



Marshall Islands Expedition

Aboard the Research Vessel Alucia

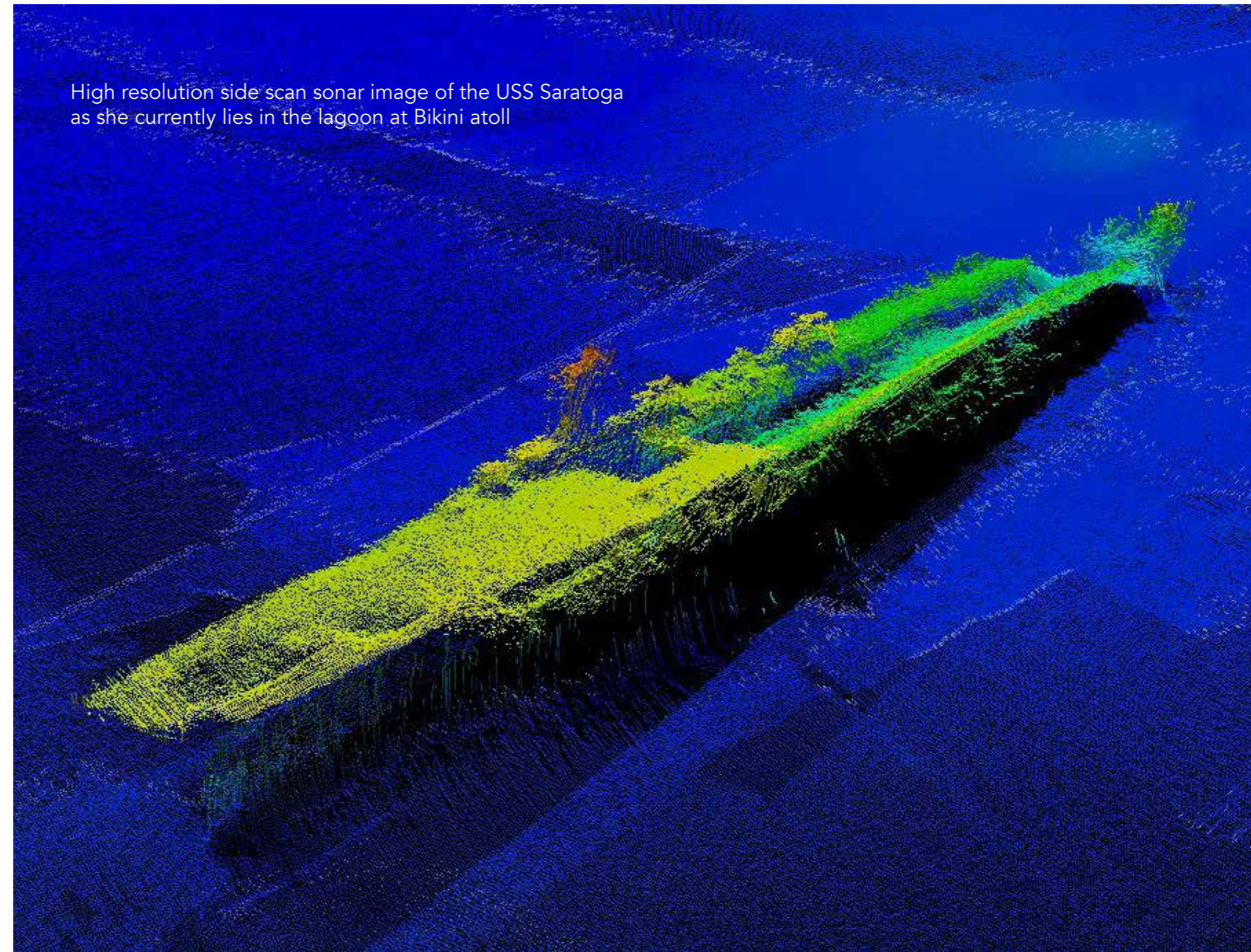
January 17-27, 2015

Woods Hole
Oceanographic
INSTITUTION

Center for Marine and Environmental Radioactivity



High resolution side scan sonar image of the USS Saratoga as she currently lies in the lagoon at Bikini atoll



Historical photo of the nuclear explosion and mushroom cloud in mid-1946 as part of Operation Crossroads. Seen in the water and carried into the air by the explosion were 95 targets consisting of surplus US and Japanese military ships intentionally placed in the blast zone.



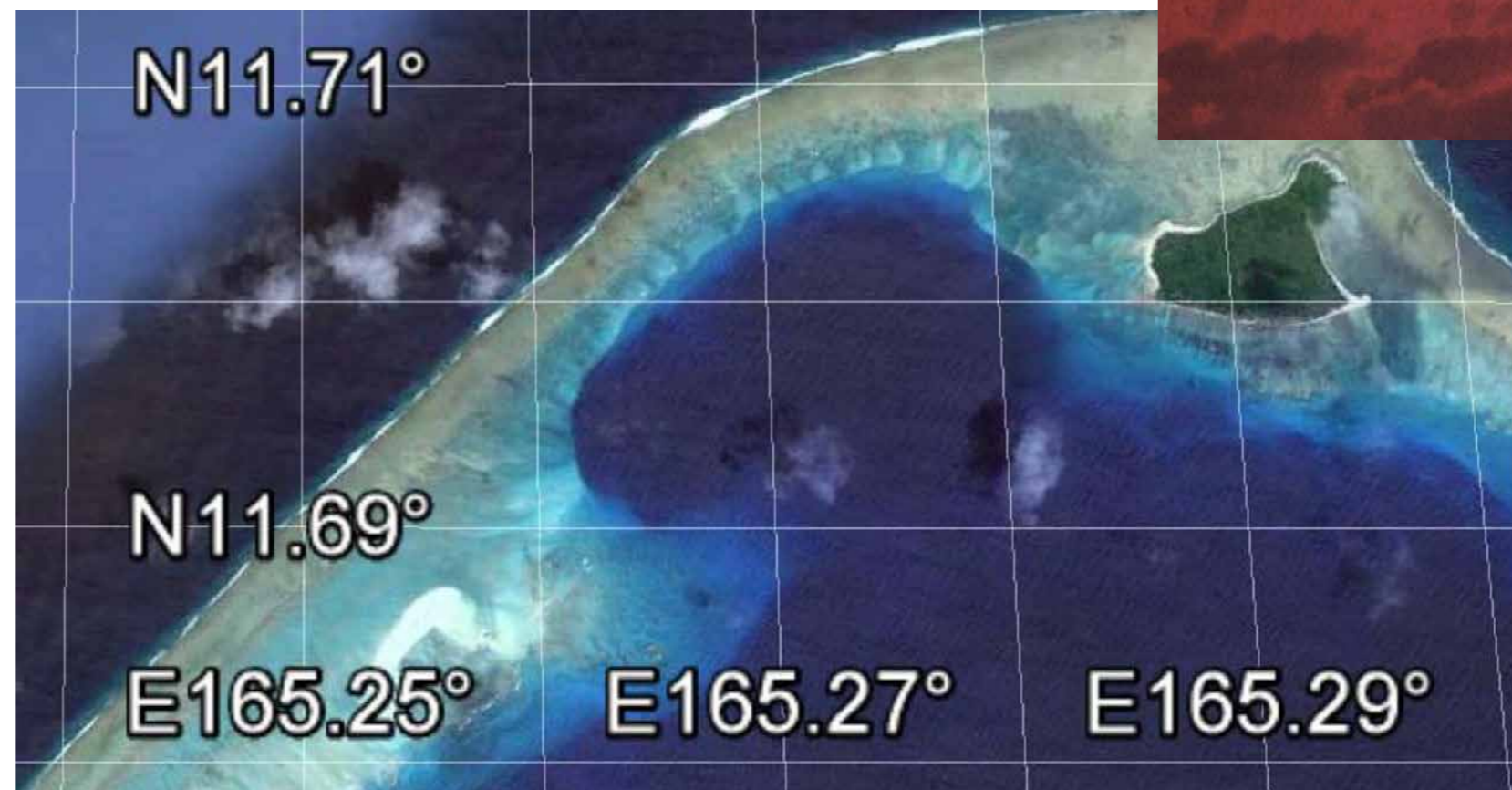
History

The Marshall Islands were the site of 67 U.S. nuclear weapons tests between 1946 and 1958, where powerful nuclear devices were detonated on the reefs, in the sea, in the air and underwater. These tests resulted in the release of the largest human-made radioactive materials to the Pacific Ocean. The testing began with the Operation Crossroads series in July 1946 on Bikini atoll where Baker, a 40kiloton atomic bomb, exploded and caused concentrated, radioactive fallout from the immense nuclear explosion. In 1954, a test of a new "H-bomb" called Castle Bravo was 1000 times more powerful than expected, shocking the scientists and military. It destroyed the very instruments that were to be used to evaluate the bomb's effectiveness and led to the most significant accidental radiological contamination to date. Nuclear testing was discontinued in 1958 due to a global ban on atmospheric testing of thermonuclear devices.

Although Marshall Island residents were evacuated and relocated to other islands, with a promise to return someday, 61 years later Bikini atoll remains uninhabited since there is still concern about levels of radioactivity in water and food grown on the island. Excavation of the debris from weapons testing along with contaminated topsoil and sealing it under concrete at Runit atoll was intended to create safer conditions to allow future habitation of the island.

1954

The United States tests its largest ever H-Bomb, codenamed: Castle Bravo



2015

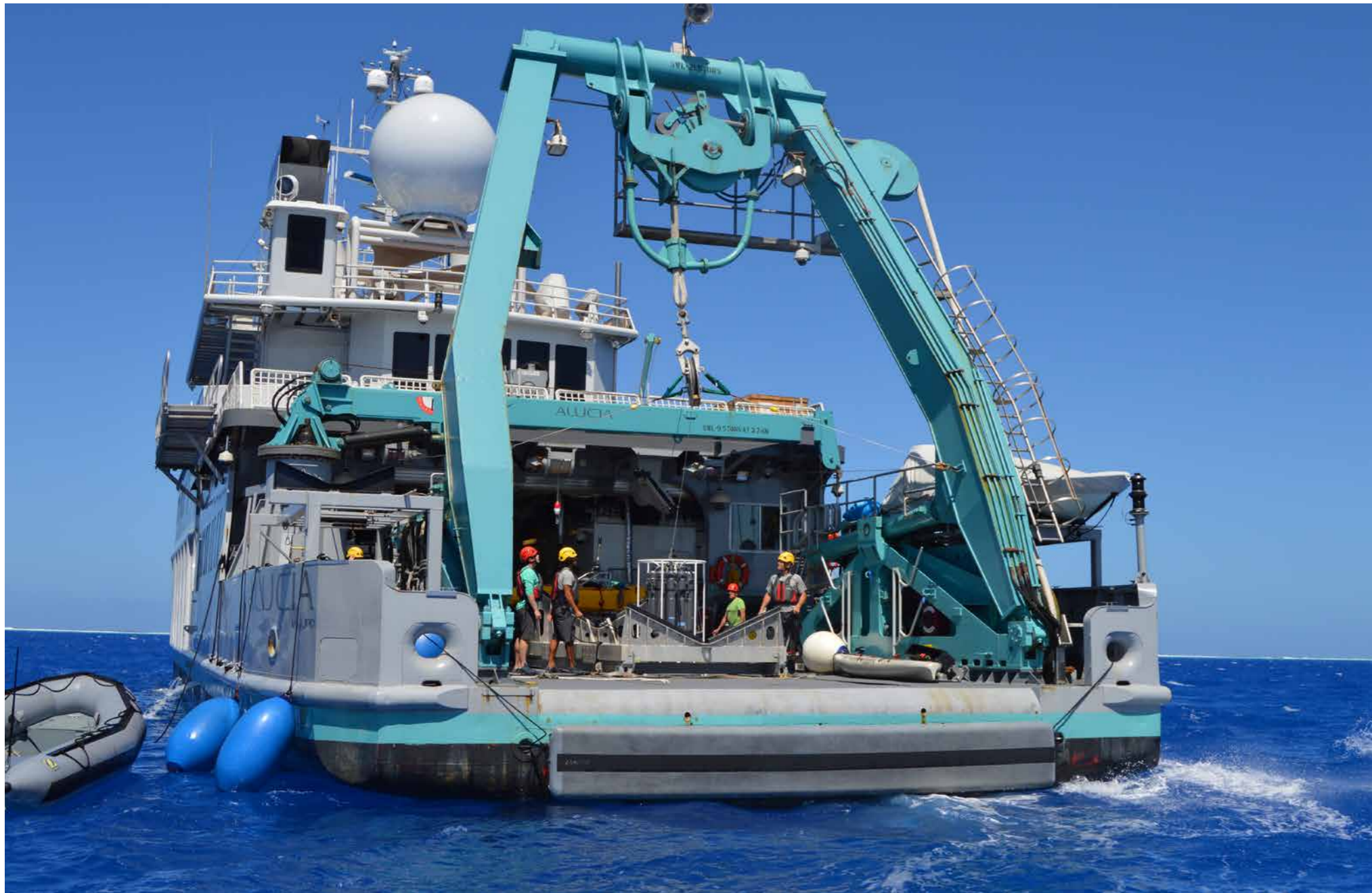
Google Earth view of the crater created by the detonation of Castle Bravo

Research Goals

Given the concern regarding longterm radioactivity in this environment, our Woods Hole Oceanographic Institution, Center for Marine and Environmental Radioactivity research team conducted scientific analyses to measure radionuclides that may be remaining in seawater, sediments and groundwater wells from the legacy nuclear testing sites on Bikini and Enewetak atolls, and in the craters created by the explosions. We will use this information to assess current conditions and increase our scientific understanding of the ongoing impacts of these tests on the ocean and atolls of the Marshall Islands while raising the public awareness about the radioactive world we live in.

WHOI Scientist Ken Buesseler is holding a hand held Geiger Counter along a pristine beach on Bikini Island. These devices were used to monitor local radioactivity levels which we confirmed were below health concern for our short visit to the sampling sites on Bikini and Enewetak.





View of the fan tail and large "A-frame" of MV Alucia used to hoist the large CTD Water Sampling Device and support vessel "Northwind" on and off the ship.



WHOI team and Marshall Islands observer (left to right) Nathan Tisdale, Kaitlyn Tradd, Paul Henderson, Lauren Kipp, John (Chip) Breier, Ken Buesseler, Matt Charette, Steve Pike, and Benedict Yamamura

Cruise Objectives

The Legacy of Atomic Weapons Testing on the Bikini and Enewetak Atolls:

Quantifying the Sources and Fate of Radionuclides in the Ocean and on the Marshall Islands Using New Sampling Devices

In an effort to continue monitoring radionuclide levels in the Marshall Islands, our Woods Hole Oceanographic Institute's Center for Marine and Environmental Radioactivity research team focused on sampling seawater in lagoons, groundwater wells, open water and the seafloor, while also developing and testing new devices for monitoring contaminant inputs using an autonomous surface ocean vehicle. Principle Pictures accompanied the research team to create a video documentary that chronicles the legacy of nuclear bomb testing in the Marshall Islands.

During the 10 days of our expedition, we visited Bikini and Enewetak atolls aboard M/V Alucia to study the distribution and sources of radioactive contaminants. We predict that runoff from these islands, specifically in the form of groundwater seepage, may be a continuing source of radioactivity into the ocean. At both islands, we sampled lagoon waters and the groundwater in wells to determine the presence and possible route of radionuclide inputs into the lagoons. To determine the history and magnitude of radionuclide

inputs, we also collected underwater push core samples of the sediments in the craters created by the weapons tests in the 1940's and 1950's from shallow depths down to over 150 feet below the surface. These samples will be compared to prior studies in the 1970's and 1980's to better understand and quantify the extent of ongoing contamination entering the lagoons in the Marshall Islands 60 years after the nuclear bomb testing ended. The results of these studies will be an interesting comparison to the more recent radioactive contaminant releases at Fukushima, Japan. Finally, to put these data from the lagoons in context of radionuclide distributions outside, we sampled 6 to 12 depths in the upper 2000 meters between Guam and Majuro, Marshall Islands, for cesium, iodine, tritium and plutonium isotopes on a separate research trip earlier in January 2015 as the M/V Alucia transited to Majuro in the Marshall Islands.

In addition to the radionuclide studies, this research expedition allowed us to test new technologies for the monitoring of ocean radioactivity. We assembled and tested a custom-made water sampling device carried by a "JetYak", an autonomous surface vehicle that combines a jet-ski motor with a kayak that can be remotely controlled. This sampling device pumps waters through cesium extraction columns as the JetYak moves forward to sample the levels of cesium in ocean waters. If successful, it could be used along coastlines world-wide to routinely monitor seawater

around nuclear power plants or in response to accidents such as Fukushima. The third component of this project, beyond science and engineering, was a partnership with Principle Pictures in Boston, to film our activities and to produce a documentary on the legacy of nuclear testing and the scientific assessment of current conditions. Over 30 hours of video footage were shot during field sampling and interviews with the WHOI scientific team, M/V Alucia crew, and Marshall Islanders. A volunteer photographer also joined the expedition to capture and document all the research and people involved in the trip, contributing more than 4000 photos to WHOI.

Leg 1: Majuro to Bikini atoll (January 16-19)

Leg 2: Bravo Crater (January 20)

Leg 3: Bikini atoll to Enewetak atoll (January 20-22)

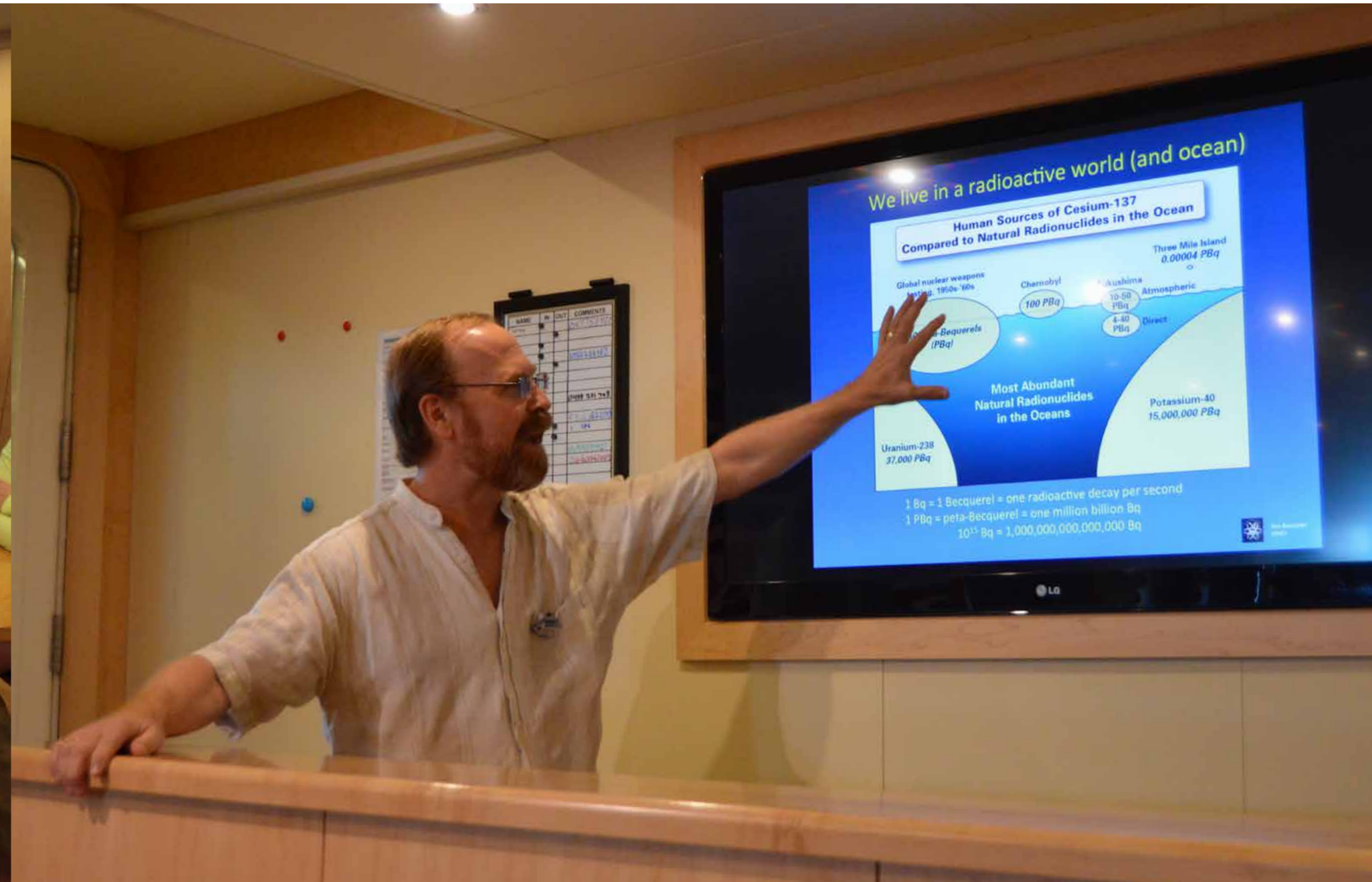
Leg 4: Enewetak atoll to Runit (January 23)

Leg 5: Runit to Mike Crater and Enjebi Island (January 24)

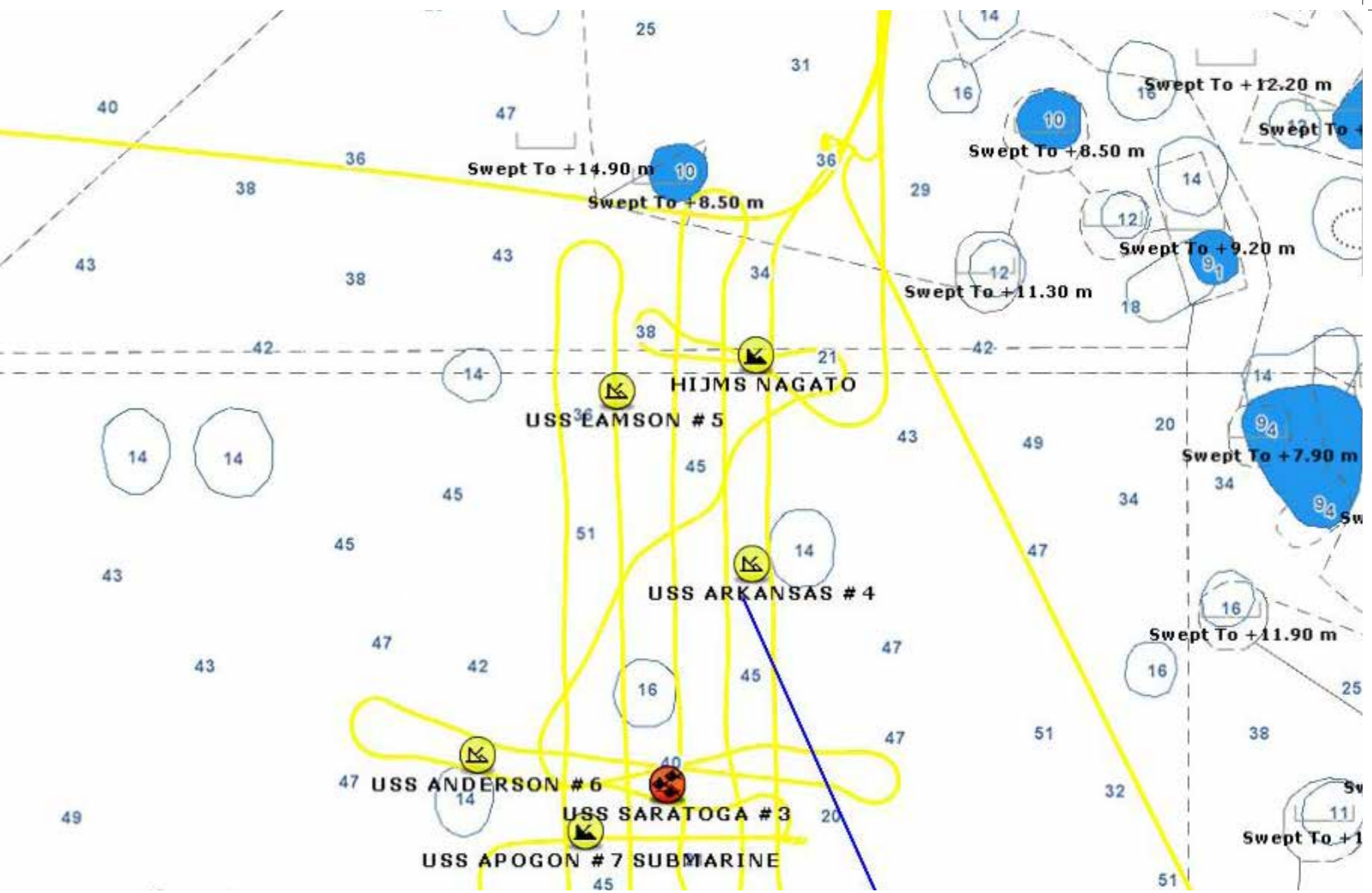
Leg 6: Enewetak atoll to Majuro (January 24-January 27)

Bow of MV Alucia

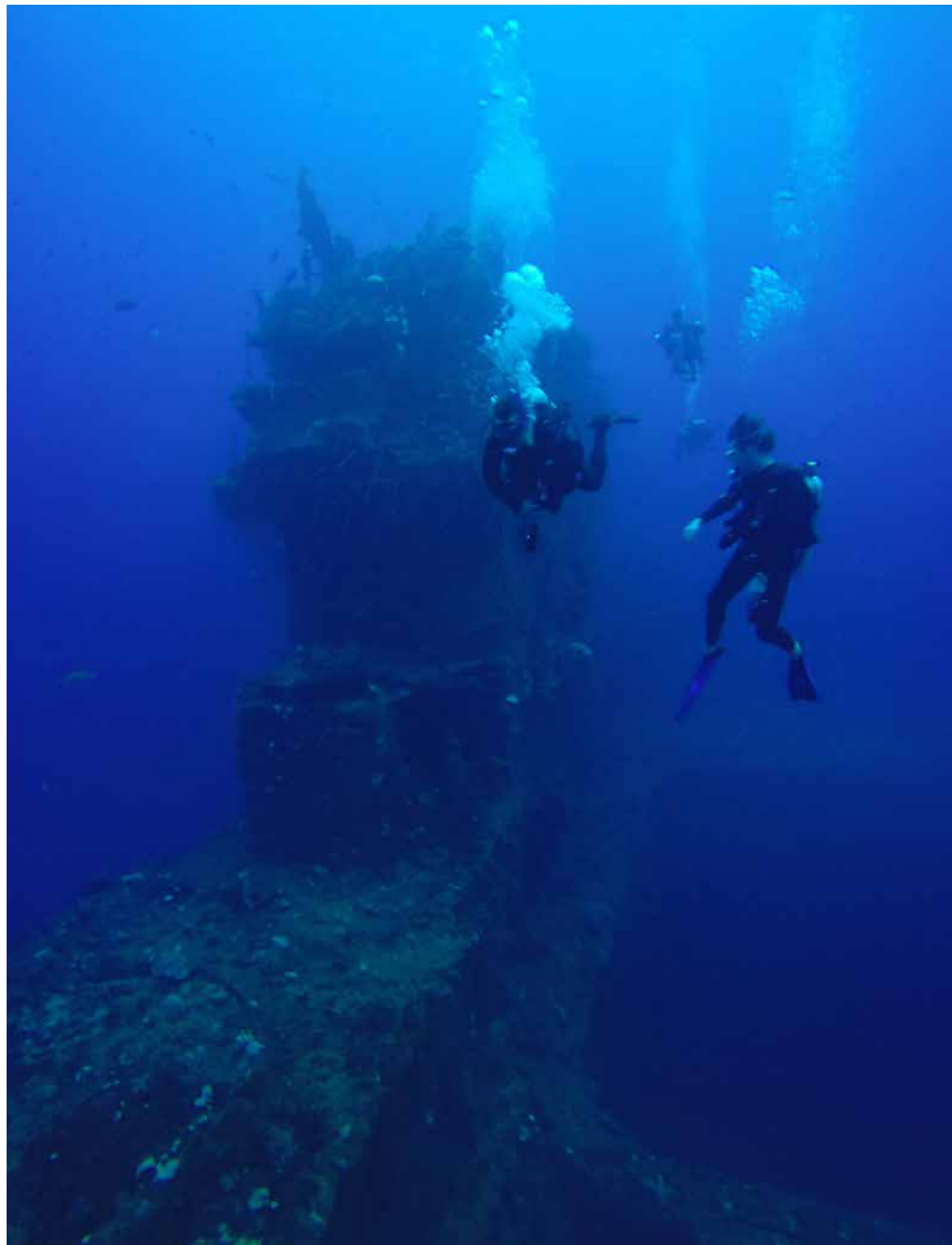




Chief Scientist Ken Buesseler (right) launched the voyage by giving a lecture about ocean radioactivity and the motivation behind the cruise to an audience of MV Alucia crew members and scientists in the galley of the MV Alucia.



Map of Bikini atoll (left) and track taken over the USS Saratoga and other dive sites (right)



Divers (from left) Paul Henderson, Krystyna Wolniakowski, and Chip Breier exploring the USS Saratoga which sunk in 1946 after nuclear weapons testing and now lies in 150 feet of water off Bikini Atoll.



Hand driven "push cores" were taken by divers Steve Hudson and Walter Bubby at several sites in the Bikini and Enewetak lagoons to obtain a record of radioactive contaminants that remains associated with the seafloor sediments after the nuclear blasts.



Diver Steve Hudson (left) seals the sediment core underwater to assure the pure sample reaches the surface safely.



Divers returning to the surface with a successful core.



Eddy Maddison and Ken Buesseler secure the sediment core sample to the rail on Northwind for transport back to the ship for analyses of radioactive contaminants.



This "Welcome to Bikini" sign greeted us on the island of Bikini where for several (failed) attempts have been made to resettle these islands and bring in ecotourism.



Local officials provide transport by truck on Bikini island to well sampling sites for Ken Buessler (left), Nathan Tisdale (center) and Lauren Kipp (right)



Matt Charette's team sample groundwater from existing wells on several islands in both Bikini and Enewetak atolls. Shown here, Paul Henderson and Benedict Yamamura check a chemical sensor.



MIT/WHOI student Lauren Kipp (seated left) assisting Matt (center) and Paul Henderson (right) collect a groundwater sample in the 5 gallon plastic "cubitainer".



As part of government sponsored remediation studies, Ken Buessler stands near a test plot on Bikini Island where different vegetables have been grown for studying of the uptake of radioactive contaminants that remain to this day in the soils.



Matt Charrette and colleagues use a well pump to collect additional groundwater samples.



Krystyna Wolniakowski wears an intricate and unique necklace made of shells handmade by an Enewetak Island resident.

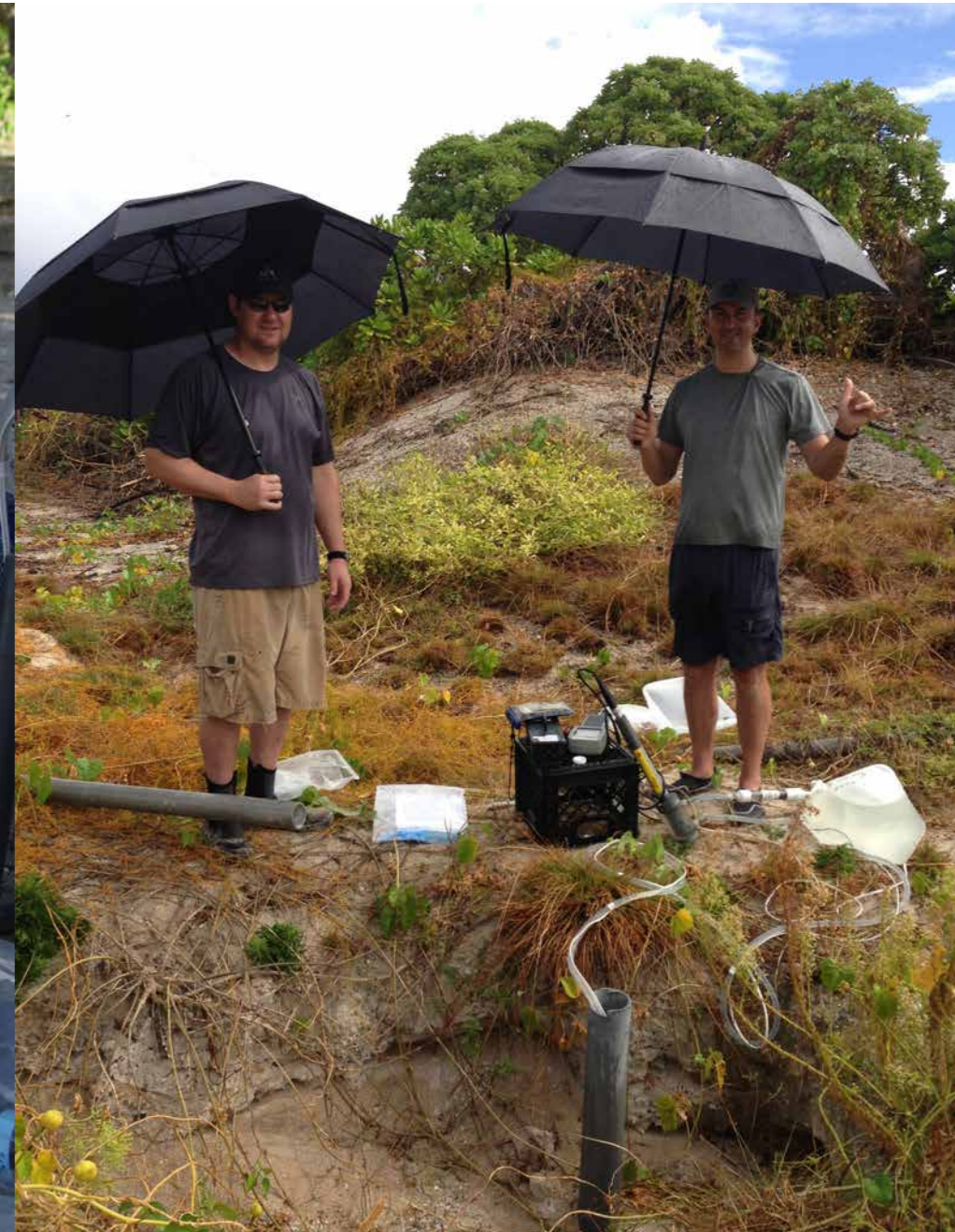
Sampling site associated with test plot on Bikini Atoll (right) Image of pristine beach on Enewetak atoll



We were greeted on Enewetak by curious children, here along the runway at Enewetak Island.



Sampling groundwater from existing well (white pipe) at Runit dome by (left to right), Benedict Yamamura, Paul Henderson, Eddy Maddison and Nathan Tisdale, videographer for the expedition.



Rain or shine, various groundwater sites were sampled, ranging from public wells (Lauren Kipp on left), to test wells put in place for ongoing monitoring of radioactivity levels (center -Matt Charette, right- Paul and Matt).



Runit dome on the Enewetak atoll, was created in a former blast crater to bury and contain low level radioactive debris and soil scraped from large parts of the atoll.



Assessing the potential for ongoing leaks of radioactive contaminants from the Runit dome and in to the lagoon was one of the objectives of our study.



Our team takes daily trips to the islands in our zodiac from MV Alucia, packed with sampling equipment and supplies for a days work.



Paul Henderson (center) and Benedict Yamamura (right) dig a well in the sand to reach groundwater while Matt Charette (left under umbrella) hides from the sun as he records the data.



Flying in from Honolulu and arriving at Majuro in the Marshall Islands is quite a beautiful sight, although the view of these low lying islands makes it obvious how susceptible this island nation is to sea level rise.



Children were curious about our work wherever we visited- here two girls smiling for the camera in Majuro.

RESULTS & REFLECTIONS:

Success! There is no other way to describe what we accomplished on this short, but intense, research cruise to this remote part of our world. With sampling at over 78 locations, times or depths, and collection of more than 125 ocean, groundwater and seafloor samples, we have captured a snap shot of current radiological conditions at Bikini and Enewetak atolls.

We processed 67 samples for cesium and plutonium isotopes. We collected 22 barrel samples of surface waters as well as onshore, 26 groundwater samples from islands of Bikini, Namu (near Bravo crater) Runit (near dome), and Enjebi (near Mike Crater). These are processed for radium isotopes, along with Pu and Cs and other supporting samples and data (temperature, salinity, some radon, trace metals, nutrients, and 129-iodine).

On the M/V Alucia and on shore, we measured our daily exposure using portable Geiger counters, and found dose levels on these coral atolls even less than in our WHOI lab in New England, where granite rocks are a larger source of radon and other naturally occurring radionuclides, than levels found in the coral reefs in the Pacific which are built largely from calcium carbonate. However, most of the radionuclides cannot be seen using hand

held devices, and our samples were shipped to WHOI for analyses using more sensitive and selective instruments. Of particular importance are the samples on transects along the shoreline and across the lagoons, many at the same locations as the JetYak was tested. Early results show the detectable levels of cesium in the lagoons to be elevated compared to the open seas, but are not high enough to be of any direct human health concern.

NEXT STEPS:

The detection of trace levels of radionuclides in our samples requires a combination of physical and chemical purification steps to isolate the specific isotopes from each other and often from much higher levels of background radioactivity. A combination of gamma, alpha and scintillation detection techniques are used to measure the radioactivity levels. The key component will be combining the estimates of the rate of groundwater input to the lagoon (using radium isotopes) with the measured levels of the legacy radionuclides remaining from nuclear testing, like cesium or plutonium. This combination of unique results has never been done before in these atolls, and will allow us to quantify and identify radionuclides that are still leaking from the nuclear testing sites, or from other structures/sources such as the waste stored under the Runit dome—the nuclear crater on Enewetak atoll where nuclear debris from the testing on these islands was consolidated, buried, and capped in 1977. For more about our work, please visit our website: www.ourradioactiveocean.org.

Final photo of the captain, crew and science team on the helicopter pad of MV Alucia at the end of a successful cruise.



Dr. Ken Buesseler
Senior Scientist and Director, Center for Marine and Environmental Radioactivity

Dr. Buesseler specializes in the study of natural and man-made radionuclides in the ocean. His work includes studies of fallout from atmospheric nuclear weapons testing, assessments of Chernobyl impacts on the Black Sea, and examination of radionuclide contaminants in the Pacific resulting from the Fukushima nuclear power plants. Dr. Buesseler has served as Chair of the Marine Chemistry and Geochemistry Department at WHOI, as Executive Scientist of the US Joint Global Ocean Fluxes Planning and Data Management Office and two years as an Associate Program Director at the US National Science Foundation, Chemical Oceanography Program. In 2009 he was elected Fellow of the American Geophysical Union and in 2011 he was noted as the top cited ocean scientist by the Times Higher Education for the decade 2000-2010. He is currently Director of the new Center for Marine and Environmental Radioactivity at WHOI. He also began a crowd funded citizen scientist campaign called “Our Radioactive Ocean (<http://ourradioactiveocean.org>)” to monitor Fukushima ocean radioactivity levels along the west coast of North America and educate the public. Dr. Buesseler led the Marshall Islands Expedition on M/V Alucia and provided oversight for the team’s work on all research and sampling conducted for both the marine and terrestrial studies completed.



Dr. Matt Charette
Senior Scientist and Director, Coastal Ocean Institute



Dr. Charette’s main research focus has been on submarine groundwater discharge and its role as a vector for chemical transport to the ocean. Recently, he has broadened his research scope to include studies of Greenland Ice Sheet hydrology and global ocean inputs of trace elements and isotopes through participation in the international GEOTRACES program (www.geotraces.org). He came to WHOI in 1998 after receiving his Ph.D. degree at the University of Rhode Island and is currently serving as the Director of the Coastal Ocean Institute. During the Marshall Islands Expedition, Dr. Charette led the effort to quantify groundwater sources of man-made radionuclides from nuclear weapons testing using naturally occurring radium isotopes and radon. More information can be found on his lab website (<http://www.whoi.edu/groundwater>).



Mr. Paul Henderson
Research Associate III and Manager, Nutrient Analytical Facility

Mr. Henderson researches nutrient cycling in coastal systems and using radioisotope tracers to help quantify groundwater inputs of radionuclides and inorganic nutrients to the ocean. This latter process has significant societal relevance due to its potential to negatively affect the ecological balance in coastal systems and lead to eutrophication. In his work at WHOI, Mr. Henderson has pioneered research beyond the coastal zone through use of the radium quartet as a proxy for quantifying vertical and horizontal mixing rates for trace elements and isotopes in the open ocean. Mr. Henderson also

manages the WHOI nutrient facility (www.whoi.edu/nutrient), in which water samples collected worldwide are processed for inorganic nutrients. The studies he conducted aboard the M/V Alucia included groundwater and surface water collection and analysis of radon, radium isotopes, and dissolved inorganic nutrients. The data obtained from this will help assess the release rate of plutonium, cesium isotopes, and anthropogenic nutrients from groundwater to the ocean from the previous weapons testing conducted and non-point sources of nitrogen inputs in the Marshall Islands.

Dr. John “Chip” Breier
Associate Scientist, Deep Submergence Laboratory of the Applied Ocean Physics & Engineering Department

Dr. Breier is a trained geochemist and ocean engineer. His research focuses on the transfer of material and chemical energy between the lithosphere and the oceans. He develops remotely operated and autonomous vehicles, along with custom sampling instrumentation to study the biogeochemical processes associated with mixing of geofluids and seawater. As part of his research he studies deep-sea hydrothermal fluids, methane seeps on the continental shelf, and groundwater discharge to the oceans. An exciting and growing aspect of his scientific research concerns the potential feedbacks between geofluid chemistry and marine microbial communities. Such a survey would have applications showing that life processes, ocean chemistry, and the ocean’s role in shaping Earth’s environment are fundamentally linked. His work with Dr. Buesseler during the Marshall Island Expedition included building and testing an autonomous radionuclide sampling system. <http://www.whoi.edu/science/AOPE/dsl/jbreier/>





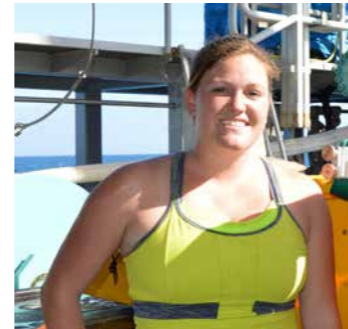
Steven Pike
Research Associate and Manager
of the Radioanalytical Facility

Mr. Pike earned an M.S. degree in marine chemistry from the Graduate School of Oceanography at the University of Rhode Island after a career as a commercial fishing captain. His research interests include trace metal and radiochemical analysis. He has developed new methods for isolating and analyzing natural and artificial radioisotopes in ground and sea water including ²³⁴thorium, ²⁴⁴curium and cesium isotopes ¹³⁴ and ¹³⁷. His cesium technique continues to be instrumental in assessing the amount of radioactive material released to the ocean from the Fukushima Dai-Ichi nuclear power plant off the coast of Japan. His work for Dr. Buesseler during the Marshall Islands Expedition included onboard processing

of groundwater and seawater for cesium followed by laboratory isolation and analysis of legacy plutonium isotopes from nuclear tests of the 1950's and 60's. http://cafethorium.who.edu/website/about/services_radioanalytical_facility.html

Kaitlyn Tradd
Mechanical Engineer in the Advanced Engineering Lab

Ms. Tradd graduated from MIT in 2009 with a bachelor's degree in Mechanical and Ocean Engineering and has been a full-time employee at WHOI since 2011. While at WHOI, she has worked on a large variety of projects, including mooring design and the development of ship-based support equipment for the Ocean Observatories Initiative, design of new subsystems and the structural analysis for the recent major Alvin upgrade project, and a number of smaller-scale engineering projects with scientists throughout WHOI and partnering organizations. Ms. Tradd has provided mechanical engineering support for several of Dr. Breier's scientific endeavors and has sailed on several research cruises as a technician for his samplers. Recently, Dr. Breier and Ms. Tradd have been focusing on the development of a new autonomous vertically profiling underwater vehicle. A portion of this new technology was tested in the Marshall Islands. It was designed to rapidly filter large volumes of water in situ through special columns containing a cesium binding resin, collecting several discrete samples during a single deployment. Before her employment with WHOI, Ms. Tradd worked for two years as an environmental engineer, focusing on remediation and rehabilitation of coastal wetlands.



Lauren Kipp
PhD Candidate, Chemical Oceanography in the
Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program.



Ms. Kipp is currently working with Dr. Matthew Charette studying radium isotopes in the ocean. Her PhD thesis research will focus on the distribution of radium in the Arctic, and the application of these isotopes as tools to calculate rates of ocean mixing processes. Ms. Kipp earned her BS in Chemistry from the University of North Carolina Wilmington in 2013. During the Marshall Islands Expedition she assisted Drs. Charette and Henderson with the collection of groundwater and surface water samples and the analysis of radium isotopes. After receiving her PhD she hopes to continue her career in academia as a professor.

Benedict Yamamura
Coastal Fisheries Information Officer, Marshall Islands Marine Resources Authority

Mr. Yamamura has worked for the Marshall Islands Marine Resources Authority for more than three years as the Coastal Fisheries Information Officer. In this capacity, Mr. Yamamura serves as an Observer on ships to assure compliance with Marshall Islands laws and policies. As a native Marshall Islander, Mr. Yamamura finished his Bachelor of Arts degree in marine affairs and geography at the University of the South Pacific. Prior to that, Mr. Yamamura undertook several marine science units at the Haifa University in Israel. Mr. Yamamura plans to further his studies in Australia.





Nathan Tisdale
Cinematographer, Principle Pictures, Boston, MA

Mr. Tisdale has worked in documentary film for 6 years as a producer, cinematographer and editor. He was a camera operator and associate producer on “The List”, which premiered at the Tribeca Film Festival in April 2012. He was an associate producer and assistant editor on “What Tomorrow Brings”, a film about the first girls’ school in a small Afghan village. Mr. Tisdale also served as camera operator on “The Internet’s Own Boy: The Story of Aaron Swartz”, which premiered at The Sundance Film Festival in January 2014. During the Marshall Islands Expedition, Mr. Tisdale interviewed Marshall Islanders about their personal and family experiences on the islands since the bomb testing. He documented all

the sampling and research conducted during the 10 day expedition on MV Alucia, on shore and in the water. The documentary will raise awareness about the research conducted by the Woods Hole Oceanographic Institute and the life of Marshall Islanders and their challenges resulting from U.S. atomic testing.

Krystyna Wolniakowski
Expedition Photographer and Executive Director, Columbia River Gorge Commission, Portland, OR

Ms. Wolniakowski joined the Marshall Islands Expedition as the photographer to document the day to day results of the WHOI team’s research and sampling efforts on the islands and underwater. Ms. Wolniakowski is currently serving as the Executive Director for the Columbia River Gorge Commission in Washington and Oregon, and appointed by Oregon Governor Kate Brown to the Board of the Oregon Ocean Science Trust. Prior to joining the Commission in 2015, she worked for 14 years as the Western Director for the National Fish and Wildlife Foundation developing and managing conservation grant programs in seven western and coastal states. She served as the Alaska Conservation Expedition Director on the M/V Alucia voyage in 2011. She received her M.S. degree from Oregon State University in oceanographic studies and conducted research on marine productivity and radiation biology.



Acknowledgments

The Woods Hole Oceanographic Institution’s Center for Marine and Environmental Radioactivity Research Team is grateful for the generous support of Ray Dalio and the Dalio Explore Fund that enabled us to organize this Marshall Islands expedition. We could not have conducted this research without a ship as well equipped as the M/V Alucia, and without the extraordinary and talented crew that assisted us with every aspect of zodiac deployment and loading/unloading of our supplies and equipment, the exceptional healthy meals that we enjoyed and sustained us during our long days, and the technical and IT support. A special thanks to Captain Frank Allica and his crew for transporting us safely through the Marshall Islands.

We are grateful to the Ministry of Foreign Affairs Republic of the Marshall Islands for authorization to conduct research in the islands. We want to thank the Mayor of Bikini atoll, Jack Niedenthal and staff at the Bikini Council Office, for support to sample Bikini atoll, as well as the Mayor of Enewetak atoll, Niel Flores, Benjamin Maloloy, and staff at the Enewetak Council Office for support to sample Enewetak atoll. In addition, Terry Hamilton of the Lawrence Livermore National Lab, and his staff on Bikini and Enewetak atolls, assisted with the groundwater sampling. SAFECAST, a volunteer international organization devoted to tracking global radioactivity levels, also donated hand held monitoring devices to track our radiation exposure to share with public audiences.

We also appreciate the excellent guidance, good humor, expertise and invaluable assistance of the Marshall Islands observers, Benedict Yamamura,

Edward “Eddie” Maddison, and Giorgio Note who helped us to gain a better understanding of the Marshall Islands culture, history and natural resources, as well as providing support for all aspects of our sampling. Eddie was especially helpful as an expert deep diver buddy with dive master Steve Hudson when they descended below 150 feet to sample sediments in the bomb craters.

Finally, thank you to M/V Alucia and WHOI ship operations personnel for all the planning and logistical support to make this research expedition so successful.





Marshall Islands Expedition

Aboard the Research Vessel Alucia

Content Organized by

Krystyna Wolniakowski

Photography

Krystyna Wolniakowski

Ken Buessler

Matt Charette

Lauren Kipp

Nathan Tisdale

Benedict Yamamura

Design & Bookmaking

Park Photography

Livingston, MT