The Ephemeral and the Enduring: Trajectories of Disappearance for the Scientific Objects of American Cold War Nuclear Weapons Testing

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THE EPHEMERAL AND THE ENDURING: TRAJECTORIES OF DISAPPEARANCE FOR THE SCIENTIFIC OBJECTS OF AMERICAN COLD WAR NUCLEAR WEAPONS TESTING

Abstract: *The historic material culture produced by American Cold War nuclear weapons testing includes objects of scientific inquiry that can be generally categorized as being either ephemeral or enduring. Objects deemed to be ephemeral were of a less substantial nature, being impermanent and expendable in a nuclear test, while enduring objects were by nature more durable and long-lasting. Although all of these objects were ultimately subject to disappearance, the processes by which they were transformed, degraded, or destroyed prior to their disappearing differ. Drawing principally upon archaeological theory, this paper proposes a functional dichotomy for categorizing and studying the historical trajectories of nuclear weapons testing technoscience artifacts. In examining the transformation patterns of steel towers and concrete blockhouses in particular, it explores an associated loss of scientific method that accompanies a science object's disappearance.*

Keywords: *Cold War; Bikini Atoll; bunkers; nuclear weapons testing; zero towers*

Efemérní a trvalé: trajektorie zániku vědeckých předmětů amerického testování jaderných zbraní

Abstrakt: *Historická materiální kultura, která je výsledkem amerického testování jaderných zbraní za studené války, zahrnuje objekty vědeckého výzkumu, jež lze obecně kategorizovat jako efemérní nebo trvalé. Objekty považované za efemérní měly méně solidní podstatu, jelikož byly pomíjivé a určené ke zničení při jaderném testu, zatímco trvalé objekty byly z podstaty odolné a dlouhotrvající. Ačkoli všechny tyto objekty nakonec podlehly zkáze, procesy, jež jejich zániku předcházely a jimiž byly objekty transformovány, degradovány nebo ničeny, se lišily. Tento text čerpá především z archeologické teorie a navrhuje funkční dichotomii pro kategorizaci a výzkum historických trajektorií technovědeckých artefaktů určených k testování jaderných zbraní. Zkoumáním zejména transformačních vzorců ocelových věží a betonových pevností se tento text zabývá související ztrátou vědecké metody, která doprovází zánik vědeckého objektu.*

Klíčová slova: *studená válka; atol Bikini; bunkry; testování jaderných zbraní; testovací věže*

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Introduction

In the Republic of the Marshall Islands, on the Bikini Atoll island of Airukiraru, a relic of American Cold War nuclear weapons testing stands precariously on the lagoon shoreline. Built in early 1954 for use in Operation Castle, the concrete blockhouse dubbed Station 2300 (Figure 1) avoided immediate nuclear destruction multiple times by virtue of its virtual indestructibility. Yet over the past sixty years, the erosional actions of wind, waves, and tide have moved the Airukiraru shoreline more than 100 meters inland threatening to do what the most destructive forces ever wielded by mankind could not: reduce it to rubble. When the end comes for Station 2300, fewer than a dozen nuclear weapons testing blockhouses will remain on Bikini Atoll's historic Cold War landscape.

Figure 1: Scientific Station 2300 at the Bikini Atoll lagoon's edge in 2009.
Source: Photo courtesy of Steve Brown.

The slow decay and disappearance of Scientific Station 2300 will be the last phase in a trajectory that is uncommon to most epistemological objects of modern science. Its demise is uncommon in the sense that it presents a unique situation in which the object was used scientifically for only a brief period of time before being abandoned and left to degrade and disappear. As a consequence of the station's formidable concrete construction, the final phase of the structure's existence will be a slow and gradual degradation, deformation, and disappearance. This is very unlike other substantial objects of twentieth-century physics, such as astronomical telescopes and particle accelerators, which typically serve their original purposes for lengthy periods of time and often only out of obsolescence are either decommissioned or repurposed to further prolong their use in scientific research.

Drawing upon archaeological and material culture studies theory, this paper examines some of the transformations and deformations that the steel instrument towers and reinforced concrete blockhouses of American Cold War nuclear weapons testing science follow in trajectories toward their ultimate disappearance. The objects of Cold War nuclear weapons science discussed here are "epistemic" in that they are structures and tools of scientific inquiry that are distinctly separate from the objects of nuclear weapons science, which are the nuclear devices themselves. This focus upon the trajectories of epistemic nuclear weapons testing objects is intentionally neoteric in light of the fact that history of science studies has traditionally focused more upon the origins and employments of scientific objects than on their decay and disappearance. That said, it seems important to note that the notion of disappearance in this particular context does not necessarily denote an immediate and complete passing from physical existence, although in many nuclear weapons testing instances this is the case. Here the term is intended to connote the abandonment, extinction, or other loss of an object from use in scientific processes and practices. For example, in the case of the Station 2300 blockhouse, its eroding concrete ruins will likely be recognizable as such for decades, if not hundreds, of years, while in all practical and political senses its use in nuclear weapons testing has long ended. Disused and abandoned, the object has metaphorically "disappeared", both from the global scientific landscape and current work of nuclear physics. And although this paper engages specifically with several of the epistemological structures used in aboveground experiments, dubbed AGEX by its Cold War practitioners, used in American nuclear weapons testing at Bikini and Enewetak atolls (known collectively as the Pacific Proving Grounds, or PPG) and the Nevada Test Site in the United States, the functional dichotomy and trajectories proposed here likely apply to all scientific objects of nuclear weapons testing, including those used historically and at the present time by other nations engaged in nuclear weapons testing.

A Functional Dichotomy

As simplistic as it may initially appear, partitioning the scientific objects that comprise the entire materiality of Cold War nuclear weapons testing as a dichotomy is actually a promising functional approach to exploring and understanding the trajectories of their disappearance. Objects of a less substantial nature – impermanent and generally expendable – are generally ephemeral, whereas artifacts regarded as enduring are by their very nature exceptionally robust, durable, and persistent. With these two subsets of objects being both mutually exclusive and jointly exhaustive, with no object belonging simultaneously to both subsets, and with all objects of nuclear weapons testing science belonging to one subset or the other, the dichotomy is valid, which provides a thesis upon which to base comprehensive interrogations of the tangible material culture of nuclear weapons testing science. This dichotomy is more than a rhetorical contrivance, as it is a convention loosely drawn from the way in which nuclear weapons scientists nominally defined the structures they built and used for testing as being either expendable or non-expendable.[1] Employed as an epistemological tool, this elemental dichotomy seems particularly promising in helping to more fully understand the complex transformations and trajectories of Cold War science objects where comprehensive material culture interrogations of nuclear weapons testing science are still a relatively new, but growing, field of scholarly activity within the social studies of science.

Distinctive in its aspirations to understand better the materiality of both the history and the culture of the era, the archaeology of Cold War science is capable of making substantive contributions to the study of historic and contemporary science.[2] Studies of scientific experiments during the Operation

[1] See *Completion Report – Operation Redwing 1954–1956*. Los Angeles: Holmes & Narver, Inc. 1956, pp. 2–151.

[2] For more on this topic, see Colleen M. BECK, "The Archaeology of Scientific Experiments as a Nuclear Testing Ground." In: SCHOFIELD, J. – JOHNSON, W. – BECK, C. (eds.), *Matériel Culture: The Archaeology of Twentieth-Century Conflict*. London: Routledge 2002; Todd A. HANSON, *The Archaeology of the Cold War*. Gainesville: University Press of Florida 2016; Michael B. SCHIFFER, *The Archaeology of Science: Studying the Creation of Useful Knowledge*. Cham, Switzerland: Springer International Publishing 2013.

Crossroads atomic tests at Bikini Atoll was the first archaeological research aimed at identifying the nature of the dichotomy between the enduring and the ephemeral in nuclear testing.[3] At Bikini, a collection of 95 American, German, and Japanese naval ships were set up in the atoll's lagoon in July 1946 as targets for atomic weapons tests. Whereas American nuclear weapons scientists were already somewhat knowledgeable of the atomic bomb's destructive capabilities before Crossroads, based on conventional explosives detonations, the Trinity test, and the devastation recorded at Hiroshima and Nagasaki, the specifics of the nuclear blast effects were lesser known. In particular, the measurement of the extreme thermal, pressure, and radiation effects produced by nuclear weapons proved particularly daunting. Even at Crossroads, these data were difficult to collect because the sparse laboratory instrumentation that existed to measure these effects was often of such a delicate nature that it was highly unsuitable for rigorous field use. As a result, rudimentary, but extremely durable, pressure measurement instrumentation became the principle method for quantifying some of the more elementary physics characteristics of nuclear blasts. In his studies of nuclear weapons effects blast metrology on Operation Crossroads shipwrecks, marine archaeologist Delgado points to pressure gauges recovered from the wreck of the USS *Saratoga* that were constructed of simple lead plates with small steel balls attached to their faces.[4] Blast overpressures were approximated by measuring the depth of the indentations made when the steel balls were pressed into these lead plates by the force of the atomic explosion.

Operation Crossroads and the nuclear weapons tests that followed it allowed scientists to delineate an ephemeral and enduring dichotomy for all scientific objects, including structures. Structures such as reinforced concrete blockhouses invariably fell within the class of enduring objects, whereas other objects of a more expendable nature, such as the steel towers, belonged to a class of ephemeral objects that also included the cameras, oscilloscopes, blast pressure recording devices, and radiation measurement instruments that were required for field testing. Because these instruments were rarely designed or intended to be deployed in environments as hostile as a nuclear explosion, the most fragile of them would require improvements

[3] James P. DELGADO – Daniel J. LENIHAN – Larry E. MURPHY – Larry V. NORDBY – Jerry L. LIVINGSTON. *The Archeology of the Atomic Bomb: A Submerged Cultural Resources Assessment of the Sunken Fleet of Operation Crossroads at Bikini and Kwajalein Atoll Lagoons.* Santa Fe: National Park Service 1991.

[4] James P. DELGADO, *Ghost Fleet: The Sunken Ships of Bikini Atoll.* Honolulu: University of Hawaii Press 1996.

in order to be used in nuclear weapons testing without being damaged or destroyed. If an increased robustness was impossible or impractical, the sensitivity of the devices might be enhanced to allow them to operate at greater distances from the blast's effects, out of harm's way. Eventually, a dichotomy would emerge into which all objects of American Cold War nuclear weapons testing science could be considered either enduring or ephemeral.

The Enduring and Ephemeral in Nuclear Weapons Testing

Beyond the reinforced concrete blockhouses built at the PPG and Nevada Test Site, some of the other objects considered to be enduring within the proposed dichotomy include massive cubes of solid concrete used to measure the physical force of a nuclear blast by their movement, concrete walls employed as collimators to channel neutron particles for detection and measurement, and concrete enclosures used to protect cameras from intense heat and radiation during a nuclear explosion. While not essential to being enduring, the above examples derive much of their durability from being constructed of concrete, which also gave them substantial mass. Non-expendable objects

Figure 2: Empty 5 gallon cans being stacked against a blockhouse wall on Enewetak Atoll prior to an Operation Sandstone nuclear test in 1948. The degree to which the cans were crushed by the extreme pressures created by the explosion provided data on the blast's magnitude.
Source: Photo courtesy of Los Alamos National Laboratory.

were frequently built for repeated use, with consideration given to both their location and durability. Camera enclosures and blockhouses were sited in the PPG for use in recording several detonations of an operation and designed and constructed to withstand the maximum estimated blast overpressures of an entire test series.

Conversely, objects of Cold War nuclear weapons scientific inquiry that were deemed expendable included a wide array of sensors, detectors and recording devices ranging from simple metal cans (as shown in Figure 2) that collapsed at extreme atmospheric pressures to more advanced instrumentation such as oscilloscopes, mass spectrographs, beta particle spectrographs, photocells and photomultipliers, and various types of particle detectors and ion chambers, which even now are rarely considered expendable in scientific research but were considered such in the practices of American Cold War nuclear weapons testing.[5] The expendable scientific objects used in nuclear weapons testing were generally small in size, but not necessarily fewer in number as redundancy and replication were common practices in tests where there was generally only one fleeting opportunity to collect data. As a result, there was never only one detector, recording station, automobile, or other expendable scientific object placed intentionally in the experiment's blast zone, but dozens or more. Exceptions to the generally smaller size of most expendable objects included the barges, towers, and even islands upon which the tests were staged and then routinely destroyed as a consequence of the test. Complicated by the fact that an object's financial cost appears to have only occasionally been a consideration in determining its expendable versus non-expendable nature, the rules for deciding what could be lost in a blast and what survived seems to have been premised principally upon scientific objectives. Perhaps nowhere is the complex nature of this premise better exemplified than in the steel towers and concrete blockhouses, which served as primary scientific objects on each side of the ephemeral/enduring dichotomy.

Steel Towers

Among the scientific structures used in Cold War nuclear weapons testing, towers stood above all others in their importance, functionality, and expendability. Used to both situate the nuclear devices being tested and hold

[5] Chuck HANSEN, *U.S. Nuclear Weapons: The Secret History.* New York: Orion Books 1988, p. 51.

cameras and instrumentation recording the detonation, the towers served as critical tools of scientific inquiry.

The use of towers in nuclear weapons testing began with the test of the first atomic bomb in July 1945 at a remote section of New Mexico's *Jornada del Muerto*, which was known thereafter as the Trinity Site. However, over the course of the Cold War test towers would be neither uniform nor ubiquitous in their use, design, or height. During the period from 1946 to 1962, only 56 of the United States' 206 aboveground nuclear weapons tests were staged on towers.[6]

Figure 3: July 1945: the atomic test tower at Trinity Site in New Mexico.
Source: Photo courtesy of Los Alamos National Laboratory.

Ranging in height from 30 to 200 meters and consisting of columnar steel lattices topped with an enclosed instrumentation platform designed to house a nuclear device, "zero towers" were critically important to attaining the scientific objectives of testing as an apparatus for precisely positioning a nuclear device at a specific location and elevation.[7] Zero towers varied

[6] UNITED STATES DEPARTMENT OF ENERGY, *United States Nuclear Tests July 1945 through September 1992*. DOE/NV-209-Rev.16. Las Vegas: National Nuclear Security Administration 2015, p. xiv.

[7] Named for their location at ground zero, towers of this use type were also often referred to colloquially as "shot" towers. In the technical, scientific, and design literature and language of the testing era, however, the "zero tower" or "scientific station" nomenclatures were more common.

somewhat in form or design over the course of AGEX testing, but evolved substantially in terms of height and load capacities due to advances in strengthening the towers' lattices.[8]

Designed and erected by Holmes & Narver, Inc. (H&N), a Los Angeles engineering and construction firm hired by the United States Atomic Energy Commission to construct almost all United States Cold War nuclear weapons testing structures at the Pacific Proving Grounds and the Nevada Test Site, the three or four-legged towers were fabricated with 6-meter-wide triangular or square cross sections in 7.62-meter lengths and shipped to ground zero for erection. Even with a 92-meter-high tower weighing as much as 45,000 kilos, towers could be erected in weeks, but construction was often intentionally halted after some initial groundwork to prevent possible damage to a completed tower from other nuclear testing in the

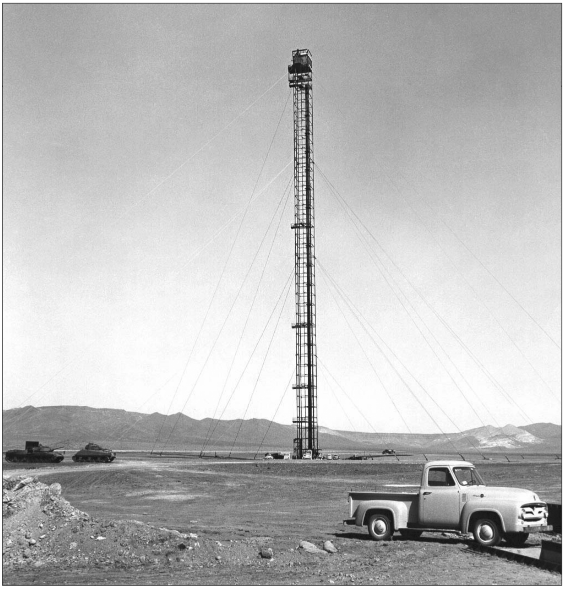

Figure 4: One of the zero towers used for Operation Teapot in 1955 at the Nevada Test Site.
Source: Photo courtesy of Los Alamos National Laboratory.

[8] HOLMES & NARVER, *Completion Report – Operation Redwing.* p. 45.

vicinity. Stabilized by steel guy wires attached to the tower at 15-meter increments and moored to steel stanchions anchored to concrete blocks in the ground, the zero tower's legs were set in a concrete foundation at its base. The cost of an average 100-meter-high steel zero tower, such as that shown in Figure 4, was US$275,000 in 1954 (or roughly $2.5 million in current US dollars).[9] Early lattice towers were built to support only a few thousand kilos, which included the weight of the cab enclosure, the nuclear device and its firing hardware, and the dynamic weight loads of personnel working on the device in the cab. As weapons diagnostics techniques advanced and additional electronics, instrumentation, and cooling equipment were required in the cab, both the sizes and load-bearing capacities of the cabs increased. And as cabs grew larger, stronger steel lattices were required to hold the additional weight. By the summer of Operation Redwing in 1956, American zero towers were capable of routinely accommodating loads up to 90 thousand kilos.[10] Meanwhile, hundreds of other types and sizes of steel towers were used extensively from 1946 to 1962, almost anytime an instrument, camera, or communication device needed to be positioned above ground level for a test. These observation and photo towers rose above any surface obstructions that might be created by topography, vegetation, or other man-made structures.

Atop every zero tower was a weatherproof compartment built of corrugated sheet aluminum, glass windows, and steel or aluminum decking. The cab, or "tower house" as it was occasionally called, not only provided personnel, devices, and instrumentation with protection from any extreme or inclement weather, but also helped keep secret the design, appearance, and operational aspects of the nuclear device prior to detonation. The roughly 7.5-meter by 7.5-meter floor area of the cab provided space for the device and its associated electronics and instrumentation, as well as working space for engineers and technicians. Winches built into the apex of the cab roof allowed equipment and the experimental nuclear devices to be lifted from the ground. Elevators and ladders attached to the side of the towers, such as those shown in Figure 5, allowed for the movement of personnel and equipment up and down the tower.

As epistemic objects of American Cold War nuclear weapons testing science, the purpose of zero towers was to hold the nuclear device at a specific

[9] *Completion Report – Eniwetok Proving Ground Facilities, Vol. VIII Facilities and Stations*. Los Angeles: Holmes & Narver, Inc. 1951, p. 142.
[10] HOLMES & NARVER, *Completion Report – Operation Redwing*, p. 45.

distance above ground level, but situating the exact point of detonation had both technical and political purposes. The technical purpose of the zero towers was to provide precisely known geographical and altitudinal coordinates for the detonation point. These coordinates were critically important in aiming both the cameras used for recording images of the detonation and instrumentation used for measuring the thermal, pressure, and radiation effects of the explosion. Both these cameras and some of the instrumentation were also mounted on steel towers.

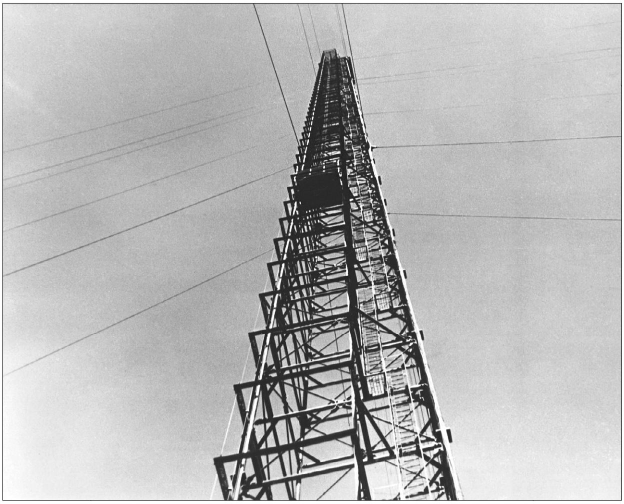

Figure 5: A view of the zero tower used for Operation Plumbbob at the Nevada Test Site in 1957 showing the elevator, access ladders and guy wires.
Source: Photo courtesy of Los Alamos National Laboratory.

The political reasons for increasing zero tower heights were the result of the fact that when a nuclear device was detonated close to the ground, its fireball picked up significant amounts of soil and debris which, when fused with metals from the tower and weapon, became entrained in the explosion's so-called mushroom cloud. Radioactive debris from this cloud, called fallout, posed deleterious environmental and health effects that in the nuclear testing era became of ever-increasing concern to the general public. As a result, every tower test performed after Trinity was increasingly higher off the ground, principally to help mitigate any radioactive fallout. Whereas the Trinity test had been fired on a 30-meter-high tower (Figure 3), zero towers used for subsequent tests extended to 61 meters for Operation Sandstone in 1948, 92 meters for Operation Greenhouse in 1951, and 153 meters for Operation Teapot by 1955 (See Figure 4). In 1957, the Operation Plumbbob Smoky shot used a 213-meter-high tower.[11] The higher elevation of the nuclear device also meant its fireball could be observed and measured at greater distances, which became increasingly necessary as weapon yields increased.

Concrete Blockhouses

As enduring as the towers were ephemeral, the concrete blockhouses used in nuclear weapons testing provided critical thermal, blast, and radiation protection for personnel, instrumentation, and data during and after the tests.[12] Eponymously named for their block-like form, blockhouses containing from one to as many as nine rooms were built by the United States in relatively small numbers to support atmospheric nuclear weapons testing activities at Enewetak Atoll and Bikini Atoll in the Marshall Islands and at the Nevada Test Site. Structures of similar design and purpose were also built for nuclear weapons testing at Maralinga in Australia for British testing, at Mururoa Atoll in French Polynesia by the French, at Lop Nor in China, and in Kazakhstan, as shown in Figure 6, at the former Soviet Union's Semipalatinsk nuclear testing site.

All of the blockhouses used in American Cold War nuclear weapons testing operations were designed and built by Holmes & Narver, Inc. From 1950–1958, H&N built more than 50 reinforced concrete blockhouses for use as scientific stations at the PPG. The largest and most robust of these were constructed at Bikini Atoll for the testing of thermonuclear devices, which required greater protection from higher levels of destructive energy than the lower yield weapons tests at Enewetak. The structures ranged in size from small instrument enclosures, often only a few cubic meters in volume, to large, multi-room, multi-story, blockhouses. Construction of the larger

[11] Bob CAMPBELL – Ben DIVEN – John MCDONALD – Bill OGLE – Tom SCOLMAN, "Field Testing: The Physical Proof of Design Principles." *Los Alamos Science,* Winter/Spring, 1983, p. 171. Available at: <https://www.fas.org/sgp/othergov/doe/lanl/pubs/00285892.pdf> [cit. 30. 11. 2016].

[12] Blockhouses are often referred to colloquially as "bunkers", although the term bunker is more conventionally used to refer to the reinforced underground shelters used in warfare as protection against bombs.

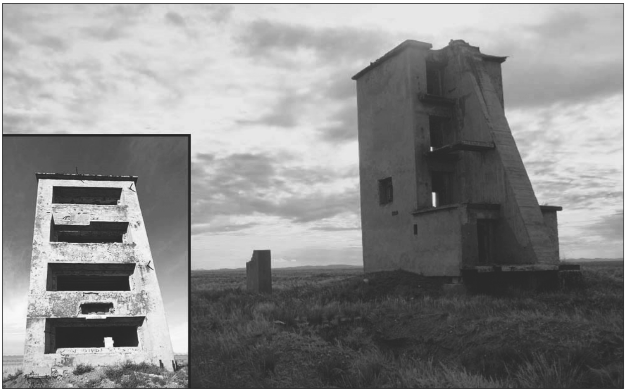

Figure 6: Front (left) and rear (right) views from 2013 of a reinforced concrete scientific station at the former Soviet nuclear weapons testing site at Semipalatinsk in Kazakhstan.
Source: Photo courtesy of Jacob Baynham.

Figure 7: Reinforced concrete blockhouses, such as this former electrical generator building on Eneu Island at Bikini Atoll, often took numerous forms. The two wing walls extending from the building's front face allowed for sand to be mounded up against and on top of the structure for increased protection from explosive damage and radiation.
Source: Photo courtesy of Ron Van Oers, UNESCO.

blockhouses often required several months to complete, depending upon the complexity of the station's design. Construction on Station 2300, for example, began in September 1953 as a scientific station for Operation Castle and was completed four months later in January 1954. With three rooms on the first floor, one room on the second floor, and one room on the third, the structure was 10-meters wide by 21-meters long and 10-meters high on a one-meter-thick foundation. The exterior wall and roof thicknesses of Station 2300, as well as other similar blockhouses, typically varied from 1-meter thick to nearly 2-meters in some cases. The concrete was reinforced with steel rebar (short for reinforcing bar) varying in size from 1 cm to 4 cm in diameter.[13] Depending on its size and design, the average cost of a concrete blockhouse like that shown in Figure 7 was more than US$125,000 in 1956, which would today be more than one million in US dollars.[14]

Widely used around the world in Cold War military and civilian construction, concrete is an amalgamation of Portland cement, hard stone aggregate, sand, and water. Although the concrete used for constructing blockhouses at the Nevada Test Site followed this conventional mix, the unavailability of hard stone (metamorphic) aggregate and pure water required that H&N use crushed coral and seawater in the construction of most concrete testing structures in the Pacific. For structures such as Station 2300, the coarse aggregates used for concrete production were mined from the Atoll's seaward reef, where the coral rock was harder.[15] Although still able to obtain sufficient concrete compressive strengths, this coral concrete did not provide high levels of gamma radiation shielding. As a result, many nuclear testing structures in the Pacific incorporated one or more sections consisting of limonite concrete.

The limonite concrete mixture used at the Pacific Proving Grounds (PPG) was invented in 1948 by researchers at Princeton University, who discovered in their search for a concrete capable of protecting researchers working at the university's cyclotron that a 1-meter-thick wall of concrete made of limonite mixed with scrap iron proved to be 280 times more effective

[13] *Completion Report – Operation Castle 1953–1954*. Los Angeles: Holmes & Narver, Inc. 1954.
[14] *Nevada Test Site Guide*. United States Department of Energy. DOE/NV-715 Rev. 1. Las Vegas: National Nuclear Security Administration 2005, p. 70. Available at: <https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/doe%20nv%202001e.pdf> [cit. 5. 12. 2016].
[15] D. Lee NARVER, "Good Concrete Made with Coral and Sea Water." *Civil Engineering*, vol. 24, 1954, no. 10, pp. 40–44.

in stopping neutrons than ordinary concrete.[16] Their concrete was a blend of Portland cement, seawater, and, in lieu of sand, finely ground limonite: an amorphous hydrous iron oxide ore. The addition of scrap iron, in the form of so-called "punchings" ranging from 1 to 2 cm in diameter, as a substitute for gravel, completed the concrete mixture. Being more difficult to work with and more expensive to make, limonite concrete was used sparingly at the PPG and only in components where radiation protection was necessary. For example, the front wall of Station 2300 was constructed of limonite concrete whereas the other walls, roof, and foundation were made of coral concrete.[17] In addition to providing direct shock and heat protection, the limonite concrete offered heavy shielding against both the strong radiation fields created by a nuclear detonation and latent radiation, which would have impaired data collection by ionizing gasses in instrument vacuum tubes, fogging photographic film in high-speed cameras, and damaging sensitive recording instrumentation.

The key to the nuclear weapons testing blockhouses' protective strength was as much in their design as in their constituent materials. Designed to withstand high blast overpressures, they often used angular walls and buttresses, thick walls protected by earth berms on one or more sides, and roofs covered with meter-thick layers of sand and soil.[18] In cases where even brief exposure to any of the weapon's effects might have been harmful to personnel or instruments, the extreme durability of the blockhouses provided critical protection. As safe as they were, however, few blockhouses were actually occupied by humans during nuclear weapons tests. Although several were used as firing control points during Pacific testing activities, more often than not, the principal function of a blockhouse was as a scientific station for instrumentation, often functioning as an integral part of the experimental setup for blocking or channeling extreme and unwanted thermal, blast, and/or radiation energies. In this way, blockhouses should be regarded as necessary structures in helping create scientific knowledge.

[16] Piet C. GUGELOT – Milton G. WHITE, "On the Shielding Qualities of Different Concrete Mixtures." *Journal of Applied Physics*, vol. 21, 1950, no. 5, pp. 369–379.

[17] Although similar in exterior appearance, at Bikini and Enewetak Atolls limonite concrete components can be differentiated from coral concrete by the remains of a bitumen (tar) coating that was regularly applied to the surfaces to help forestall corrosion.

[18] Rick A. EHLERT, "Coral Concrete at Bikini Atoll." *Concrete International,* vol. 13, 1991, no. 1, pp. 19–24.

Discussion: Transformations, Degradations and Disappearance

To no small degree, discussions about trajectories of use, disuse, and disappearance of material culture seem to naturally fall into the domain of archaeological theory. Specifically, Schiffer and Rathje's theories on the cultural (c-transforms) and non-cultural (n-transforms) transformations of objects in systemic and archaeological contexts seem particularly applicable.[19] C-transforms are those human activities, either accidental or intentional, that lead to objects (artifacts) being deposited in the archaeological record. In this case, the archaeological record is any state of disuse, whether discarded, buried, or like the blockhouses of nuclear weapons testing, simply abandoned in situ. N-transforms are the physical or environmental processes that affect the archaeological record in some way. Schiffer's theories of systemic and archaeological contexts define artifact categories as durables and consumables, analogous here to being enduring or ephemeral. In Schiffer's object life cycle model for durable elements he enumerates procurement, manufacture, use, and discard as discrete phases of the systemic context through which objects pass while en route to an archaeological context.[20] It is these c-transforms and n-transforms that actively and meaningfully affect the two exemplars discussed in the previous sections.

In the procurement of steel, lattice component manufacturing, transportation, assembly, erection, and use of the towers, Schiffer's c-transforms are particularly evident. Requiring only weeks to be erected, but months to be prepared for a test, zero towers would then disappear from the Cold War testing landscape in a matter of milliseconds: consumed in a fireball of heat and radiation (as shown in Figure 8), along with the cab, nuclear devices and instrumentation they held. With each tower's destruction being nearly complete, right down to its concrete foundation, little was left for the archaeological record, except perhaps for some steel stubs in concrete foundations. At Enewetak Atoll these remains (including their concrete foundations) were later removed in the course of environmental cleanup efforts, providing a definitive finality to both c-transforms and n-transforms. Conversely, at the Nevada Test Site where some tower remains exist (mostly steel stubs in concrete foundations), the n-transform processes have not been

[19] Michael B. SCHIFFER – William L. RATHJE, "Efficient Exploitation of the Archeological Record: Penetrating Problems." In: REDMAN, C. L. (ed.), *Research and Theory in Current Archeology*. New York: Wiley-InterScience 1973, p. 171 (169–179).
[20] Michael B. SCHIFFER, "Archaeological Context and Systemic Context." *American Antiquity*, vol. 37, 1972, no. 2, pp. 156–165.

so severely disrupted.[21] At Bikini Atoll, towers were used less commonly in lieu of barges and ground structures and the greater magnitude of the thermonuclear detonations created deep craters, which would have completely destroyed a tower's concrete foundations.

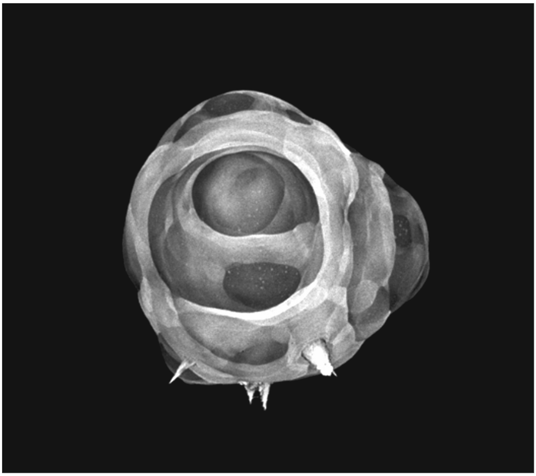

Figure 8: The development of Rapatronic photographic technologies capable of capturing microsecond-length images allowed nuclear weapons scientists to capture the burning of a zero tower. This Rapatronic photo of the Operation Tumbler-Snapper detonation in 1952 shows a nuclear fireball consuming the tower roughly 1 millisecond after detonation. Estimated to be 20 meters in diameter at this point, the fireball has several spike-shaped protrusions created as it consumes the guy wires mooring the tower to the ground.
Source: Photo courtesy of Los Alamos National Laboratory.

With the concrete blockhouses used in nuclear weapons testing having distinctly different transformative trajectories, they were nonetheless subject to c-transforms and n-transforms. The concrete types, construction practices, and scientific use not only defined each blockhouse's function, but its form as well. As some of the largest epistemic objects used in nuclear weapons testing science, blockhouses played a critical role in protecting

[21] BECK, "The Archaeology of Scientific Experiments," p. 69.

personnel, scientific instrumentation, communications devices, and power supplies before, during, and after the nuclear detonation. They were also the quintessential example of durability in nuclear weapons testing.

Blockhouses were not, however, indestructible. Depending upon their architecture and proximity to ground zero, the damage sustained by a blockhouse as a result of a nuclear test explosion varied, although it was frequently negligible. Really severe damage to the concrete structures was rare, although degradation in the form of sand scouring to its surfaces from blast winds and steel doors warping due to intense heat was not uncommon. Station 2300 survived the extreme blast overpressures of several nuclear detonations with only minimal damage. Most of the damage to the structure came from deactivation and decommissioning activities in 1969, which saw the removal of steel doors, exterior ladder rungs, and steel buttresses from the structure. Today the most transformational threats to the Station 2300 and other structures like it are the constant effects of weathering and erosion caused by climate and vegetation.

At the same time, n-transforms affecting Station 2300 are numerous. Vegetation, most notably in the form of *Scaevola taccada*, a woody shrub commonly known as beach naupaka, along with the trees *Tournefortia argentea*, *Pisonia grandis*, and *Guettarda speciosa* (zebra wood), grow in and around the blockhouses. Along with *Cocos nucifera* (coconut palms) their roots undermine and crack concrete foundations in a type of mechanical weathering known as root pry. Meanwhile, tropical humidity corrodes rebar and spalls, erodes, and crumbles the aging concrete as a form of chemical weathering. Unprecedented increases in sea levels, tidal swells, and tropical storm severity caused by climate change exacerbates mechanical weathering and erosion. Strangely, however, the effects of these n-transforms are not uniform across all concrete structures at Bikini. Studies of the deteriorated Bikini reinforced coral concrete structures conducted in the early 1990s indicated that the use of coral aggregates and seawater in the concrete mix, once thought deleterious to the strength of the concrete, do not appear to be the primary causes of their structural deterioration. Other factors, including the amount and nature of atmospheric exposure, thickness of concrete covering the reinforcing steel, and degree of surface cracking, appeared to be of greater effect.[22] At the same time, the presence of shrubs and trees growing

[22] EHLERT, "Coral Concrete," p. 23.

around the Bikini blockhouses seems to provide some protection from the weathering effects of wind and rain.[23]

Essentially all nuclear weapons testing objects were and are susceptible to c-transforms and n-transforms as they follow their own trajectories of transformation and disappearance. The rudimentary pressure gauges discovered at the USS *Saratoga* wreck by Delgado, for example, remain subject to constant sand scouring and aqueous corrosion, which will degrade and ultimately disintegrate them. Meanwhile, the oscilloscopes, mass spectrographs, beta particle spectrographs, photocells, photomultipliers, and neutron detectors used in Cold War nuclear weapons testing were reused and recycled in science in a process described by Schiffer as "lateral cycling", where the end of an object's use for one set of activities is followed by re-use by another group or individual as the object is re-purposed or re-used.[24] The objects described here as used for AGEX were often re-purposed for underground nuclear weapons testing.

Conclusion

The scientific experiments of the United States Cold War nuclear testing program employed extensive research spaces that produced, used, and discarded tens of thousands of scientific objects. Among these artifacts are two discrete classes of epistemic objects, each showing differing patterns of use, transformation, and disappearance. Presenting steel towers and concrete blockhouses structures as exemplars along a broader continuum of objects that can be identified as either enduring or ephemeral, this paper proposed a functional dichotomy for the wider study and analysis of the structures and tools of scientific inquiry that comprise the objects of Cold War nuclear weapons science. With features and functions that make them unique to nuclear weapons testing science, towers and blockhouses of Cold War nuclear weapons testing fit empirically into Schiffer's object life cycle model for durable elements. Starting with each object's procurement, manufacture, use, and disposal, they pass through discrete phases of the systemic context en route to an archaeological context, all the while being changed by

[23] Stephen BROWN, *Physical Traces of the Nuclear Test History of Bikini Atoll: A Preliminary Survey Report.* Report to International Council on Monuments and Sites (ICOMOS) and Kili-Bikini-Ejit Local Government and Historic Preservation Office, The Republic of the Marshall Islands, June 2010.
[24] SCHIFFER, "Archaeological Context," p. 159.

cultural and non-cultural transforms, and with the terminal phase of this transformative trajectory being disappearance.

Ultimately, all objects of science disappear as a result of evolution, revolution, or destruction. That evolution generally comes as the slow, methodical change that occurs as science advances technology and vice versa. Revolution comes more rapidly, bringing with it new methods and new objects for doing science. Destruction, as we have seen with the objects of nuclear weapons testing science, can be sudden or gradual. For the structures of nuclear weapons testing science, one might minimally posit that their disappearance is substantially reliant upon whether they are ephemeral or enduring in their original existence. Ephemeral objects of nuclear testing science disappeared quickly as a result of destruction, whereas the field's more enduring objects are likely to disappear as a result of obsolescence and disuse. Disappearance can also take multiple forms as was the case where nuclear weapons testing's AGEX metrological technologies fell into obsolescence as the entire nuclear testing regime literally moved underground, leaving its most monumental concrete objects to crumble to dust.

Although the disappearance of steel towers from the nuclear weapons science landscape was instantaneous on a singular event scale, their disappearance in the history of nuclear weapons science as a whole was more gradual. No longer needed after nuclear testing began being conducted underground, the towers disappeared from American nuclear weapons science completely after the United States ceased AGEX nuclear weapons testing in October 1962, which was amid the political chaos of the Cuban Missile Crisis but only peripherally related to the event. With the tower's disappearance from nuclear weapons testing science came an associated loss of a scientific research method that had evolved specifically and substantially over the course its 17-year history, during which the towers had served as more than simply platforms upon which to stage physics experiments; they were part of a grand scientific method of nuclear weapons testing aimed at understanding the complex physics and physical effects of nuclear explosions. No longer needed to sustain the state of the science, their disappearance as a scientific method is plausibly permanent, as in no sound and responsible nuclear weapons testing science protocol are humans ever again likely to see nuclear bombs detonated on steel towers while instruments record data in massive concrete blockhouses. In fact, by the end of America's AGEX testing era, airplanes had replaced blockhouses as methods for photographing and recording nuclear detonation data.

Although this paper considers only the disappearance of scientific objects in a specific twentieth-century scientific space, the implications of the ephemeral/enduring duality are potentially more timeless. The trajectories by which all objects of science disappear from the scientific landscape are important patterns for social studies of science and the archaeological study of science. Because the epistemic objects of science neither spontaneously appear nor disappear from the scientific landscape, the manner and means of their appearance and disappearance is crucial to understanding better the complex historical and contemporary practices of scientific inquiry and discovery.