn could generate a tsunami (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[2]. The mean elevation of Enewetak Atoll was ten feet above sea level. A decision was made to perform the test by remote control. The test plan provided for the following safety precautions: (i) evacuation of all military personnel from Enewetak Atoll (previous plans had been for the MIKE firing party to remain ashore at Enewetak Island.) (ii) evacuation of the people of Ujelang Atoll

[1] 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 [metes per second] and 206 m/s).

[2] 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...*"

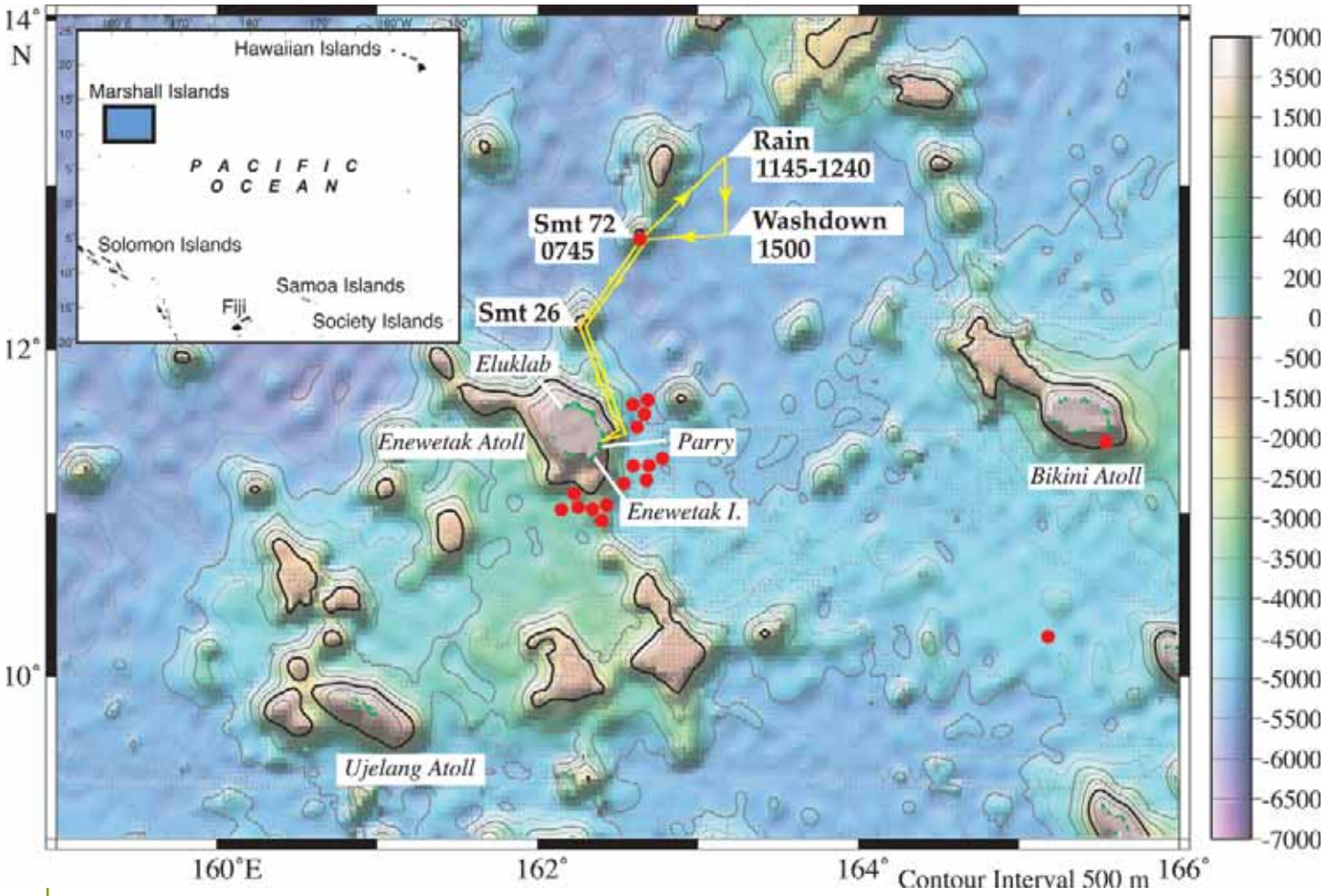


Figure 3. The Pacific Proving Grounds. Ground Zero was at Eluklab Island at the northern end of Enewetak Atoll, with Headquarters at Enewetak and Parry Islands to the south. Red circles indicate location of vessels of Joint Task Force 132 on 1 November 1952, at 0715 local (zero) time. Scripps research vessel *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 degrees T at flank speed in an effort (unsuccessful) to escape the radioactive fallout.

and their domestic animals[3], and (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[4].

THE TEST

So in October 1952 we were making our way via Military Air Transport Service (MATS) to meet the Scripps research vessel *Horizon* at Enewetak. 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 (with on-the-way lubrication provided by 25-cent martinis served at the local BOQ's [Bachelor's Enlisted Quarters]). When we arrived, we were issued identification badges, high-density 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

[3]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 Enewetak were evacuated in 1947 to Ujelang Atoll. (MARSHALL ISLANDS, A CHRONOLOGY: 1944-85, Maka'ainana Media, Honolulu, 1978).
[4]The expedition was initially called OPERATION IVY, but when the supervisor of the Scripps fleet pointed out that the term IVY was classified, the expedition became known as Operation Capricorn, and finally Capricorn Expedition. SIO Subject Files, Box 7, Folder 5, Scripps Archives UCSD.

of all hazard at the time of detonation…" (Operation Ivy, 1952).

Task Force 132 comprised 25 Navy vessels and auxiliary craft, plus the lonely *Horizon* (Figure 4). The Scripps' task was led by Willard (Bill) Bascom, with Cdr. Hendrix providing liaison with TF132. Bascom was John Isaacs' colleague at the Engineering Department at the University of California, 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 (Hendrix, 1952) written by Cdr. Hendrix, the ONR Research and Liaison Officer, to the Commander of TG132.1, he described Bascom's many assignments and remarked on Bascom's performance, among them:

(1c) make detailed bathymetric survey of Seamount 26 in the deep ocean area north of Enewetak 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 Enewetak 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 Enewetak Island.

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

The response of your group in undertaking the difficult and sometimes dangerous job… has been most gratifying…. The manner in

Figure 4. The R/V *Horizon* on Capricorn Expedition, circa 1952. 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.

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 SCUBA (Self Contained Underwater Breathing Apparatus) 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 diving in pairs. Bascom dove alone and 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 a two-minute period (intermediary between swell and tides) to provide the tsunami warning (Figure 5).

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 to within 4500 feet 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 to Seamount 72 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 (i.e., bomb explosion). A taut piano wire led from the anchor on top of the seamount to a buoyant raft at the surface. Flotation for the raft was provided by four truck inner tubes. 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 pressure transducer was clamped to the piano wire mooring at 130 feet beneath the mean surface, with leads up to the surface raft. 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. A tsunami crest would raise the surface and increase the recorded pressure.

Bascom and I tended identical moorings separated by about two miles on Seamount 72. *Horizon* was between and within sight of the two observers. We stood on 3 foot by 3 foot rafts (Figure 6), ready to send a semaphore flag signal (alphabet flag signal-

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

ing system) to *Horizon,* which was in open contact with 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.*

Time Zero had been set for 1952 November 1 0715 hours Enewetak 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 millibar air shock arrived, a sharp report followed by angry rumbling. After that, nothing.

By then Eluklab Island was already gone (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 ever seen captured this impression). The *Horizon* was barely visible over the horizon. I felt lonely on my little raft, and kept penciling 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 a course of 045T and at flank speed (the absolute maximum speed of a vessel, which in this case was 11.5 knots) 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 Capt. Rogers (U.S. Army) 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

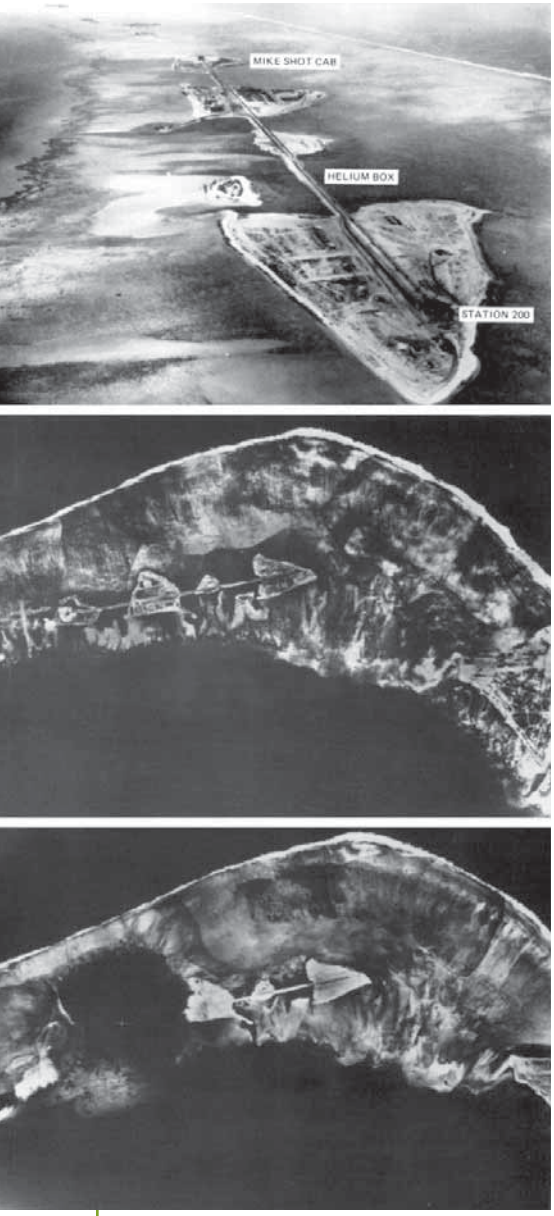
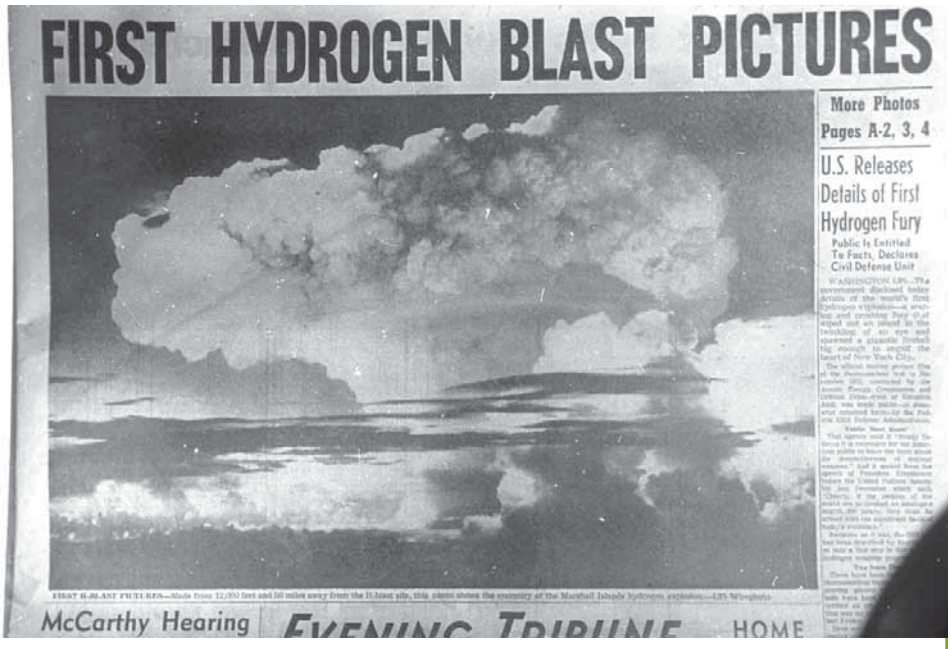


Figure 7. Top: View of north Enewetak Atoll looking east towards the arrow-point of Bogon Island, then Bogeirik Island, Lidilbut Island, and Eluklab Island with the Mike shot cab. It was exactly 2 statute miles from the western tip of Bogon Island to the eastern edge of Eluklab Island. Middle: Aerial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


FIRST HYDROGEN BLAST PICTURES

More Photos Pages A-2, 3, 4

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 circa 1952. Courtesy of Union Tribune Publishing Company.

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 (milliroentgens per hour). 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 in the tropical heat and humidity.

At 1400 we received orders from Task Group 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 3 R. 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 I had abandoned the raft on the previous day. Within 90s following my final time mark, the record showed a positive pressure jump (perhaps the pressure gauge had slipped down the mooring wire). On hindsight the signature was suspicious, too late, too large and too step-like to be consistent with our pre-test calculations. There was no signal at the neighboring mooring tended by Bascom. But if the rafts had still been manned, would I have flagged 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 Time 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 Time Zero + 31 minutes (Barr, 1990)! By strange coincidence a real tidal wave alert was issued by the U.S. Coast and Geodetic Survey for 4 November at 1030. It fizzled.

We returned to Enewetak Island on 6 November for a final report to the Task Force Commander. Lots of things had not gone according to plan. Evacuation of Enewetak Island had occurred and it 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."

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

We have never been able to reconstruct the reasoning behind the *Horizon* evacuation orders issued by Task Group 132.4.[5] The exact wording was: (Defense Nuclear Agency, 1982): "The conduct of the tests went essen-

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

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.

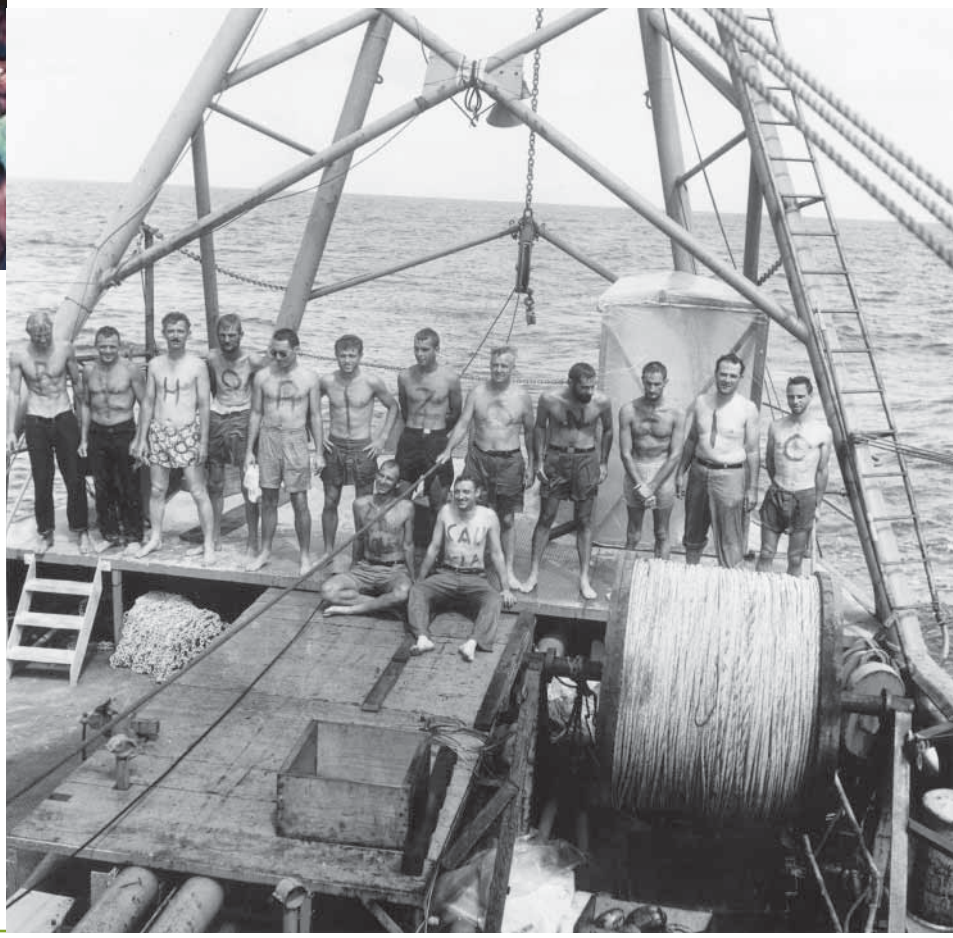


Figure 11. Scientists and crew aboard R/V *Horizon*, Capricorn Expedition, circa 1952. The writing on each man's chest reads RV *HORIZON* SIO LA JOLLA CAL UCLA. Walter Munk seated is on the front left.

tially as planned. The winds remained favorable, carrying the radioactive fallout northwesterly over the open ocean." Perhaps this signaled a higher than expected tolerance for collateral damage.[6]

On one of the frequent pre-bomb visits to the Bikini Officers Club (Figure 10), I asked a Berkeley theoretical physicist serving on TG132.4 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.

[6]Fifteen months later, in February 1954, BRAVO was exploded at the Bikini site; estimated at 15 megatons, it remains the largest ever U.S. explosion. (Scripps was not involved, but still no tsunami.) A late wind shift brought radioactive debris to three islands to the east, Rongelap and Ailinginae (evacuated after two days) and Utirik (in three days). For the next decade the native island populations suffered severe health problems. A Japanese fishing boat, the *Lucky Dragon*, was trawling 87 miles from Ground Zero; with no wash-down procedure available, and unaware of the nature of the white dust, the crew was suffering from radiation sickness when they returned into port two weeks later. One of the fishermen died after six months.

AFTER THE TEST

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 significant discoveries (Figure 11). Russell Raitt's seismic surveys were consistent with a sedimentary layer of order 100 m thickness, much thinner than expected. 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 research vessel *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 metastases (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 in the Mediterranean. He died in September 2000 in La Jolla, California as a result of an automobile accident. Cdr. Hendrix maintained a close association with his fellow oceanographers until his death in 1976. He worked with scientists to locate *Thresher* and founded the U.S. Naval 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 respective 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 Horton. In 1954 we started building *Seiche* and roofed the 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 "above the store."

ACKNOWLEDGEMENT

We thank Breck Betts for his help in preparing this paper. We thank Eric Hartwig, Winter Horton, Kim McCoy, Richard Spinrad, Anitra (Bascom) Wirtz and Herbert York for helpful comments.

REFERENCES

Barr, E.S., 1990.: *The Venturesome Voyages of Scripps into the South Pacific Ocean* 1950-1952 11. Edward S. Barr Papers, MC96, Scripps Archives, University of California, San Diego, La Jolla.

Bascom, Willard, 1952: Willard Newell Bascom Papers, 89-9, Box 6, folder 311. Scripps Archives, University of California, San Diego, La Jolla.

Bascom W., W. Munk and W. van Dorn, 1952: Barometric and Water-surface waves produced by MIKE shot (declassified in 1981). Operation IVY, Joint Task Force 132, WT-635. The first draft of this paper: Munk, W. and W. van Dorn, 1955. Operation Ivy: Interpretation of Water Wave Records can be found in John Dove Isaccs Papers 1943-1980, Box 80, Scripps Archives, University of California, San Diego, La Jolla.

Bolster, C.M., 1953: Letter to Roger Revelle, 24 March 1953, SIO Biographical Files, AC5, Box 2, folder 52, Scripps Archives, UCSD.

Bolt, Bruce, 1976: *Nuclear Explosions and Earthquakes: The Parted Veil*. W.H. Freeman and Company, San Francisco, 34-36.

Fairbridge, R.W., 1950: Landslide Patterns on Oceanic Volcanoes and Atolls. *The Geographical Journal* 115:84-88.

Hendrix, C.N.G., 1952: Letter to Commander 132.1, 10 December 1952, SIO Biographical Files, AC5, Box 2, folder 52, Scripps Archives, University of California, San Diego, La Jolla.

Holter, N.J., 1946: Measurement of Ocean Waves Generated by Atomic Bombs. *Electronics* 19, 94-98.

Munk, W., 1984: Affairs of the sea. In: *A Celebration in Geophysics and Oceanography, 1982: in Honor of Walter Munk on His 65th Birthday, October 19, 1982 at Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California.* SIO Reference Series 84-5, 20, Scripps Institution of Oceanography, La Jolla, California.

Munk, W, G. C. Ewing and R.R. Revelle, 1949: Diffusion in Bikini Lagoon. *Transactions of the American Geophysical Union* 30: 59-66.

Operation Ivy, 1952: Joint Task Force 132, Official Observers pamphlet, 1952. JTF 132, Washington, D.C.: 19 pages. Russell W. Raitt Papers, MC 35, Box 10, folder 34, Scripps Archives, UCSD.

Russell W. Raitt Papers, undated: MC 35, Box 10, folder 34, Scripps Archives, University of California San Diego, La Jolla.

Proposed Tidal Wave Warning Plan using Scripps vessel *Horizon*. Expedition: Capricorn, 1952. SIO Subject Files, AC6, Box 7, folder 16, Scripps Archives, UCSD.

Revelle, R., 1952: Memorandum to Robert Gordon Sproul, 16 April 1952. SIO Subject Files, AC 6, Box 7, folder 5, Scripps Archives, University of California San Diego, La Jolla.

Revelle, R., 1953: Letter to UC President Robert Gordon Sproul, 28 April 1953. SIO Office of the Director (Revelle) Records, AC16, Box 2, Folder 5. Scripps Archives, University of California San Diego, La Jolla.

Revelle, R., J. Isaccs and W.Munk, 1952: Memorandum to Kirk Stevenson, Los Alamos Scientific Laboratories, J Division, 11 September 1952. Walter Munk Papers, MC17, Box 41, folder 12 Scripps Archives, University of California San Diego, La Jolla.

Rhodes, R., 1995: *Dark Sun; The Making of the Hydrogen Bomb*. Simon & Schuster, New York, 510-511

Teller, E. and J. Shoolery (contributor), 2001: *Memoirs: A Twentieth-century Journey in Science and Politics.* Perseus Publishing, Cambridge, Massachusetts, 628pp.

TFL132 refers to DIRECTOR, Defense Nuclear Agency. Defense Nuclear Agency, 1982: *Operation IVY* 1952. The Agency (DNA 6036F), Washington, D.C., declassified in 1982. Note: TFL132 refers to DIRECTOR, Defense Nuclear Agency.