Appendix A

DOE-ID Managers and Contractors

DOE-ID Managers

Leonard E. “Bill” Johnston	4/49-4/54
Allan C. Johnson	4/54-12/61
Hugo N. Eskildson	1/62-11/63
William L. Ginkel (Acting)	11/63-3/64
William L. Ginkel	3/64-9/73
R. Glenn Bradley	9/73-3/76
Charles E. Williams	5/76-6/83
Troy E. Wade	7/83-6/87
Don Ofte	6/87-12/89
Phil Hamric (Acting)	1/90-4/90
Augustine Pitrolo	4/90-2/94
John Wilcynski (Acting)	2/94-10/94
John Wilcynski	10/94-2/99
Warren E. Bergholz, Jr. (Acting)	2/99-5/99
Beverly A. Cook	5/99-2/02
Warren E. Bergholz, Jr. (Acting)	2/02-4/03
Elizabeth A. Sellers	4/03-2/09
Dennis Miotla (Acting)	1/09-5/10
Richard B. (Rick) Provencher	5/10-1/19
Robert D. Boston	1/19-2/23
Lance L. Lacroix	2/23-

Prime Operating Site Contractors

1950-1966	Phillips Petroleum Company
1966-1972	Idaho Nuclear Corporation (Allied Chemical Corporation, Aerojet General Corporation and Phillips Petroleum Company)
1972-1976	Aerojet Nuclear Corporation
1976-1994	EG&G Idaho
1994-1999	Lockheed Martin Idaho Technologies Company
1999-2005	Bechtel BWXT Idaho, LLC
2005-	Battelle Energy Alliance, LLC

Argonne National Laboratory-West (Materials and Fuels Complex)*

1949-2005	University of Chicago
2005-	Battelle Energy Alliance, LLC

Idaho Chemical Processing Plant (Idaho Nuclear Technology and Engineering Center)

1950-1953	American Cyanamid Company
1953-1966	Phillips Petroleum Company
1966-1972	Idaho Nuclear Corporation
1972-1979	Allied Chemical Corporation
1979-1984	Exxon Nuclear Idaho Company
1984-1994	Westinghouse Idaho Nuclear Company
1994-1999	Lockheed Martin Idaho Technologies Company
1999-2005	Bechtel BWXT Idaho, LLC
2005-2016	CH2M-Washington Group Idaho, LLC
2016-2021	Fluor Idaho, LLC
2022-	Idaho Environmental Coalition

Advanced Mixed Waste Treatment Project

1996-2005	BNFL Inc.
2005-2011	Bechtel BWXT Idaho, LLC
2011-2016	Idaho Treatment Group
2016-2021	Fluor Idaho, LLC
2022-	Idaho Environmental Coalition

APPENDIX A

Specific Manufacturing Capability*

1983-1986	Exxon Nuclear Idaho Company
1986-1991	Rockwell INEL
1991-1994	Babcock & Wilcox Idaho Inc.
1994-1999	Lockheed Martin Idaho Technologies Company
1999-2005	Bechtel BWXT Idaho, LLC
2005-	Battelle Energy Alliance, LLC

Naval Reactors Facility

1950-1999	Westinghouse Electric Corporation
1999-2009	Bechtel Bettis Inc.
2009-2018	Bechtel Marine Propulsion Corp.
2018-	Fluor Marine Propulsion, LLC

*Consolidated into INL prime operating contract in 2005

In 2004, the Department of Energy made the decision to split the INL contract into two, distinct business lines: (1) nuclear energy research and development and (2) environmental cleanup. The Department of Energy Idaho Operations Office created the Idaho Cleanup Project, the name it gave for the cleanup mission. In May 2005, CH2M-Washington Group Idaho, LLC, became the first Idaho Cleanup Project contractor. The word “Core” was added to the ICP name as part of Fluor Idaho, LLC’s contract. For the most recent contract, the cleanup mission’s name returned to the Idaho Cleanup Project.

Appendix B

Fifty Years of Reactors at the Site

After the first reactor at the National Reactor Testing Station (Experimental Breeder Reactor-I) went critical in 1951, scientists built and operated dozens more reactors in the next five decades. Since the 1970s, it has become accepted that 52 reactors operated at the Site.

But counting reactors at a reactor research facility is not as straightforward as it might seem, nor is accumulating vital statistics about each reactor. While considering the reactors that operated on the Idaho desert, the following thoughts might be kept in mind.

First, scientists in different programs did not seem to follow the same rules when it came to naming reactors. For example, the Aircraft Nuclear Propulsion (ANP) program modified the core of the reactor it called HTRE-1 and named it HTRE-2. These were subsequently known as two reactors. In another program, experimenters changed the core of the Organic Moderated Reactor more than once, but the reactor retained the same name and was counted as one reactor. When the Experimental Breeder Reactor-II operated as a prototype of the Integral Fast Reactor, the name did not change. Thus, any list of reactors very definitely understates and under-represents the actual complexity of reactor development at the Site.

Second, the list-maker must decide what to commemorate in a list of reactors. Should reactors that never went critical be given a place? If so, the list will include the Experimental Organic Cooled Reactor. No uranium fuel ever was loaded into the reactor and it never operated or went critical before the program was canceled. It was “a reactor,” but never “an operating reactor.” This was true as well for the Experimental Beryllium Oxide Reactor.

This list does not include simulated reactors such as Semiscale, which was part of the reactor safety testing program. The omission of facilities like this is another way in which a list can understate the variety and complexity of the INEEL’s nuclear reactor history.

Finally, not all the information one might desire about the history of a reactor is easily found. For example, one goal for this list was to identify the day, month, and year of initial criticality for each reactor—and the date of its final shutdown. But the INEEL Technical Library’s vast collection of archived reports did not yield this information for each reactor. Some report writers were content to report that a reactor went critical “in the summer of” a certain year and leave it at that. The same writers may have considered other milestones, such as its first operation at “full power,” to be more meaningful in the progress of their particular reactor.

This alphabetical list of reactors contains the names of 52 reactors (the fifty that operated and the two that did not) as they have been known traditionally, their acronyms, selected milestone dates, and descriptive information about each reactor. All references to megawatts are “thermal” megawatts. Readers who examine this list are invited to contribute additional milestone dates and other vital statistics about the reactors so that future lists might be made more complete and more accurate.

Name	Acronym	Reactor Startup	Last Day of Operation
1. **Advanced Reactivity Measurement Facility No. 1** The ARMF-I, a reactor located in a small pool in a building east of the MTR in the Test Reactor Area, was used to determine the nuclear characteristics of reactor fuels and other materials subject to testing in the MTR. Together with the MTR, the reactor helped improve the performance, reliability, and quality of reactor core components. Until the next generation reactor, the ARMF-II, this was considered the most sensitive device for reactivity determinations then in existence.	ARMF-I	10-10-60	1974
2. **Advanced Reactivity Measurement Facility No. 2** The ARMF-II was built in the opposite end of the tank occupied by ARMF-I. It had a "readout" system which automatically recorded measurements on IBM data cards. This refinement over the ARMF-I meant that operators could process data quickly in electronic computers. Designers of the ARMF-II benefitted from previous experience with the ARMF-I and the Reactivity Measurement Facility (described below).	ARMF-II	12-14-62	
3. **Advanced Test Reactor** Located at the Test Reactor Area, the ATR, which continued to operate in 2000, is a materials testing reactor. It simulates the environment within a power reactor for the purpose of studying the effect of radiation on steel, zirconium, and other materials. The ATR produces an extremely high neutron flux up to 1 x 10^{15} neutrons per square centimeters per second. Target materials are exposed to the neutron flux for selected periods of time to test their durability within an environment of high temperature, high pressure, and high gamma radiation fields. Data that normally would require years to gather from ordinary reactors can be obtained in weeks or months in the ATR. The ATR can operate at a power level of 250 megawatts. Its unique four-lobed design can deliver a wide range of power levels to nine main test spaces, or loops. Each loop has its own distinct environment apart from that of the main reactor core. Therefore, nine major experiments can take place simultaneously. Additional smaller test spaces surrounding the loops allow for additional tests. In addition to materials testing, the ATR has made radioisotopes used in medicine, industry, and research.	ATR	7-2-67	Continuing
4. **Advanced Test Reactor Critical Facility** The ATRC performs functions for the ATR similar to those of the ARMF reactors in relation to the MTR. It was a valuable auxiliary tool in operation long before the ATR startup. It verified for reactor designers the effectiveness of control mechanisms and physicists predictions of power distribution in the large core of the ATR. Low-power testing in the ATRC conserved valuable time so that the large ATR could irradiate experiments at high power levels. The ATRC is also used to verify the safety of a proposed experiment before it is placed in the ATR.	ATRC	5-19-64	Continuing
5. **Argonne Fast Source Reactor** The Argonne Fast Source Reactor was a tool used to calibrate instruments and to study fast reactor physics, augmenting the Zero Power Plutonium Reactor research program. Located at Argonne-West, this low-power reactor—designed to operate at a power of only one kilowatt—contributed to an improvement in the techniques and instruments used to measure experimental data.	AFSR	10-29-59	Late 70s
6. **Boiling Water Reactor Experiment No. 1** BORAX-I was a pioneer reactor that tested the safety and operating parameters of reactors which used boiling water as a moderator and coolant. In this reactor type, water is allowed to boil in the core. Saturated steam drives the turbines and generates power. BORAX-I, like the later BORAX experiments, was located just north of EBR-I. It demonstrated that the boiling water moderated reactor concept was feasible for power reactors. Its design capacity was 1.4 megawatts. Operators destroyed it in July 1954 in a deliberately planned "destructive test," the purpose of which was to subject it to extreme operating conditions and learn more about the limits of its safe operation.	BORAX-I	1953	July 1954

Name	Acronym	Reactor Startup	Last Day of Operation
7. **Boiling Water Reactor Experiment No. 2** BORAX-II continued the testing program for boiling water reactors, this time at a power level capacity of 6 megawatts. Tests used fuels with varying enrichments of uranium-235.	BORAX-II	10-19-54	March 1955
8. **Boiling Water Reactor Experiment No. 3** The operating capacity of BORAX-III was 15 megawatts. The reactor was connected to a 2000-kilowatt turbine/generator set so that engineers could generate electricity, the ultimate objective of the reactor test program. On the night of July 17, 1955, the reactor produced sufficient power to light the city of Arco (500 kilowatts), the BORAX test facility (500 kilowatts), and part of the Central Facilities Area at the NRTS (1000 kilowatts).	BORAX-III	6-9-55	1956
9. **Boiling Water Reactor Experiment No. 4** BORAX-IV, with a power level of 20 megawatts, tested fuel elements made from mixed oxides (ceramics) of uranium and thorium. These materials had a high capacity to operate in the extreme heat of a reactor before they failed. The ceramic core demonstrated that a reactor loaded with this fuel could operate safely and feasibly. The fuel could operate in higher temperatures, was less reactive with the water coolant in case the cladding ruptured, was cheaper to manufacture, and burned a larger percentage of the fuel before loosing its reactivity. The reactor produced measurable quantities of the artificial thorium-derived fuel, uranium-233. One series of BORAX-IV tests involved operating the reactor with experimentally defective fuel elements in the core.	BORAX-IV	12-3-56	June 1958
10. **Boiling Water Reactor Experiment No. 5** BORAX-V could operate at a power level of 40 megawatts. This flexible reactor advanced the boiling water reactor concept by testing the safety and economic feasibility of an integral, nuclear superheat system. On October 10, 1963, it produced superheated (dry) steam entirely by nuclear means for the first time. The reactor demonstrated that improved efficiency from manufactured steam is obtainable by incorporating as a design feature a number of superheated fuel assemblies in the reactor core lattice.	BORAX-V	2-9-62	September 1964
11. **Cavity Reactor Critical Experiment** Located at TAN, CRCE was an outgrowth of a program begun by NASA in the 1960s to investigate the propulsion of space rockets by nuclear power, offering the possibility of much greater thrust per pound of propellant than chemical rockets. The concept for the cavity reactor core was that the uranium would be in a vapor, or gaseous, state. Hydrogen propellant flowing around it would theoretically attain much higher temperatures—up to 10,000° F—than in conventional solid core rockets. The experiments at TAN used simulated hydrogen propellant and produced data on the reactor physics feasibility of a gaseous core being able to go critical. The core was uranium hexafluoride (UF_6); the experiments were all done at the relatively low temperature of about 200° F. In the proposed ultimate application, the ball of uranium gas would be held in place by the hydrogen flowing around it, something like a ping-pong ball suspended in a stream of air. Uranium core temperatures as high as 100,000° F were considered possible.	CRCE	5-17-67	Early 1970s
12. **Coupled Fast Reactivity Measurement Facility** When the ARMF-II reactor was modified in 1968, it was given a new name, the CFRMF. A section of the core was modified to produce a region of high-energy neutron flux useful in comparing calculated and observed results. This tool provided physics information about the behavior of fast (ie, unmoderated) neutrons. Physicists studied differential cross sections and tested calculational methods. The CFRMF contributed to the development of fast neutron reactors.	CFRMF	1968	1991
13. **Critical Experiment Tank** The CET reactor produced a source of neutrons used to calibrate various types of neutron sensors and chambers. Part of the Aircraft Nuclear Propulsion program and located at Test Area North (TAN), the CET was a low-power reactor (one of three in the ANP program) originally designed to mock-up the HTRE-I and HTRE-II reactors. Later, fuel test bundles intended for testing in HTRE-II were first evaluated for reactivity characteristics in the CET.	CET	1958	1961

Name	Acronym	Reactor Startup	Last Day of Operation
14. **Engineering Test Reactor** When the Engineering Test Reactor started up at the TRA in 1957, it was the largest and most advanced materials test reactor in the world. The 175-megawatt reactor provided larger test spaces than the older MTR and provided a more intense neutron flux. The ETR evaluated fuel, coolant, and moderator materials under environments similar to those of power reactors. In 1972 the ETR was modified by the addition of a Sodium Loop Safety Facility into the reactor core. With this, the reactor played a new role supporting DOE's breeder reactor safety program. ETR test programs related to the core design and operation of breeder reactors. As testing progressed, the reactor was again modified with a new top closure accommodating the irradiation loop. Other additions included a helium coolant system and sodium-handling system. The ETR was the first complete reactor facility to be deactivated and documented immediately after shutdown.	ETR	9-19-57	December 1981
15. **Engineering Test Reactor Critical Facility** ETRC was a full-scale, low-power nuclear facsimile of the ETR, similar in function to the ARMF and ATRC. It was used to determine in advance the nuclear characteristics of experiments planned for irradiation in ETR and the power distribution effects for a given ETR fuel and experiment loading. Since no two ETR loadings were identical, the ETRC allowed operators to predict the ETR's nuclear environment when completed experiments were removed or new ones added. This information was necessary to calculate the experiment irradiation and determine core life, control rod withdrawal sequences, reactivity worths, and core safety requirements. Proposed fuel and experiment loadings were first mocked up in ETRC and manipulated until a desired power distribution throughout the core was attained, satisfying pertinent safety requirements. The ETRC's low-power tests allowed the ETR to operate without interruption, saving time and money.	ETRC	5-20-57	1982
16. **Experimental Beryllium Oxide Reactor** Modifications of a former ANP building at TAN, the Shield Test Pool Facility, began in May 1963 to house the Experimental Beryllium Oxide Reactor (EBOR). The objective of the reactor was to develop beryllium oxide as a neutron moderator in high-temperature, gas-cooled reactors. The project was canceled in 1966 before construction was complete. Among the reasons for the cancellation was the encouraging progress achieved, concurrent with EBOR construction, in developing graphite as a moderator. This reduced the importance of developing beryllium oxide as an alternate.	EBOR	Never operated	
17. **Experimental Breeder Reactor No. I** EBR-I, the first reactor built at INEEL, began operation in 1951. The reactor produced the first usable electricity from nuclear heat on December 20, 1951. It achieved full-power operation the next day. In 1953, the reactor confirmed that a nuclear reactor designed to operate in the high-energy neutron range is capable of creating more fuel than its operation consumes ("breeding"). The reactor, which used enriched uranium as fuel, was unmoderated. It used sodium-potassium alloy (NaK) as coolant. A blanket of uranium-238 around the core provided the "fertile" material in which breeding took place. The liquid-metal coolant permitted the neutron energies to be kept high, thus promoting fissionable-material breeding. The coolant also enabled high-temperature and low-pressure operation, both conducive to efficient power production. President Lyndon B. Johnson dedicated EBR-I as a National Historic Landmark on August 26, 1966. It was subsequently opened to the public for visits and tours.	EBR-I	8-24-51	12-30-63
18. **Experimental Breeder Reactor No. II** Part of the continuing investigation of fast neutron breeding reactors, the EBR-II, located at Argonne-West inside a containment shell, was built to demonstrate the feasibility of on-site fuel reprocessing as an adjunct	EBR-II	9-30-61	9-30-94

Name	Acronym	Reactor Startup	Last Day of Operation
Experimental Breeder Reactor No. II (continued) to a liquid metal-cooled fast-breeder-reactor power plant. These objectives were met within the first few years of its operation. By September 1969, EBR-II operated at a capacity of 62.5 megawatts and supplied electricity to Argonne-West and the power grid at the Site until its shutdown in 1994. The reactor operated submerged in a tank of liquid sodium coolant. During recycle experiments between 1964-1969, spent fuel was sent by automated handling methods to the Fuel Cycle Facility adjacent to the reactor building, treated by pyrometallurgical techniques, and the useful fissile metal refabricated into new fuel pins. EBR-II also was used to irradiate reactor fuel and structural material samples, testing their durability in breeder-reactor environments. This information helped improve fuel and material performance for future breeder reactors.			
19. **Experimental Organic Cooled Reactor** Because the OMRE (see below) was built as a minimum-cost facility ($1,800,000) to test the feasibility of the organic-cooled reactor concept, it lacked test loops needed to investigate various organic coolants and experimental fuel elements. The EOCR was intended to extend and advance the OMRE studies. During the final stages of its construction, EOCR was placed in standby status in December 1962 when the AEC decided that the organic-cooled concept would not significantly improve nuclear power plant performance over what other reactor concepts already had achieved. The building, located east of the Central Facilities Area, was recycled for other (non-nuclear) uses.	EOCR	Never operated	
20. **Fast Spectrum Refractory Metals Reactor** This low-power critical facility operated at TAN to collect data for a proposed fast-spectrum refractory-metal reactor concept called the 710 Reactor. The concept involved using metals such as tungsten and tantalum in a compact, very high-temperature reactor for generating power in space.	710	March 1962	1968
21. **Gas Cooled Reactor Experiment** Built at the Army Reactor Experimental Area, later called the Army Reactor Area (ARA), the GCRE was a water-moderated, nitrogen (gas)-cooled, direct- and closed-cycle reactor. It generated 2,200 kilowatts of heat, but no electricity. The U.S. Army wanted to develop a mobile nuclear power plant, and the GCRE was the first phase of the program, proving the principle of this reactor concept. The reactor provided engineering and nuclear data for improved components. The GCRE was also used to train military and civilian personnel in the operation and maintenance of gas-cooled reactor systems.	GCRE	2-23-60	4-6-61
22. **Heat Transfer Experiment No. 1** Test Area North was opened in 1952 for the Aircraft Nuclear Propulsion program, which operated during the 1950s to develop for the U.S. Air Force a nuclear-powered jet airplane using direct-cycle heat transfer engineering. The program involved ground tests only, but proved the principle of nuclear-powered turbojet engine operation with a full-power test in January 1956, with Heat Transfer Reactor Experiment No. 1 (HTRE-I), which produced 20 megawatts of heat energy on a test stand at TAN's Initial Engine Test Facility. The water-moderated reactor used enriched uranium fuel clad in nickel-chromium.	HTRE-1	11-4-55	1956
23. **Heat Transfer Experiment No. 2** In order to irradiate fuel elements that were too large to fit in the MTR for materials tests, the ANP program drilled a hexagonal hole in the center of HTRE-1 and renamed it HTRE-2, converting it to a materials test reactor and subjecting test fuels to environments reaching 2,800° F. The ANP materials test program advanced the technology of high-heat ceramic reactor fuels.	HTRE-2	July 1957	3-28-61 (End of ANP program)

Name	Acronym	Reactor Startup	Last Day of Operation
24. **Heat Transfer Experiment No. 3** After substantial testing and experimentation, this new experiment arranged the reactor, engine, shielding, and heat transfer systems in a horizontal configuration anticipating final design in an airframe. President John F. Kennedy canceled the ANP program on March 28, 1961. Work on the project came to an abrupt and permanent end on that date. The two HTRE experiments were moved to the site of EBR-I, where they are on display at the visitors center.(See Heat Transfer Experiment No. 1)	HTRE-3	1958	December 1960
25. **High Temperature Marine Propulsion Reactor** The 630-A reactor, a low-power critical experiment, was operated at TAN to explore the feasibility of an air-cooled, water-moderated system for nuclear-powered merchant ships. Further development was discontinued in December 1964 when decisions were made to lower the priority of the entire nuclear power merchant ship program.	630-A	1962	1964
26. **Hot Critical Experiment** HOTCE was an elevated-temperature critical experiment designed to obtain information on temperature coefficients of solid-moderated reactors, to develop a theory consistent with this information, and to develop measurement techniques for high-temperature reactors. A part of the ANP program, it operated in the Critical Experiment cell of the Low Power Test Facility at TAN. HOTCE was one of three low-power reactors supporting the ANP program, along with the Shield Test Pool Facility Reactor (see below) and the Critical Experiment Tank (CET). The ANP program ended in 1961.	HOTCE	1958	3-28-61 (End of ANP program)
27. **Large Ship Reactor A**	A1W-A	10-21-58	1-26-94
28. **Large Ship Reactor B** The A1W (aircraft carrier, first prototype, Westinghouse) plant consisted of a pair of prototype reactors for *USS Enterprise*, a U.S. Navy nuclear-powered aircraft carrier. Located at the Naval Reactors Facility, the two pressurized-water reactors (designated A and B) were built within a portion of a steel hull. The plant simulated *Enterprise's* engine room. All components could withstand seagoing use. The A1W plant was the first in which two reactors powered one ship propeller shaft through a single-geared turbine propulsion unit. As the Navy program evolved, new reactor cores and equipment replaced many of the original components. The Navy trained naval personnel at the A1W plant and continued a test program to improve and further develop operating flexibility.	A1W-B	July 1959	1987
29. **Lost of Fluid Test Facility** The LOFT reactor, located at TAN within a containment building, was a centerpiece in the safety testing program for commercial power reactors. The reactor was a scale-model version of a commercial pressurized-water power plant built chiefly to explore the effects of loss-of-coolant accidents (LOCAs). Thirty-eight nuclear power tests were conducted on various accident scenarios, including the real accident at Three Mile Island, between 1978 and 1985. Among other goals, the program investigated the capability of emergency core cooling systems to prevent core damage during a LOCA. Experiments at LOFT simulated small-, medium-, and large-break LOCAs, sometimes complicated with other events such as "loss of offsite power." LOFT was inactivated in 1986, following completion of the LP-FP-2 experiment, the most significant severe-fuel-damage test ever conducted in a nuclear reactor. This test, which involved the heating and melting of a 100-rod experimental fuel bundle, provided information on the release and transport of fission products that could occur during an actual commercial reactor accident where core damage occurs.	LOFT	1973	7-9-85
30. **Materials Test Reactor** The MTR was the original reactor at the Test Reactor Area and the second reactor operated at the NRTS. Fueled with enriched uranium fuel, water-cooled and -moderated, the reactor was a key part of the Atomic Energy Commission's post-war reactor development program. It supplied a high neutron flux in support of a reactor development program subjecting potential reactor fuels and structural materials to irradiation. In	MTR	3-31-52	4-23-70

Name	Acronym	Reactor Startup	Last Day of Operation
Materials Test Reactor (continued) addition, its "beam holes" made it possible to perform cross-section and other physics research. The high-flux radiation fields available in this reactor made it possible to accelerate the screening of potential reactor materials. In its early years, the MTR contributed to the design of pressurized water, organic-moderated, liquid-metal-cooled, and other reactors. Successful operation of the MTR itself was a great experiment resulting in a family of plate-type reactors. The reactor operated at a power level of 30 megawatts until September 1955 when thermal output was increased to 40 megawatts. The MTR logged more than 125,000 operating hours and more than 19,000 neutron irradiations. During August 1958, the MTR became the first reactor to operate using plutonium-239 as fuel at power levels up to 30 megawatts. The demonstration showed that a plutonium-fueled reactor could be controlled satisfactorily. The materials testing workload of the MTR was taken over by the new and larger Advanced Test Reactor.			
31. **Mobile Low-Power Reactor No. 1** Following the operation of the GCRE, the ML-1 was the next major step toward the development of a mobile low-power power plant for the U.S. Army. The entire ML-1 plant was designed to be transported either by standard cargo transport planes or standard Army low-bed trailers in separate packages weighing less than 40 tons each. The reactor was operated remotely at the ARA-IV area from a control cab at a distance of approximately 500 feet. It could be moved after a 36-hour shutdown. The reactor was designed for ease of operation and maintenance by enlisted technicians at remote installations, for reliable and continuous operation under extreme climatic conditions, and for the rigors of shipment and handling under adverse conditions. The ML-1 shut down for the last time after operating for a total of 664 hours. Before the ML-1 had reached all of its performance goals, the Army phased out its reactor development program around 1965.	ML-1	3-30-61	5-29-64
32. **Natural Circulation Reactor** The S5G (submarine reactor, 5th prototype, General Electric) was the prototype of a pressurized-water reactor for *USS Narwhal*. Located at the Naval Reactors Facility, it was capable of operating in either a forced or natural circulation flow mode. In the natural mode, cooling water flowed through the reactor by thermal circulation, not by pumps. Use of natural circulation reduced the noise level in the submarine. To prove that the design concept would work in an operating ship at sea, the prototype was built in a submarine hull section capable of simulating the rolling motion of a ship at sea. The S5G continued to operate as part of the Navy's nuclear training program until that program was reduced after the end of the Cold War.	S5G	9-12-65	5-1-95
33. **Neutron Radiography Facility** The NRAD, located in the Hot Fuel Examination Facility at Argonne-West, is a nondestructive examination tool. Using two collimated neutron beams produced by a 250-kilowatt reactor, NRAD produces neutron radiographs showing the internal condition of highly irradiated test specimens without physically cutting into the specimen. The reactor also has been used as a neutron source for isotope production, activation analysis, and the evaluation of radiation effects on materials.	NRAD		Continuing
34. **Nuclear Effects Reactor** The Nuclear Effects Reactor (FRAN) was a small-pulsed reactor, capable of supplying bursts of high-intensity fast neutrons and gamma radiation. FRAN was transferred to the NRTS in mid-1967 from the Nevada Test Site, where it had been operated by Lawrence Livermore National Laboratory. Located in the ARA building formerly occupied by the ML-1 reactor, FRAN was used for a short time to test the performance of new detection instruments then being developed for reactor control purposes. The reactor was moved back to DOE's Lawrence Livermore National Laboratory in June 1970.	FRAN	8-28-68	June 1970

Name	Acronym	Reactor Startup	Last Day of Operation
35. **Organic Moderated Reactor Experiment** OMRE demonstrated the technical and economic feasibility of using a liquid hydrocarbon as both coolant and moderator, a reactor concept developed and partially financed by Atomics International. Located a few miles east of the Central Facilities Area, the reactor operated with a succession of cores. The waxy coolant was considered promising because it liquified at high temperatures but didn't corrode metal like water did. Also, it operated at low pressures, significantly reducing the risk of leaking. A scaled-up reactor, the Experimental Organic Cooled Reactor, was built next door in anticipation of further development of the concept.	OMRE	9-17-57	April 1963
36. **Power Burst Facility** Located southeast of the Test Reactor Area, the PBF was part of the reactor safety testing program. It was designed to simulate various kinds of imagined accidents caused by sudden increases in the operating level of a reactor. The PBF was the only reactor in the world that could perform rapid power changes (bursts) within milliseconds. It performed severe-fuel-rod-burst tests and also simulated loss-of-coolant accidents within a special assembly that fit inside the main reactor core. The initial mission for PBF was to test light water reactor fuel rods under representative accident conditions. Data from these tests were used to develop and validate fuel behavior computer codes for the Nuclear Regulatory Commission. After its test program ended in 1985, the PBF reactor was considered for use in defense-related programs or for use in a brain cancer treatment program called Boron Neutron Capture Therapy (BNCT). The BNCT program would have treated patients with glioblastoma multiforme—a form of brain cancer. However, neither of these missions materialized.	PBF	9-22-72	1985
37. **Reactivity Measurement Facility** RMF, a detector reactor that measured reactivity changes in materials irradiated in the MTR or ETR, was operated for more than eight years. The RMF was used to assay new and spent fuel elements and to assist in experiment scheduling by evaluating reactivity losses and flux depression caused by in-pile apparatus.	RMF	2-11-54	4-10-62
38. **Shield Test Pool Facility** The SUSIE reactor was used for bulk shielding experiments that were performed in support of the ANP Shielding Experimentation Program. The reactor, situated in a water-filled pool at TAN, could be operated safely, was adaptable to many forms of nuclear research, and was easy to operate at minimum cost. After the ANP program was discontinued in 1961, SUSIE continued in use by other programs at the NRTS.	SUSIE	1961	
39. **Special Power Excursion Reactor Test No. I** SPERT-I was the first in a series of four safety-testing reactors designed to study the behavior of reactors when their power level changed rapidly. Power runaways were produced deliberately by moving the control rods. The variables in the thousands of SPERT studies included fuel plate design, core configuration, coolant flow, temperature, pressure, reflectors, moderators, and void and temperature coefficients. All operations were conducted from a control building located a half mile from the reactors, situated a few miles east of the Central Facilities Area. SPERT-I was an open-tank, light-water-moderated and reflected reactor, originally using 92 percent enriched uranium fuel. The reactor tank, about 4 feet in diameter and 14 feet high, was filled with water to a level about 2 feet above the core. In general, SPERT-I tests demonstrated the damage-resistant capabilities of low-enrichment (4 percent enriched uranium-235) uranium-oxide fuel pins similar to those used in water-cooled reactors powering large central stations.	SPERT-I	6-11-55	1964
40. **Special Power Excursion Reactor Test No. II** This facility consisted of a closed pressurized water reactor with coolant flow systems designed for operation with either light or heavy water. The pressure vessel was 24 1/2 feet high by 10 feet inside diameter. Tests with heavy water (deuterium, an isotope of hydrogen) were desired because heavy water reactors were of growing	SPERT-II	3-11-60	October 1964

Name	Acronym	Reactor Startup	Last Day of Operation
Special Power Excursion Reactor Test No. II (continued) importance in Canada, Europe, and the United States. Also, heavy water tests allowed for the verification of various types of physics calculations on the effects of neutron lifetime on power excursions.			
41. **Special Power Excursion Reactor Test No. III** SPERT-III was considered the most versatile facility yet developed for studying the inherent safety characteristics of nuclear reactors. This reactor (which was planned as the third in the series of SPERT reactors, but was built second) provided the widest practical range of control over three variables: temperature, pressure, and coolant flow. The reactor sat in a pressurized vessel similar to those used in commercial power production. Water could flow through the vessel at rate up to 20,000 gallons per minute, temperatures up to 650° F, and pressures up to 2,500 pounds per square inch.	SPERT-III	12-19-58	June 1968
42. **Special Power Excursion Reactor Test No. IV** SPERT-IV was an open-tank, twin-pool facility that permitted detailed studies of reactor stability as affected by varying conditions including forced coolant flow, variable height of water above the core, hydrostatic head, and other hydrodynamic effects. The reactor, water-moderated and -reflected, used highly enriched, aluminum alloyed, plate-type fuel elements. The SPERT-IV facility was modified by the installation of a Capsule Driver Core (CDC), which permitted fuel samples to be inserted into a test hole in the center of the reactor core, where it could be subjected to short-period excursions without damaging the “driver” fuel in the rest of the core. The CDC work on fuel-destructive mechanisms continued until the Power Burst Facility replaced it.	SPERT-IV	7-24-62	August 1970
43. **Spherical Cavity Reactor Critical Experiment** SCRCE was the final experiment in reactor physics work for the NASA-sponsored program to determine the feasibility of a reactor going critical with a gaseous core of uranium. Previous work had been done with a cylindrical configuration because of its ease of construction. The spherical configuration was the culmination of the project, allowing for a comparison between theory and experimental results. The spherical shape was considered a more likely geometry for the ultimate application in a rocket to Mars.	SCRCE	November 1972	1973
44. **Stationary Low-Power Reactor** (Earlier name - Argonne Low Power Reactor) The SL-1 reactor, originally named Argonne Low Power Reactor (ALPR), was designed for the U.S. Army as a prototype of a low-power, boiling-water reactor plant to be used in geographically remote locations. The SL-1 was accidentally destroyed and three men killed on January 3, 1961.	SL-1, ALPR	8-11-58	1-3-61
45. **Submarine Thermal Reactor** With the S1W, also known as the Submarine Thermal Reactor (STR), the United States’ nuclear navy was born. The purpose of a nuclear-powered submarine was to transform submarines into “true submersibles,” vessels that could remain underwater powered by a fuel which did not require oxygen. The S1W (submarine, first prototype, Westinghouse) nuclear power plant was the first prototype built at the Naval Reactors Facility. Cooled and moderated by pressurized water, the reactor and its associated propulsion equipment were installed inside two hull sections duplicating the size and specifications of *USS Nautilus*, under construction at the same time in Connecticut. To facilitate shielding research, the hull sections were placed in a tank of water. After startup, the S1W accomplished a simulated voyage nonstop from Newfoundland to Ireland, “submerged” and at full power most of the way during the 96 hour test. The simulation proved the principle and the feasibility of atomic ship propulsion long before *USS Nautilus* set out to sea. Later, the S1W tested advanced design equipment and operated as part of the Navy’s personnel training program.	S1W, STR	3-30-53	10-17-89
46. **Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 1** The SNAPTRAN program extended the SPERT reactor safety testing program to aerospace applications. Three test series, involving three reactors, investigated the behavior of SNAP 10A/2 fuel under large-transient,	SNAPTRAN-1	Early 1960s	

Name	Acronym	Reactor Startup	Last Day of Operation
Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 1 (continued) power-excursion conditions. SNAPTRAN-1, located at Test Area North, was subjected to non-destructive tests in conditions approaching but not resulting in damage to the zirconium-hydride-uranium fuel.			
47. **Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 3** SNAPTRAN-3 was the first of two destructive tests on a version of the small space reactor (SNAP 10A/2) designed to supply auxiliary power in space. The test, conducted at TAN's Initial Engineering Test Facility on April 1, 1964, simulated the accidental fall of a reactor into water or wet earth such as could occur during assembly, transport, or a launch abort. The test demonstrated that the reactor would destroy itself immediately instead of building up a high inventory of radioactive fission products.	SNAPTRAN-3	4-1-64	4-1-64
48. **Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 2** This test version of the small space reactor, SNAP 10A/2, was intentionally destroyed on January 11, 1966. It provided information on the dynamic response, fuel behavior, and inherent shutdown mechanisms of these reactors in an open air environment. In normal operation, the control drums of the SNAP 10A/2 were rotated to obtain criticality after the reactor had been placed in orbit. In case of a launch abort, however, impact on the earth might cause the drums to rotate inward, go critical, conceivably destroy itself, and release fission products to the surrounding environment. The test data contributed to an understanding of reactor disassembly upon impact and methods for assessing or predicting the radiological consequences.	SNAPTRAN-2	1965	January 11, 1966
49. **Thermal Reactor Idaho Test Station** THRITS was a low-power reactor located at TAN. Its nuclear core was arranged in two halves of a vertical, aluminum, honeycomb-like matrix. The reactor could not be operated until the two halves were brought together to form the critical fuel mass. Operators mocked up reactor design concepts for thermal and fast-neutron reactor systems to obtain basic physics and design data for such concepts.	THRITS Split-Table Reactor		1964
50. **Transient Reactor Test Facility** Part of the safety program for fast breeder reactors, TREAT was a uranium-oxide-fueled, graphite-moderated, air-cooled reactor designed to produce short, controlled bursts of nuclear energy. Located at Argonne-West, its purpose was to simulate accident conditions leading to fuel damage, including melting or even vaporization of test specimens, while leaving the reactor's "driver" fuel undamaged. Early studies determined the effect of extreme energy pulses on prototype fuel pins designed for EBR-II. TREAT tests provided data on fuel-cladding damage, fuel motion, coolant-channel blockages, molten-fuel/coolant interactions, and potential explosive forces during an accident. The data helped refine computer simulations of reactor accidents, and, ultimately, design reactors with greater inherent safety.	TREAT	2-23-59	April 1994 *TREAT was restarted in Nov. 2017 and is currently supporting experiment programs.*
51. **Zero Power Physics Reactor** (Earlier name - Zero Power Plutonium Reactor) ZPPR, a low-power critical facility located at Argonne-West, provided reactor physics data for any type of fast neutron spectrum reactor, from tiny space-power reactors to large commercial breeder reactors. The (full-size) reactor core configuration to be studied was mocked up in two halves, the fuel loaded into a honeycomb lattice in each of the separated halves. Extrapolation from the zero-power measurements to full-power conditions was readily achievable. Upon moving the two lattice together, ZPPR was brought to a low power, critical state by control rods. Heat removal was by air flow over the fuel elements.	ZPPR	4-18-69	April 1992 Standby
52. **Zero Power Reactor No. 3** This was a low-power split-table reactor that achieved criticality by bringing two halves of a fuel configuration together. A low-power reactor, ZPR-III was used to determine the accuracy of predicted critical mass geometries and critical measurements in connection with various loadings for makeup of fast-reactor core designs. The cores of EBR-II, Fermi, Rapsodie, and SEFOR reactors were originally mocked up in this facility. Experimental critical assembly results in this field were almost completely lacking before this reactor started up. The reactor was placed on standby in 1970 and later went on display in the EBR-I Visitor Center.	ZPR-III	October 1955	November 1970

Appendix C

Processing Runs, Idaho Chemical Processing Plant

Between 1953 and 1988 the Chem Plant recovered from spent reactor fuel 31,432 kilograms of uranium containing uranium-235. At times, the plant also recovered radioactive lanthanum (RaLa), neptunium, and radioactive krypton and xenon for use by private industry or other nuclear facilities.

Among the more frequent sources of fuel were the MTR, ETR, ATR, and STR (S1W), ZPR-III, EBR-I, and EBR-II—all NRTS/INEL/INEEL reactors. In addition, the plant processed SL-1 fuel, SNAPTRAN debris, and fuel from OMRE, BORAX, and SPERT reactors, and other test materials. The largest single source of reprocessed fuel was from naval nuclear propulsion reactors: prototype reactors, submarines, cruisers, and other vessels

Other sources included SRP (Savannah River Plant), Hanford, LITR (Low Intensity Test Reactor, Oak Ridge), SIR (Submarine Intermediate Reactor), OWR (Omega West Reactor, Los Alamos), GETR (General Electric Test Reactor), LPTR (Livermore Pool-type Reactor), BGRR (Brookhaven Graphite Research Reactor), ASTR (Aerospace Systems Test Reactor), JRR (Japanese Research Reactor), NRX (Nuclear Engine Reactor Experiment, Jackass Flats, Nevada), SER (Sandia Engineering Reactor), KUR (Kyoto University Reactor), STIR (Shielding Tests Irradiation Reactor), ORR (Oak Ridge Research Reactor), JANUS (Biological Research Reactor, Argonne National Laboratory), BMI Reactor (Battelle Memorial Institute of Columbus, Ohio) ML-1 (Mobile Low-Power Reactor), SFR (Segmented Fast Reactor), and many other university and research reactors.

Run Number	Fuel	Process Period
1	Hanford C and J slugs	2-53 to 8-53
2	MTR, LITR, NRX, ORNL shielding	10-53 to 12-53
	Cold test EBR-I Core 1	7-54 to 7-54
3	EBR-I Core 1, NP Cold Run, MTR, LITR, BORAX, BORAX scrap, Hanford C and J slugs	7-54 to 2-55

Run Number	Fuel	Process Period
4	Hanford J slugs, MTR, BORAX bulk shielding, BORAX, LITR	3-55 to 7-55
Cold tests	Cold test SRP reject slugs	9-55 to 11-55
5	Hanford J and C slugs, Chem Dev Test SRP reject slugs	12-55 to 3-56
6	MTR, LITR, BORAX, CP-3, CR	3-56 to 5-56
7	Hanford C and J slugs, CR, MTR, BORAX, LITR, ANL plates, LM slugs, STR, RaLa MTR	5-56 to 3-57
	CPM cold start with LM slugs	8-57 to 9-57
8	LM slugs, RaLa MTR	10-57 to 12-57
9	STR	12-57 to 1-58
10	Hanford C slugs, RaLa MTR, SRP LM slugs	1-58 to 2-58
11	SRP LM slugs, SRP Tube, MTR, RaLa MTR, Chalk River, SRP Tube	5-58 to 11-58
12	SRP slug, SRP Tube, NRX, RaLa MTR	12-58 to 4-59
13	SRP Tube, SRP slug, SRP Tube ends, Chalk River	4-59 to 8-59
14	SIR, OMRE, BMI, RaLa MTR	7-59 to 12-59
15	MTR, RaLa MTR, ETR, LITR, Convair (ASTR), Hanford C, J, and KW slugs, SRP LM slugs	12-59 to 2-60
16	SIR, RaLa MTR	2-60 to 3-60
17	STR, RaLa MTR	3-60 to 4-60
18	ETR	1-61 to 2-61
19	MTR, ETR, BORAX IV, RaLa MTR, Hanford C and J slugs, LITR, Chalk River, CP-5, LPTR, GTR (Convair), OWR, SL-1 scrap	12-61 to 2-62
	SL-1	10-62 to 10-62
20	MTR, ETR, RaLa MTR, SPERT, GETR, BRR, SL-1, BNL, LITR, CP-5, LPTR, GTR (Convair), OWR, WTR, BORAX III, SUSIE, Hanford AEC, Hanford Rey, NRU	6-63 to 9-63

Run Number	Fuel	Process Period
21	BGRR, NRX, McMasters, NRU, NRL, SWE, IRL, University of Michigan—FNR, GTR, MTR, OWR, LPTR, LITR, UF, ETR, CP-5, STR, SPERT, NASA	6-64 to 12-64
	Cold Zr, unirradiated Zr scrap, PWR Core I Seed I, Zr, EBR-I Core 3 codissolution, EBR-I Core 3, SNAPTRAN 2/10A-3 core debris	1-65
22	VBWR, Atomics International UO_2SO_4	4-65 to 6-65
23	Cold from ATR, MTR, ETR, and SPERT; MTR, ETR, LITR, LPTR, OWR, SPERT, GTR, ASTR, GETR, EBR-II Vycor glass, EBR-I Mark 2, plastic-coated Al fuel plates	12-65 to 1-66
24	JRR-2 Core 1, NRX, NRU, BGRR, EBR-II Vycor glass, JRR-2 Cores 2 and 3	3-67 to 9-67
25	MTR, WSU, ETR, LITR, LPTR, OWR, GTR, CP-5, SER, IRL, GETR, NRL, graphite leaching, Zr, EBR-II Vycor glass	4-68 to 6-68
26	Zr, MTR, ETR, GETR, Korean, SER, LITR, AFNETR, JRR-2, KUR, LPTR, OWR, ATR, SPERT, ZPR-III, SNAPTRAN 2/10-2 debris	8-69 to 10-69
	ETR types	1-70 to 4-70
27	Zr, JRR-2 (6 batches), EBR-II scrap, WADCO	2-71 to 7-71
28	Zr, ETR, custom miscellaneous	6-72 to 9-72
29	EBR-II, EBR-II slurry and denitrator product	1-73 to 5-73
30	Zr, GETR, ATR, MTR, MTR 20%, TRA scrap, JRR, ETR, CP-5, OWR, JMTR, Juggernaut, KUR, UM, SER, LPTR, EBR-II Vycor glass, G.G.A. Thermionic, ETRC plates, University of Wyoming UO_2SO_4, Atomics International fission disc, HTRE scrap, Walter Reed Army Hospital, Nuclear Test Gauge/Split Table Reactor, HTGR secondary burner ash leaching, BML fission disc	2-74 to 5-74
31	EBR-II, APPR cold fuel scrap	2-75 to 5-75
32	Zr, PWR	5-76 to 9-76
33	Godiva reactor fuel, HTRE, ATR, MTR, LPT, ETR, GETR	3-77 to 6-77

Run Number	Fuel	Process Period
34	EBR-II, OMRE, SPERT, ORNL-17-1, BMI, Kinglet, Sandia (Godiva reactors), PBF metallurgical samples	8-77 to 9-77
35	Zr, custom	7-78 to 3-79
36	Zr, Rocky Flats U_3O_8, GETR, OWR, STIR, LPTR, UCLA-MTR, ATR, ETR, ATR-XA	9-80 to 3-81
37	EBR-II, Los Alamos metal fuel scrap, Rocky Flats U_3O_8, Rover cold	8-81 to 11-81
38	ETR, BSR, ATR, OWR, ORR, HFR-PETTEN, SAPHIR, GETR, FRG, FRJ/FRM, SFR, UO_2SO_4	9-82 to 11-82
39	Rover, Sandia, Rocky Flats, cold FLUORINEL, FLUORINEL Phase 1 cold run	4-83 to 6-84
40	ITAL, FRG, DR-3, UCLA, MURR, OWR, HFBR, LPTR, TR-1, ATR, BSR, ORR, HMI, Triton, FRJ-2, HRF, BR-2, ORPHEE, ASTRA, SRF, R-2, JUNTA, McMaster, JRR-2, JMTR, JANUS, SR, UCSB UO_2SO_4, FLUORINEL Phase II cold run, FLUORINEL pilot plant	8-85 to 1-86
41	FLUORINEL	10-86 to 10-87
42	FLUORINEL, EBR-II Vycor glass, BYU UO_2SO_4, EBR-II fuel scrap, ANL-E fuel scrap	12-87 to 7-88

Sources:

M.D. Staiger, *Calcine Waste Storage at the Idaho Nuclear Technology and Engineering Center*, Report No. INEEL/EXT-98-00455 (Idaho Falls: Lockheed Martin, June 1999), Appendix pp. A-163 to A-168.

Dieter Knecht, et al., "Historical Fuel Reprocessing and HLW Management in Idaho," *Radwaste Magazine* (May 1997).

Leroy Lewis, Science and Engineering Fellow, Bechtel BWXT Idaho, contributed corrections to the lists published in the above two documents.

APPENDIX D

Criticality Accidents, Idaho Chemical Processing Plant

A criticality accident is an unintended amassing of a fissionable material (like uranium) which results in the fissioning of the material in a chain reaction. In such an event, fission products such as heat, gamma radiation, neutrons, gases, and other emissions are released by the nuclear reaction.

The designers of chemical processing, fuel fabrication, and other plants that handle fissionable material employ a variety of strategies to avoid accidental amassing of enough material to initiate a chain reaction. The examples below refer to uranium, but similar principles would apply to the management of any other fissionable material:

- Geometric control: the dimensions of the containers and conveyors of uranium make it impossible to reach a critical mass. At the Chem Plant, for example, certain dissolver vessels and storage vessels were no more than five inches in diameter. Spacing of vessels was also important, with two feet between vessels required to prevent a criticality.

- Concentration control: Where chemical processes involve evaporation or precipitation reactions which could result in the concentration of the uranium, vessels and containers are sized to prevent accidental accumulations of a critical mass. Appropriate dilution may also be used to keep the solution concentration below a minimum value to prevent criticalities.

- Mass control: In handling enriched uranium, the quantity that can be handled at any one time is limited to a specified, known-to-be-safe number of grams of material.

- Administrative control: Operational procedures may require two or more people to approve if a particular procedure could lead to a loss of control. Check-off points, guide limits, process alarm systems, color-coding of certain valve handles, key-only procedures, personnel training, and other controls accompany non-routine and many routine procedures.

1. Criticality Accident of October 16, 1959

A bank of storage cylinders containing a uranium solution was air-sparged (air was bubbled violently into the solution to mix it). The cylinders were geometrically safe, but the sparging initiated a siphon that transferred 200 liters of the solution to a 5,000-gallon tank containing about 600 liters of water. The resulting criticality lasted about twenty minutes.

No workers were exposed to gamma or neutron radiation, as the criticality occurred in a cell below ground when no one was in the vicinity. Airborne activity spread through the plant through vent lines and drain connections, triggering alarms and an evacuation. Two people who evacuated received significant beta doses (with no detectable medical consequences) as they passed areas where radioactive gas was being released into the room from floor drains.

The incident resulted in the placement of new valves, restrictions on air-flow lines when sparging, installation of water traps, and other measures before the plant restarted.

2. Criticality Accident of January 25, 1961

About 40 liters of uranyl nitrate solution (200 grams of uranium per liter) was forced upward from a 5-inch-diameter section of an evaporator into a 24-inch-diameter vapor disengagement cylinder, well above normal solution level. Analysts later assumed that air entered associated lines while operators were attempting to clear a plugged line and improve a pump. When the air bubble reached the evaporator, solution was expelled from the lower section, and a momentary criticality occurred in the upper section. Radiation triggered alarms, but no personnel received more than 100 mrem exposure. Concrete shielding walls surrounded the location of the criticality; the vent system prevented airborne activity from entering work areas; and equipment design prevented a persistent excursion. No equipment was damaged.

Management thereafter restricted the use of air pressure to move liquids and clear lines. A borated steel grid was installed in the disengagement cylinder. Boron is a nuclear “poison” that absorbs neutrons, helping prevent criticalities.

3. Criticality Accident of October 17, 1978

During the first solvent extraction cycle in the recovery of uranium from spent fuel, the uranium was extracted from the dissolution solution and then scrubbed, stripped, and washed in various process columns to separate the uranium from fission products. The criticality occurred in the scrub column (a long narrow, vertical tank). Water had leaked into the tank where the scrub chemical, aluminum nitrate, had been made up, and reduced the aluminum nitrate concentration. But this was not known to operators because an alarm had not been repaired and was inoperable. Also, operators had not sampled the scrub solution to determine whether the aluminum nitrate was above the required concentration. As a result, the solution was too dilute to force the uranium into the organic phase and instead extracted small amounts of it out on the organic phase into the aqueous phase and accumulated it into the large-diameter disengaging head.

Over a period of a month, uranium continued to accumulate until it reached a concentration in the aqueous phase high enough to achieve criticality. It accumulated in a large-diameter part of the column designed to separate the organic phase from the aqueous phase. The criticality reaction continued for about a half an hour before the operators responded to the slight pressure build-up and took steps to terminate the reaction.

The criticality occurred in a well-shielded location inside a process cell and resulted in insignificant radiation exposures to personnel or damage to equipment.

The operation and management failures associated with this criticality led to a significant reassessment and evaluation of Chem Plant operations. A Plant Protection System (which consisted of a variety of changes in procedures, operating limits, sampling protocols, specifications, warning systems regarding analytical samples, and others) was installed to preclude this type of accident from happening again.

Appendix E

R&D 100 Awards 1986–1999

Cryogenic ZAWCAD • 1999

Research Team: Dennis Bingham, Russell Ferguson, Gary Palmer, Douglas Stacey, Richard Swainston, Carl A. Dunn, Gerald Decker

Description: Cryogenic ZAWCAD is a remarkable, patented cutting and cleaning tool that will make many industrial processes safer and more environmentally friendly by performing hazardous and non-hazardous cleaning and cutting operations while minimizing secondary waste. This unique system uses as its cutting/cleaning medium a harmless atmospheric gas that dissipates after use. As a result, there is no secondary wastestream and no cross contamination. Yet, it can cut with the precision of the most advanced cutting tool and clean or abrade surfaces with finer control, more aggressiveness, and greater efficiency than other cleaning technologies—all without creating a secondary waste to clean-up, dispose of or treat.

Cryogenic ZAWCAD is a highly controllable technology, adjustable for temperature, speed and aggressiveness.

Tractrix Valve • 1999

Research Team: John Wordin, Pio Park

Description: The Tractrix Valve is a revolutionary, self-sealing valve that doesn't leak and doesn't wear out. Based on a geometric shape called a "tractrix curve," this innovative, plug-type valve wears less than competing plug and ball valves and seals tighter the more it wears—essentially "wearing in" each time it is opened and closed. It requires up to 90% less torque to actuate and can be made of any construction material for the most severe or simple applications. This cost-competitive new valve represents a leap in technology that could make common plug and ball valves obsolete for many applications—particularly those that are environmentally sensitive.

High Void-Fraction Multiphase Flowmeter • 1999

Research Team: James Fincke, Darrell Kruse, Daniel J. Householder, Bulent Turan, Doyle Gould, Charles Ronnenkamp

Description: The INEEL High Void-Fraction Multiphase Flowmeter solves one of the natural gas industry's most difficult measurement problems: cost-effective measurement of "wet gas" (mixed-phase flows of ≤5% liquid by volume). This innovative flowmeter represents a major economic breakthrough that can impact over 300,000 natural gas wells in the U.S. alone. It offers extraordinary size and cost savings over existing technology, and is the only device to provide real-time wet-gas measurement at the wellhead. It brings better fiscal management to producers, maximizing gas recovery. Its compact size will simplify facilities design, and its low cost will reduce capital investment and total gas production costs. Most importantly, the INEEL Flowmeter gives producers a reliable, economical means of managing natural gas reservoirs for the first time, conserving a precious natural resource.

Maverick Tank Inspection Robot • 1999

Research Team: Thor Zollinger, Kerry Klingler, Charles B. Isom, Kerry Trahan, Scott Bauer, Don Hartsell

Description: The Maverick is a submersible, robot-based system that offers safe, practical and cost-effective inspection of in-service, aboveground storage tanks (AST). This patented technology provides direct and indirect cost savings of 75% or greater over traditional manual inspection methods, reduces the inspection process from four weeks (or more) to a few days, eliminates worker exposure to hazardous conditions, and enables tank owners to continue using their tanks during inspections, saving them tens of thousands of dollars in previously "lost" revenue. Maverick also is the only robotic inspection system certified for use in hazardous and potentially explosive fuel environments (Class I, Division 1, Group D) such as gasoline and other fuel oils.

The robot's payload includes a multi-channel ultrasonic sensor system to map and correlate metal thickness data, an onboard video system to provide a detailed view of the tank bottom, and position-tracking sensors so technicians know the exact location of the Maverick, and any problem spots, at all times.

Supercritical Fluid Slashing System (SFSS) • 1999

Research Team: Mark Argyle, Alan Propp

Description: Before threads can be woven into fabric, they must be "sized," a process that adds a strengthening and smoothing coating to the thread. The INEEL SFSS is a cheaper, faster, smaller and more environmentally correct method for coating threads with size, one that replaces centuries-old technology. The INEEL method transports the size (starch or polyvinyl alcohol) in a very high-pressure "supercritical fluid" that has properties of both a fluid and a gas. Individual threads pass through pressure gradient tubes, where the supercritical sizing mixture is forced into the threads. The efficient method reduces the amount of water, starch and polyvinyl alcohol that textile manufacturers dispose of. The SFSS specifically addresses an industry "wish list" to provide uniform coating, reduce yarn hairiness, reduce the amount of sizing material, eliminate standing baths and minimize drying. Because it significantly increases sizing efficiency, the SFSS can double production throughput for improved profitability.

Electro-Optic High-Voltage Sensor (EHVS) • 1998

Research Team: Thomas M. Crawford, James R. Davidson, Gary D. Seifert

Description: The EHVS is a safe, small, non-electrical optical sensor that uses photons instead of electrons to measure high voltages on power lines. The most unique aspect of this technology is that the sensor does not have to be in electrical contact to effect a measurement, but simply within the conductor's electronic field, a key advantage over the large transformers conventionally used for voltage measurement at power distribution sites. The EHVS device offers substantial improvement over potential transformers in cost, ease of installation, range of response to voltage fluctuations and richness of applications.

Rapid Solidification Process Tooling (RSP) • 1998

Researcher: Kevin McHugh

Description: RSP Tooling technology is a fast, low-cost alternative to conventional fabrication of precision tooling used to manufacture early all mass produced products, from cell phones to automobiles. This new, molten metal spray-forming technology promises to reduce the cost and lead time for producing tooling by a factor of 5 to 10, substantially shortening the time it takes industry to get products to market. Unlike other alternative tooling approaches, RSP Tooling technology makes it possible to create tooling from hard tool steels at the rate of 2,000 lb/hr or more, suitable for the largest auto industry tooling requirements.

Malt-Based Antimicrobial • 1998

Researcher: Karen B. Barrett

Description: The Malt-Based Antimicrobial is a naturally occurring biopesticide derived from malted cereal grains. Developed as an environmentally sound solution to agricultural crop protection, this product represents a major breakthrough in pesticide research. It offers an extraordinary taxonomic range—unrivaled by chemical fungicides, is easily and inexpensively produced, has an excellent shelf life; and can be used to protect crops in the field, in storage, and during transport. Most importantly, this new biopesticide is harmless to people, animals, and the environment; and is derived from a plentiful renewable resource: common cereal grain.

Nanocrystalline Composite Coercive Magnet Powder • 1997

Research Team: J.D. Branagan, J.A. Hyde, C.H. Sellers, K.W. Dennis, M.J. Kramer, R. W. McCallum

Joint entry: Ames Laboratory, Dr. R. William McCalum

Description: The development and application of a new alloying approach in rare earth-based permanent magnet systems resulted in the development of advanced alloys with a nanocrystalline composite microstructure. Atomization processing of these new alloys resulted in significant improvements in hard magnetic properties and processability over previous alloys, allowing the possibility of near term, high volume, low cost production of atomization materials.

Advanced Tensiometer • 1997

Research Team: Joel M. Hubbell, James B. Sission

Description: The Advanced Tensiometer is an instrument that measures how tightly water is held to soil in the unsaturated zone, a region that extends from the earth's surface to the aquifer. The Advanced Tensiometer's breakthrough design helps investigators determine the direction and rate of water movement at depths and with accuracies not possible before, ushering in a new era for monitoring waste disposal sites, safeguarding drinking water supplies, and controlling agricultural irrigation systems.

Gamma Neutron Assay System (GNAT) • 1995

Research Team: R. Aryaeinejad, J.D. Cole, R.C. Greenwood

Description: GNAT is a new, nonintrusive and unique patented technique of identifying fissile materials and their isotopic ratios in bulk quantities and in a field environment. It resolved, for the first time, problems of assaying and tracking special nuclear material (SNM) not previously possible, which are important in arms control, nonproliferation, and nuclear weapons dismantlement.

Biocube Aerobic Biofilter—A Biofilter for Treatment of Toxic Gases and Vapors • 1993

Research Team: W.A. Apel, F.S. Colwell, A.S. Espinosa, E.G. Johnson, B.D. Lee, M.R. Wiebe, W.D. Kant, P. Melick, B. Singleton

Joint entry: EG&G Roston, W.D. Kant

Description: The Biocube™ Aerobic Biofilter is a landmark product that ushers in a new era for degradation of toxic vapors and gases. It is novel, effective, and economical vs. conventional technologies, and is the first modular and mobile biofilter.

Portable Isotopic-Neutron Source Chemical Assay System (PINS) • 1992

Research Team: A.J. Caffrey, J.D. Cole, L. Forman, R.J. Gehrke, R.C. Greenwood, K.M. Krebs, M.H. Putnam

Description: The PINS-based non-destructive assay system distinguishes chemical weapons (e.g., nerve gas) from high-explosive munitions for treaty verification.

Pulsed Extraction Secondary Ion Mass Spectrometer • 1992

Research Team: D. Applehans, D.A. Dahl, J.E. Delmore

Description: This is a new type of secondary ion mass spectrometer using a patented secondary ion pulsed extraction technique that prevents sample charging and allows the positive and negative ion spectra to be collected simultaneously, making possible analyses that previously could not be performed.

Sulfur Poisoning Resistant and Regenerable Hydrogenation Catalysts • 1990

Researcher: Randy B. Wright

Description: This entry is a new, unique, and advanced method for the preparation of highly active, sulfur poisoning resistant and repeatedly regenerable hydrogenation catalysts. This method utilizes the controlled manipulation of chemically induced surface segregation processes in conjunction with intermetallic compounds and binary alloys to design and synthesize a wide range of active catalysts. As specially applied to nickel-based intermetallic compounds, this approach provides a technique by which highly active hydrogenation catalysts can be prepared and regenerated by elevated temperature oxidation/reduction treatment of the starting material.

FiberOptic Moire Interferometry System (FMI) • 1990

Research Team: V. Deason, M.B. Ward

Description: The FMI System, Model FMI 1700, is a major advance in an important new technique—diffraction moire interferometry. Diffraction moire is used for the study and measurement of distortion, stress and fracture. The FMI was developed at the INEL in response to serious failings to the existing diffraction moire systems. The FMI utilizes advanced optical fiber components in a compact portable unit to replace an optical table full of standard optical devices. These fiber optic components are in all cases smaller, lighter and more stable than the discrete components normally used. At the same time, the FMI greatly simplifies the experimental process, which until now has been complicated and tedious using conventional equipment.

Diffraction Moire Interferometry, for which the FMI was developed, allows the researcher to make highly accurate (better than one Micron resolution) measurements of deformation. This deformation could be the result of stresses on a ship's hull, an airplane's frame, bridge, piping in a nuclear plant or other critical area. Understanding the relationship between stress, deformation, and such factors as aging, load, corrosion, and material properties is crucial to reducing the heavy burden on the economy and society of structural failures (estimated at tens to hundreds of billions of dollars annually, plus extensive loss of life and productivity).

Diffraction moire measures deformation in a specimen by creating full two-dimensional maps of the corresponding deformation in a diffraction grating bonded or marked on the surface of the specimen.

Finnigan MAK Gas Mass Spectrometer Model 271/251 • 1990

Research Team: R. Rankin, K.W. Guardapee, L.L. Dickerson

Joint entry: Finnigan MAT Corporation

Description: The 271/251 gas mass spectrometer defined the state-of-the-art in instrumentation for the analysis of noble gases in the environment. The unique aspect of this instrument is that it combines two diverse gas analysis functions, usually requiring separate instruments, into a single entity. The instrument performs both gas composition and gas isotope ratio analyses. In addition, typical isotopic precision capabilities with gas mass spectrometers were on the order of 0.03%. This product has been able to exceed these values by more than an order of magnitude (0.001%), thereby significantly extending the state-of-the-art in high precision gas isotopic analysis. Highly precise measurement of the concentrations of the gas isotopes in the atmosphere is indispensable to environmental studies involving nuclear facilities. This work has been recognized internationally; instruments based on these designs are now in use in Europe and Asia.

Simion PC/PS2 4.0 • 1989

Research Team: D.A. Dahl, J.E. Delmore, A.D. Applehans

Description: SIMION PC/PS2 4.0 is a personal computer program for designing and analyzing charged particle (ions and electrons) lenses, ion transport systems, and all types of mass spectrometers and surface probes that utilize charged particles. The program, which became available in June, 1988, has exclusive capabilities that significantly expand the number and types of problems that can be addressed, problems that heretofore were impossible to model with existing programs.

Neutral Molecular Beam Surface Probe • 1988

Research Team: J.E. Delmore, A.D. Apprelhans, and D.A. Dahl

Description: This device produces a well-focused beam of high energy neutral sulfur hexafluoride molecules at energies ranging from 3 to 23 keV that can be transported many meters under vacuum while retaining sharp focusing, to probe the few molecular layers of a sample's surface. The primary function of the Neutral Molecular Beam Surface Probe is the analysis of surfaces of non-electrical-conducting materials. A similar technique has been used with charged atomic particle beams for many years to analyze surfaces of electrically conducting materials, although the technique is applied with great difficulty to insulating materials. Other techniques, notably fast neutral atom beams (FAB sources) have been used with some success, but the nature of their production precludes sharp focusing. In addition, the FAB source must be mounted quite close to the specimen, and that constrains the secondary ion source design. The new Neutral Beam is much easier to use, allows much sharper focus and increases sensitivity about 1000 fold over systems using charged particle beams on insulating specimens.

Biodegradation System for Toxic Organic Waste Processing • 1988

Research Team: J.H. Wolfram, R.D. Rogers

Description: Disposing of hazardous waste is a high-priority item for every organization that produces it. Virtually every hospital, research university, and biotechnology company in the U.S. produces small quantities of hazardous wastes of organic compounds (e.g., toluene, xylene, and pseudocumene). The first two of these compounds are on the EPA priority pollutant list. A mixture of these compounds is know as liquid scintillation cocktail when the mixture also contains radioactive materials. The Biodegradation System introduces organisms to the cocktail that detoxify it at very high levels of efficiency. The system includes a bioreactor (where living cells "feed" on the toxic materials and produce carbon dioxide), accessory hardware, and a supply of the detoxifying microorganisms. Once installed, the system will continually bioprocess an inflow of the cocktail, rendering it safe for conventional disposal through the sewer system if the radioactivity is within prescribed limits, or as low-level radioactive waste otherwise. This eliminates the high cost of packing and transporting the mixed waste to the very few authorized disposal sites. Sanctioned methods for handling the waste at present are incineration and long-term storage. Converting the waste at the site eliminates dependence on these methods and the cost associated with them.

Improved Iron-Based Alloys from Noble Gas Doping • 1988

Researcher: John E. Flinn

Description: The primary function of this product is to strengthen alloys for high-temperature applications. Noble gas atoms (e.g., those of helium or argon), when entrapped during the processing of iron-base powders, stabilize the microstructure and strengthen the alloy produced. The alloying addition forms numerous small and very stable clusters with vacancies (missing atom sites) during rapid cooling. The formation of the clusters is due to the high binding energy between the noble gas atoms and the vacancies that are created by high temperature exposure (i.e., heat treating). Because they retard microstructure coarsening, the clusters allow fine microstructures to be retained during exposure to high temperatures. Cluster presence provides a form of solid solution and dispersion strengthening. The strengthening is further enhanced during aging heat treatments because the clusters provide nucleation, or preferred, sites for the formation of precipitates such as carbides. The fine dispersion of a large number of precipitates significantly improves the strength of the alloy. This process is applicable to all iron-base alloys, particularly to stainless steels.

Oxynitride Braze Method for Joining Silicon Nitride Ceramics • 1988

Research Team: R.M. Neilson, D.N. Coon, S.T. Scheutz, R.L. Tallman

Description: Structural ceramics are potential substitutes for strategic and/or critical materials. However, many potential structural ceramic applications require components that are too intricate or too large to be fabricated with existing techniques. The invention is a method for joining silicon nitride ceramics to produce large parts and/or parts that have complex geometries in which the high-temperature mechanical properties of the joined part are comparable to that of the original ceramic components. For certain applications (e.g., aerospace, engines, chemical processing), ceramic parts and complex shapes are preferred to metals. Reasons include: increased service operating temperatures; greater strength and increased corrosion resistance at the higher temperatures; greater thermodynamic efficiency in energy conversion devices; lower density and, therefore, lower inertia; lower cost of raw materials; and conservation of possibly strategic and/or critical materials in some applications. The oxynitride braze method for joining silicon nitride ceramics presented here has been demonstrated to be an effective joining technique using either a hot isostatic press or a graphite resistance furnace with small nitrogen overpressure. In this process, oxynitride glass brazes are used to join silicon nitride ceramics. The glass uses are comparable in composition to the grain boundary phase present in the ceramic pieces that results from the densification process used to consolidate the silicon nitride powders.

Die-Target for Dynamic Consolidation of Powders • 1987

Research Team: John E. Flinn, Gary E. Korth

Description: Die-Target for Dynamic Consolidation of Powders is a new and improved method of consolidating metal monoliths from rapidly solidified powders (RSP). The Die-Target controls dynamic stress waves produced by detonation of explosive charges to consolidate RSP alloys. With each detonation, the Die-Target produced four fully consolidated, fully dense, crack-free monoliths for test specimens. This process does not produce high generalized temperatures in the powders, which could seriously alter the microstructure and desirable properties for the RSP. Monoliths produced by the dynamic consolidation of RSP alloys (e.g., stainless steel) have improved mechanical properties, improved corrosion resistance, chemical homogeneity, extended solubility limits, very fine microstructures, and desirable metastable phases. At present, the primary use of the Die-Target is as a research tool. However, the theory and principles underlying the design hold promise for industrial and commercial applications of the DIE-Target where advanced materials that are harder and stronger are needed.

Vision System for High Luminosity Processes • 1986

Research Team: Jon Bolstad, M.B. Ward, C.L. Shull

Description: This system produces high-quality video imagery of industrial or experimental processes that are normally obscured by high luminosity of an electric arc, a plasma or a combustion flame. It has particular application in electric arc welding where detailed vision of the welding pool, electrode and liquid/solid interface is required. The welding site is illuminated by pulsed laser light transported to the welding torch by one or more optical fibers. The sensor assembly incorporates objective optics, a laser line filter, a microchannel plate image intensifier tube and a CCD video camera. The intensifier tube is shuttered electronically in synchronism with the flash from the laser source, which occurs only once per video frame (or some multiple thereof). The shuttering interval (about 100 nanoseconds) is very small in comparison with the 33 millisecond integration time of a standard video camera. The welding arc light is almost totally eliminated from the video picture. Visibility through the arc is regained, and extreme variation in brightness across the picture is removed. The video imagery is much superior to standard video for interpretation by eye and by electronic image processing equipment.

Appendix E

R&D 100 Awards 2000-2023

RAVEN • 2023

Research Team: Diego Mandelli, Congjian Wang, Paul Talbot, Joshua Cogliati, Mohammad Abdo, Dylan McDowell, Ramon Yoshiura, Robert Kinoshita, Cristian Rabiti, Andrea Alfonsi, Daniel Garrett

Description: RAVEN is an open-source software platform that facilitates and enhances a variety of model exploration, risk analyses and design optimizations for nuclear reactors, energy grids and other complex systems.

Ether-based Aqueous Separation & Extraction (EASE) • 2023

Research Team: Aaron Wilson, Ikenna Nlebedim, Caleb Stetson, Denis Prodius, Christopher Orme, Hyeonseok Lee, Ashini Jayasinghe.

Joint entry: Ames National Laboratory

Description: EASE is an emerging technology to separate valuable mineral salts as solids from wastewater and dilute sources. This solvent-driven process significantly reduces the energy and chemicals used for water treatment and mineral recovery without creating a new waste stream.

Cerberus • 2023

Research Team: Kenneth Rohde, Barney Carlson, Sean Salinas, Matthew Crepeau.

Description: United States government policy now calls for establishing a network of high-speed charging stations for electric vehicles. These charging stations handle a lot of energy and depend on the internet – a vector for criminals and national adversaries. Cerberus is anti-hacker hardware and software that protects equipment and the people using it.

Cardinal: Accelerating Discovery in Fusion and Fission Energy • 2023

Research Team: April Novak, Derek Gaston

Joint entry: Argonne National Laboratory

Description: Cardinal is an open-source simulation software package that accelerates scientific discovery in nuclear fusion and fission energy, delivering state-of-the-art integration of scalable algorithms that enable first-of-a-kind scientific exploration. Cardinal is applicable to neutron transport, fluid flow, heat transfer, thermos-mechanics and material behavior on platforms ranging from laptops to extreme-scale computers.

Annotated Translated Disassembled Code (@DisCo) • 2023

Research Team: Rita Foster, Jed Haile

Description: @DisCo is a scalable translated binary analysis platform that improves cyber defense by using machine learning and sophisticated visualization tools to reverse engineer firmware and malware binaries. The tool then translates these into intermediate languages that enable vulnerability discovery and code analysis.

MOSAICS • 2022

Research Team: Craig G. Rieger, Michael McCarty, Bev Novak, Roya Gordon

Joint entry: Johns Hopkins University Applied Physics Laboratory, Sandia National Laboratories and Pacific Northwest National Laboratory

Description: MOSAICS is a technology initiated by the Department of Defense to provide the first comprehensive, integrated and automated solution to detect and prevent cyberattacks on industrial control systems. INL focused its efforts to provide scalable evaluation of commercial, off-the-shelf security solutions and a test harness for initializing, launching and collecting results from cyber-resilience testing in virtual environments.

Machine Intelligence for Review and Analysis of Condition Logs and Entries (MIRACLE) • 2022

Research Team: Ahmad Al Rashdan, Brian Wilcken, Cameron Krome, Kellen Giraud.

Description: In the nuclear power industry, every issue, no matter how small, is documented in a condition report. In each plant, hundreds of these are reviewed and characterized every week by dozens of people. MIRACLE employs machine learning and natural language processing to automate this process, saving millions of dollars while improving safety. Although MIRACLE is intended for use in nuclear power plants, its methods should be valuable in any industry that requires massive volumes of documentation reviews. MIRACLE offers savings and efficiencies.

Electrochemical Leach (EC-Leach) • 2022

Research Team: Tedd Lister, Luis Diaz Aldana, John Klaehn, Joshua McNally, Meng Shi, Daniel Molina Montes de Oca.

Description: EC-Leach provides a cost-effective, highly efficient, safe, carbon-free and remarkably simple process for solving one of our world's biggest clean energy challenges: lithium-ion battery recycling. This technology unlocks the green energy potential of these batteries at the end of their lives by allowing extraction and recovery of critical materials. Although EC-Leach provides an answer to many complicated challenges, it is remarkable for its technological simplicity. By facilitating battery recycling in a closed loop, EC-Leach enables a carbon-free transportation and manufacturing sector.

Plug-N-Play Appliance for Resilient Response of Operational Technologies (PARROT) • 2021

Research Team: Craig Rieger, Edward Springer, Michael McCarty, Timothy McJunkin

Description: PARROT provides an extra layer of security from cyberattacks on critical infrastructure operations. When placed between control systems and infrastructure, PARROT isolates a cyberattack, provides a manual or automated response and prevents harmful impacts while maintaining operations.

Commercial Routing Assistance Tool • 2021

Research Team: Ollie Gagnon III, Robert Edsall, Mary Klett, Timothy Klett, Michael Overton

Description: The Commercial Routing Assistance Tool is an interactive website that maps routes and displays information about state government actions that can impact interstate transportation. The tool produces routes for commercial, emergency and disaster response vehicles to travel into or around various states in an efficient, compliant and safe manner.

Bison • 2021

Research Team: Jason Hales, Richard Williamson, Albert Casagranda, Kyle Gamble, Stephen Novascone, Stephanie Pitts, Gyanender Singh, Benjamin Spencer, Aysenur Toptan, Wen Jiang

Description: Bison is a flexible, next-generation nuclear fuel performance analysis code that uniquely analyzes fuels of varying types and geometries in one, two or three dimensions. By making advanced simulation more accessible to nuclear engineers, Bison will help enhance the safety and efficiency of both existing nuclear plants and the next generation of reactors.

RE-Metal • 2021

Research Team: Donna Baek, Robert Fox, Abderrahman Atifi

Description: RE-Metal helps solve an enormous challenge for U.S. manufacturers: enabling the environmentally friendly recycling of a limited supply of essential rare earth elements that are required for most of today's high-tech devices. Recycling rare earth elements from high-tech devices typically involves a toxic process that's banned in many countries, including the U.S. RE-Metal enables the recovery of rare earth metals from waste electronics and other sources.

Crop Artificial Intelligence Quotient (Crop AIQ) • 2020

Research Team: Mike Griffel, Damon Hartley, M. Ross Kunz

Description: Crop AIQ provides a vital function: agricultural performance assessments that allow land managers to make more informed decisions about how they grow plants for food, feed, fiber and fuel. The tool allows farmers to generate an accurate yield map without having to rely on harvester data, the only other way to produce such a map. A yield map is fundamental to precision agriculture and integrated land management. It is also a basic tool to maximize agriculture productivity and profitability, while minimizing environmental impact.

Colorimetric Detection of Actinides (CoDeAc) • 2020

Research Team: Catherine Riddle, Rick Demmer

Description: In responding to an accident or attack, handheld detectors may provide adequate screening for some radiation sources, but they lack the sensitivity to detect alpha emitters such as uranium and plutonium in dusty, outdoor environments. CoDeAc can help responders quickly detect actinides at any disaster or accident scene. CoDeAc's color change in the presence of very low concentrations of uranium and plutonium gives a go/no-go result in seconds, allowing professionals to make decisions based on actual data instead of assumptions on-site. These decisions impact everyone and can mean the difference between evacuating hundreds of thousands of people within square miles or just 100 people within a square block during a radiological event.

Carbon Capture & Utilization through Reduction Electrolysis (Carbon Cure) • 2020

Research Team: Luis Diaz Aldana, Ningshengjie Gao, Tedd Lister, Birendra Adhikari, Aaron Wilson, Eric Dufek

Description: Decarbonizing energy production through carbon capture and sequestration is a popular idea that has been plagued by operational and economic challenges. Integrating carbon capture with reuse to make high-value products could offer an operational advantage. The Carbon CURE process provides a solution by using recyclable solvents as a carbon capture medium that can be fed directly to an electrochemical cell. The cell converts carbon dioxide to syngas, the building block for a raft of high value products. The process will help achieve economical carbon capture at an industrial scale.

Consequence-driven Cyber-informed Engineering (CCE) • 2019

Research Team: Robert Smith, Curtis St. Michel, Amanda Belloff, Andy Bochman, Sarah Freeman, Michael Assante

Description: CCE's four-phase process provides users with knowledge and skills to protect against and prepare for serious cyberthreats to control systems that assure economic growth, public health and national defense. This first-of-its-kind engineering-centric methodology proved to be a transformational cybersecurity solution during pilot studies with a large electric utility and a U.S. government national security platform.

Wireless Radio Frequency Signal Identification and Protocol Reverse Engineering (WiFIRE) • 2019

Research Team: Christopher Becker, Kurt Derr, Samuel Ramirez, Sneha Kasera, Aniqua Baset

Joint entry: University of Utah

Description: WiFIRE provides real-time wireless communications security by continuously monitoring the wireless spectrum. WiFIRE revolutionizes spectrum protection and analysis by including capabilities for real-time identification of multiple signal types used by different frequencies, tracing system communication activities, and reporting the presence of authorized and unauthorized wireless users.

Electronic Neutron Generator Calibration System (N-Meter) • 2019

Research Team: David Chichester, Scott J. Thompson, James T. Johnson, Scott M. Watson, Robert S. Schley, Jay D. Hix

Description: The N-meter is an elegant, one-of-a-kind device. This portable, reusable and adaptable instrument has a unique capability to calibrate electronic neutron generators (ENGs) regardless of manufacturer. Using this new capability, experts can design and use ENGs with much higher confidence in making critical measurements for applications, including nuclear security, geological exploration and medicine.

HTIR Thermocouples • 2019

Research Team: Richard Skifton, Josh Daw, Kurt Davis, Pattrick Calderoni, Keith Condie, Darrell Knudson, Joy Rempe, Curt Wilkins

Description: To operate modern marvels safely, engineers must have precise information about how materials perform under harsh conditions. Extreme heat and especially radiation have made direct sensor readings of nuclear fuel temperatures impossible to obtain over extended periods. HTIR Thermocouples can operate reliably in the harshest conditions for months, even years.

Phosphate Sponge • 2018

Special recognition for Green Technology

Research Team: Troy Garn, Mitchell Greenhalgh, Jack Law, Steve Hammon

Joint entry: Global Phosphate Solutions

Description: The Phosphate Sponge provides a solution for remediating freshwater algae blooms caused by phosphate pollution. Filled with a proprietary powder developed by Rocky Mountain Scientific Corp., the beads are made of an INL-developed sorbent material. When contaminated water passes through a bed containing the beads, contaminants are absorbed, reducing phosphate levels in water. The beads can be "wrung out" and reused indefinitely, and the phosphates can be recycled.

On-Site Inspection Radioisotopic Spectroscopy (OSIRIS) • 2018

Special recognition for Corporate Social Responsibility

Research Team: Gus Caffrey, Kenneth Krebs, Jayson Wharton

Joint entry: Pacific Northwest National Laboratory and Lawrence Livermore National Laboratory

Description: OSIRIS is a portable, rugged gamma ray spectroscopy and laptop computer system for nuclear explosion detection that can be taken anywhere in the world to perform precise radioisotopic measurements for on-site inspections. OSIRIS uses a software "data filter" coupled with a powerful spectrometer to focus the display of information it collects on just the 17 fission-product radioisotopes agreed on by international technical experts to be indicative of nuclear explosions. OSIRIS has been tested extensively for its intended application and has been made commercially available through partnership with ORTEC.

Autonomic Intelligent Cyber Sensor (AICS) • 2018

Research Team: Todd Vollmer, Craig Rieger, Milos Manic

Description: AICS is an artificial intelligence breakthrough that can protect the nation's critical infrastructure from devastating cyberattack. AICS works autonomously to give industries the power to quickly identify and divert hackers, using machine learning to identify and map industrial control systems. It can identify anomalous network traffic, alert operators and deploy virtual decoys to slow or halt hacking attempts. Following installation within an industrial control system and an initial learning phase, AICS automatically updates what it knows about a control system, adapting and remapping as it goes. AICS sets up and continually updates decoy virtual hosts – honeypots – to distract attackers from targets, giving asset owners time to gather information that can help identify both a hacking threat and a potentially compromised system.

Antenna Coupled THz (ACT) Film • 2018

Researcher: Dale Kotter

Joint entry: RedWave Energy, Inc.

Description: Converting waste heat into power represents one of the largest opportunities to improve efficiency and reduce emissions to the energy sector. Using nanorectifying antenna research from INL, RedWave Energy Inc. has developed ACT Film capable of harvesting low-temperature waste heat at power plants. Each sheet of ACT Film is made of tiny, square, gold-wire rectennas embedded in plastic sheeting that can be used nearly anywhere. The ACT Film absorbs heat between 70 and 250 degrees Celsius and converts it to electricity. Conceivably, composite stacks of ACT Film could be engineered to be compatible with existing power plant designs and used to replace cooling towers. By recovering 20% of low-temperature waste heat at a typical power plant, the electricity generated would equal the amount produced by burning 112,000 tons of coal.

Advanced Electrolyte Model (AEM) • 2014

Researcher: Kevin Gering

Description: Advanced Electrolyte Model (AEM) is a molecular based, scientifically proven simulation tool. It transforms electrolyte selection, optimizing material combinations and key design elements to make battery design and experimentation quick, accurate and responsive to specific needs. AEM predicts and catalogs electrolyte metrics, evaluation and comparison of more than 35 parameters to recommend optimal solutions and explore and report with certainty and clarity on molecular-to-macroscale-level aspects of electrolyte behavior.

Multiphysics Oriented Simulation Environment (MOOSE) • 2013

Research Team: David Andrs, Derek Gaston, Richard Martineau, Jason Miller, Cody Permann, JW Peterson, Andrew Slaughter

Description: MOOSE offers a framework that makes it easier for scientists to predict phenomena ranging from nuclear fuel and reactor performance to groundwater and chemical movement. It speeds the pace of scientific discovery that traditionally required more computing resources than most scientists and engineers could readily access. MOOSE has spawned numerous other research tools addressing nuclear reactor design, microscopic response of nuclear fuel to irradiation, chemicals flowing through bedrock, as well as water and heat flow in geothermal reservoirs.

Switchable Polarity Solvent Forward Osmosis (SPS FO) • 2013

Research Team: Mark Stone, Fred Stewart, Aaron Wilson

Description: SPS FO combines the switchable polarity quality with forward osmosis to clean industrial wastewater. It leverages the switching qualities of selected specialized thermolytic salts and the characteristics of specialized membranes to accomplish the task. Low cost and environmentally friendly, the SPS FO process can purify water from extremely concentrated solutions, especially those containing salts, organics, inorganics, biologics and many other materials.

Wireless Spectrum Communications (WSComm) • 2012

Research Team: Hussein Moradi, Behrouz Farhang, Carl Kutsche, Daryl Wasden, Jose Loera, David Couch

Description: This technology offers potential short-term and long-term solutions to expand the use and availability of the radio frequency spectrum that delivers mobile phone and other services for six billion devices. The patent-pending WSComm technology fills an existing technology void and offers secure, nearly undetectable control communication channels for use in public safety and national defense.

Rad-Release • 2011

Research Team: Julia Tripp, Karen Wright, Laurence Hull, Dean Peterman, Craig Cooper, Rick Demmer

Joint entry: Environmental Alternatives Inc.

Description: Rad-Release is a highly effective (up to 99% removal rate), affordable, patented chemical foam-clay decontamination process that removes specific radiological and metal contaminants on a wide variety of substrates. The chemical process involves the topical application of a single decontamination solution to treat various substrates bearing radiological contamination. A second part using montmorillonite clay may be used, depending on the decontamination requirements.

Impedance Measurement Box (IMB) • 2011

Research Team: Jon P. Christopherson, John L. Morrison, William H. Morrison, Chester G. Motloch

Joint entry: Montana Tech, Motloch Consulting and Qualtech Systems, Inc.

Description: Batteries and other energy storage devices are more important to consumers, industries and the military, creating a demand for accurate battery assessment. Until now, only passive monitoring of voltage, current and temperature have been the norm. IMB assesses battery health with a simple, sophisticated and well-engineered breakthrough that directly measures impedance during battery operation. This diagnostic tool uses proprietary algorithms and hardware to input a predetermined, benign signal; capture a response; process the data; analyze it; and display results.

osgBullet • 2010

Research Team: Joshua Koch, David Muth, Mark Bryden, Terry Jordan, Joe Kleiss, Paul Martz, Douglas McCorkle

Joint entry: Ames National Laboratory, National Energy Technology Laboratory, Skew Matrix Software, U.S. Army Armament Research Development and Engineering Center

Description: INL researchers David Muth and Joshua Koch collaborated with researchers at Ames National Laboratory and the National Energy Technology Laboratory to develop osgBullet, which provides an open-source software toolkit that enables real-time creation and interaction with multibody dynamics simulations in a 3D graphical environment.

MicroSight • 2010

Researcher: David Crandall

Description: MicroSight transcends the laws of physics by simultaneously imaging two distinct focal planes so that a marksman can clearly focus on both the gun sight and the target. As a result, hunters, target shooters and military marksmen can clearly see their targets and the sights at the end of their gun barrels simultaneously. This can dramatically improve a shooter's situational awareness with better vision and safety. MicroSight is durable, incredibly small and adds less than 1/1000th of an ounce to the firearm. MicroSight has been licensed by Apollo Optical Systems of Rochester, N.Y., a world leader in lens design and engineering.

Supercritical/Solid Catalyst (SSC) • 2010

Research Team: Robert Fox, Daniel Ginosar, Lucia Petkovic, Daniel Wendt

Description: Discarded and environmentally unfriendly wastes can now be converted into biodiesel fuels using a chemistry breakthrough called SSC. The research team found ways to create liquid fuels from a variety of streams, including municipal wastewater and food processing waste. SSC mixes fat or oil feedstock with supercritical fluid solvents and alcohols at specific temperatures and pressures to completely dissolve the materials during a single supercritical phase. This approach overcomes a key barrier — the polar liquid phase in conventional biodiesel production, which requires multiple steps.

RFinity • 2009

Research Team: Kurt Derr, Steve McCown, Troy Moore, Kenneth Rohde, Aaron Turner

Description: This technology offers a hardware/software solution that enables secure transaction computations and transmissions to and from other RFinity-enabled devices. RFinity can transform current cell phones that use a microSD card into safe, secure financial and transaction devices. RFinity's plug-n-play hardware contains a radio frequency identification transponder that uses two-way near-field communications among cell phone, RFID product labels and other enabled systems. Using U.S. National Security Agency Suite B encryption standards, RFinity uses a one-time code infrastructure for contactless, single-click transactions for business, identification, sensitive record retrieval and much more.

Precision Nanoparticles • 2009

Research Team: Robert Fox, Joshua Pak, Rene Rodriguez

Description: This process uses supercritical carbon dioxide to produce high quality, uniform nanoparticles of a prescribed size, which can range from smaller than 1 nanometer to 100 nanometers. Using temperature and pressure variances well within current commercial capabilities, Precision Nanoparticles can deliver specified-sized copper indium disulfide nanoparticles to harvest photon energy across the most intense segments of the solar spectrum. This may offer a major advance in producing new, more efficient solar materials to heat and power homes, businesses and the nation.

Water Sample Concentrator • 2009

Research Team: Michael Carpenter, Lyle Roybal, Paul Tremblay, Vincente Gallardo, Alan Lindquist

Description: Water Sample Concentrator can reduce a test sample size from a suspected contaminated source from 100 liters (more than 200 pounds) to a concentrated 250 milliliter sample (about half a pound). This permits easier transport of a sample to a qualified laboratory and faster sample gathering, while preserving suspected pathogens. It also safeguards the individual gathering samples with a fully contained and isolated sample system.

Antibody Profiling Identification (AbP ID) • 2008

Research Team: William Apel, Joni Barnes, Debra Bruhn, Karen Delezene-Briggs, Gregory Lancaster, Gordon Lassahn, Heather Silverman, Elizabeth Taylor, Vicki Thompson

Description: AbP ID is a rapid, inexpensive method to identify forensic evidence based on unique individual auto-antibody patterns. AbP ID incorporates a testing system and innovative pattern recognition software to expedite identifications.

Xtreme Xylanase (Hemicellulase) • 2006

Research Team: William Apel, Kastli Schaller, Elizabeth Taylor, David Thompson, Vicki Thompson, Morgan Bruno

Description: Xtreme Xylanase is a highly acid- and heat-stable xylanase enzyme isolated from the Yellowstone National Park microbe Alicyclobacillus acidocaldarius, cataloged in 1971. This enzyme can efficiently convert components of biomass feedstocks into energy-rich sugars that can replace petroleum to make fuels and high-value chemicals.

INL Robot Intelligence Kernel • 2006

Research Team: Douglas Few, Miles Walton

Description: The Robot Intelligence Kernel is a low-cost, onboard control architecture that gives robots exceptional new levels of autonomy and "intelligence." It provides any mobile robot with intelligence comparable to a highly trained police dog, allowing it to navigate complex spaces, search for objects and people, chase suspects at high speed, identify target items, and detect the movement of people or objects.

Compact High-Efficiency Natural Gas Liquefier • 2006

Research Team: Dennis Bingham, Frank Carney, Michael McKellar, Douglas Stacey

Description: This technology does not require a large traditional production facility, making it less expensive to build and operate while producing a lower-cost product than existing commercial approaches, including large-scale, centralized processing plants. This new liquefier also boasts a design with only two major moving parts and sophisticated software that allows virtually unattended, low-maintenance operation.

Nano-Composite Arsenic Sorbent (N-CAS) • 2006

Research Team: R. Scott Herbst, Nicholas Mann, Terry Todd

Description: N-CAS is a long-lasting, high-capacity nanocomposite polymer particle engineered to remove harmful arsenic concentrations from water. It is cost-effective, making it ideal for small communities, impoverished nations and individual users. N-CAS will be employed into a small cartridge device for point-of-use drinking water treatment. Once used, the material is considered nonhazardous and can be safely disposed of in a landfill.

Visual First Responder • 2005

Researcher: Kevin Young

Description: The Hazmat Cam, a lightweight, wireless video camera system that allows emergency first responders to send real-time, high-quality images from terrorism, accident or disaster sites to video or computer monitors at remote command centers up to five miles away.

Ultra-Stable Catalase • 2004

Research Team: Vicki Thompson, William Apel, Kastli Schaller

Description: This enzyme catalyzes the decomposition of hydrogen peroxide into oxygen and water at high temperature and pH. The enzyme could have a major impact on textile, food, and pulp and paper industries by enabling conversion to environmentally safe, cost-effective hydrogen peroxide processes as oxidizing and antimicrobial agents.

Geologic and Environmental Probe System • 2004

Research Team: Jim Loftus, Richard Jones

Description: The Geologic and Environmental Probe System is a multifunction probe system that safely characterizes and monitors conditions within or below suspected contaminated sites.

Change Detection System • 2003

Research Team: Greg Lancaster, James Jones, Gordon Lassahn

Description: Change Detection System is a new imaging system that has achieved unparalleled ability to bypass hurdles that can complicate comparisons of similar images. While computers can scrutinize every pixel of an image, they are often bogged down by trivial differences in camera angles or lighting. Whether they are photos of forged documents or surveillance images of container locks and seals, Change Detection System can spot subtle discrepancies that are often impossible to spot by comparing side-by-side pictures.

Micro Laser Ultrasonic Bond Detection System • 2003

Research Team: Vance Deason, John A. Johnson, Ken Telschow

Joint entry: Simpex Technologies

Description: The Micro Laser Ultrasonic Bond Detection System is a high-speed, noncontact, nondestructive method to determine the bond integrity of materials at the micro level. The technology uses two tightly focused light beams to test the integrity of bonds within nanoscale spaces of less than 0.0005 inches.

Stronger, finer grained steel • 2002

Details unavailable for this award.

Super Hard Steel • 2001

Researcher: Daniel James Branagan

Description: Super Hard Steel forms a tough, low cost, wear- and corrosion-resistant coating that outperforms traditional high-performance coatings. It offers a wealth of possibilities for new industrial applications. Super Hard Steel can be sprayed on to a wide variety of metal surfaces using conventionally available thermal spray technologies, and surpasses the existing commercial coatings in wear, corrosion and impact resistance.

Real-Time Neutron Gamma Dosimeter • 2000

Research Team: Rahmat Aryaeinejad, Tyler Gomm

Description: In 1998, researchers at Idaho National Engineering and Environmental Laboratory began investigating the application of {sup 6}Li and {sup 7}Li isotopes to measure neutron and gamma radiation. Various size pairs of {sup 6}Li- and {sup 7}Li-based detectors were exposed to mixed neutron and gamma radiation. Experiments demonstrated that these detectors could be used to measure low-level neutron radiation in the presence of high-level gamma radiation.

Notes

Abbreviations

IHS	Idaho Historical Society
BSU	Boise State University Library Special Collections
HREX	Human Radiation Experiments, Internet site: http://tis.eh.doe.gov/ohre/

Chapter One

Epigraph: Susan M. Stacy, *Conversations, A Companion Book to Idaho Public Television's Proceeding On Through a Beautiful Country* (Boise: Idaho Public Television, 1990), 47.

1. Mike Atwood, interview with author, January 22, 1999, recounted his story as retold in this chapter.
2. "Fourteen Stockmen Testify at AEC Land Hearing," *Post-Register*, May 3, 1950, 2.
3. See Dr. Bill Hackett, et al, *Geohydrologic Story of the Eastern Snake River Plain and the Idaho National Engineering Laboratory* (Idaho Falls: Idaho Operations Office, 1986), 11.
4. (Lava tubes) Hackett, *Snake River Plain*, 11; (date) personal communication from Dr. Richard P. Smith to Julie Braun, INEEL, March 9, 1999. Lava flows at Craters of the Moon National Monument west of the INEEL may be only 2,000 years old.
5. Mike Atwood, January 22, 1999.
6. E.S. Lohse, "Aviator's Cave," *Idaho Archeologist* 12 (Fall 1989): 23.
7. Susanne J. Miller, *Idaho National Engineering Laboratory Management Plan for Cultural Resources (Final Draft)* (Idaho Falls: Lockheed Idaho Technologies Company Report DOE/ID-10361, Revision 1, 1995), 2-17.
8. Lohse, "Aviator's Cave," 23-28.
9. Miller, *Cultural Resources Plan*, pp. 2-18 to 2-21.
10. (Homesteading) Miller, *Cultural Resources Plan*, pp. 2-21 to 2-22; (quotation) Hugh Lovin, "Footnote to History: `The Reservoir Would Not Hold Water,'" *Idaho Yesterdays* (Spring 1980): 14.
11. (Traditional routes) to Clayton Marler from Diana Yupe, Tribal Cultural Resources Coordinator, Shoshone-Bannock Tribes, June 21, 1999, copy at Cultural Resources Office, INEEL.

Chapter Two

Epigraph: Kay Lambson, interview with author, February 9, 1999.

1. Wyle Laboratories, *Interim Ordnance Cleanup Program Record Search Report*, hereafter, *Scientech Report* (Norco, California: Scientific Services and Systems Group, 1993), Reference 2, "History of the Naval Ordnance Plant, Pocatello, Idaho," p. 1. This report reprints documents found in Naval Historical Center and other archives. See also Arrowrock Group, *The National Environmental and Engineering Laboratory: A Historical Context and Assessment*, (hereafter *Context Report*) INEEL/EXT-97-01021, Revision 2 (Idaho Falls: INEEL, 1997), 29-30; and United States, *Building the Navy's Bases in World War II: History of the Bureau of Yards and Docks and the Civil Engineer Corps, 1940-1946*, Vol. 1 (Washington D.C.: Government Printing Office, 1947), 1-13.
2. *Context Report*, 29-30.
3. *Context Report*, 30.
4. *Scientech Report*, Reference 2, pp. 4-5.
5. *Context Report*, 30.
6. *Context Report*, 31. The letters on the concrete were still visible in 1999.
7. Margaret and Orville Larsen, interview with author, March 19, 1999; *Scientech Report*, p. 3-2 (road names).
8. Kay Lambson, Gloria Lambson, interviews with author, February 9, 1999; and *Scientech Report* Reference 1, "Register of Pertinent Information," p. 2.
9. *Scientech Report*, Reference 2, p. 22; Reference 85, p. 135; and map of Naval Proving Ground, p. 2-8. See also 1951 INEEL photo no. 02974; map U.S. Naval Proving Ground.
10. Stan Coloff, "The High and Dry Navy: World War II," *Philtron* (October 1965): 3, reprinted as "WWII: The Arco Naval Proving Ground" in *INEL News* (May 1989): 18; *Scientech Report*, p. 3-2 (road names), Reference 2, p. 5 (Scoville). Extant buildings from the Naval Proving Ground era in 1999 included the commanding officer's house (CFA-607), the Marine barracks (CFA-606), the pumphouse (CFA-642), a brick-veneer cottage (CFA-613), and a wood frame cottage (CFA-603). Three of the magazines were still in use: CFA-635 and -637 stored hazardous materials; and CFA-638 was used as a Dosimetry Calculation Laboratory.
11. Coloff, 3.
12. Gloria Lambson, February 9, 1999.
13. Gloria Lambson, February 9, 1999; *Scientech Report*, Reference 1, p. 6 (buoy repair).
14. Kay Lambson, Gloria Lambson, February 9, 1999.
15. *Scientech Report*, p. 2-6, 2-9, 2-10, 6-1.
16. One designated area was about five miles northwest of the INEEL's Radioactive Waste Management Complex; the other centered on what is today's U.S. Highway 20 between East Butte and the site of EBR-II. See *Scientech Report*, Reference 96, p. 2-74, 6-7.
17. (Quote, air-gap) to Captain M.A. Sawyer from Captain Walter E. Brown, August 11, 1944, in *Scientech Report*, p. 2-23 to 2-25.
18. *Scientech Report*, p. 2-22, 2-29, 2-35 to 2-38.

19. *Scientech Report*, p. 6-7, References 76-80, 82.
20. *Scientech Report*, p. 2-31.
21. *Scientech Report*, Reference 92.
22. *Scientech Report*, Reference 67, p. 7; Reference 88.
23. Depleted uranium was a byproduct of uranium enrichment plants at Oak Ridge, Tennessee. It contained less than the natural amount of the isotope of uranium-235. The material has several uses. In breeder reactors, it can be bred into Plutonium-239 and then fissioned. It is used in armor-piercing shells, in tank armor, and for counterbalances on aircraft control surfaces. For Elsie, Marsh see *Scientech Report*, p. 2-72.

Chapter Three

1. Edward R. Landa and Terry B. Councell, "Leaching of Uranium from Glass and Ceramic Foodware and Decorative Items," *Health Physics* 63 (No. 3, September 1992): 343.
2. Raymond W. Taylor and Samuel W. Taylor, *Uranium Fever; or No Talk Under $1 Million* (New York: Macmillan, 1970), 79.
3. In some reactors, such as the fast-fissioning EBR-II, some U-238 atoms will fission.
4. Norman Polmar and Thomas B. Allen, *Rickover, Controversy and Genius, A Biography* (New York: Simon and Schuster, 1982), 118-120. Enrico Fermi observed uranium fission in a 1934 experiment. He thought the fission products were new elements and did not recognize them as krypton and barium. Four years later, Austrian physicist Lise Meitner realized that the uranium atom had actually split apart.
5. William Benton, *The Annals of America*, Volume 15 (Chicago: The Encyclopedia Britannica, Inc., 1968), 601-602.
6. Rhodes, *The Making of the Atomic Bomb* (New York: Simon and Schuster, 1986), 427; Stephane Groueff, *Manhattan Project: The Untold Story of the Making of the Atomic Bomb* (New York: Little, Brown, and Co., Bantam, 1967), 55-56; Taylor, *Uranium Fever*, 81; Polmar and Allen, *Rickover*, 120. The first two of these sources and Richard G. Hewlett and Oscar E. Anderson, Jr., *The New World, 1939-1946* (Philadelphia: Pennsylvania State University Press, 1962) are histories of the Manhattan Project.
7. Rhodes, *Atomic Bomb*, 711, 740. Estimates on TNT yield equivalent differ. Rhodes' source was the Committee for the Compilaton of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, p. 21, in *Hiroshima and Nagasaki* (Basic Books, 1977, 1981).
8. Jack M. Holl, *Argonne National Laboratory, 1946-1996* (Urbana: University of Illinois Press, 1997), 40.
9. See Holl, *Argonne*, 62.
10. (Groves approval) Holl, *Argonne*, 40. For an account of the early deliberations of the AEC, see Richard G. Hewlett and Francis Duncan, *Atomic Shield, 1947/1952* (University Park: Pennsylvania State University Press, 1969).
11. Atomic Energy Act of 1954 (Public Law 79-585).
12. For a history of early corporate interest in nuclear energy, see Mark Hertsgaard, *Nuclear, Inc., The Men and Money Behind Nuclear Energy* (New York: Pantheon Books, 1983).
13. See Hewlett, *Atomic Shield*; Herbert York, *The Advisors, Oppenheimer, Teller, and the Superbomb* (San Francisco: W.H. Freeman and Company, 1976); and Herbert York, *Race to Oblivion* (New York: Simon and Schuster, 1970).
14. David Lilienthal, *Atomic Energy, A New Start* (New York: Harper and Row, 1980), 1.
15. John Tierney, "Take the A-Plane: The $1 Billion Nuclear Bird that Never Flew," *Science* 82 (Jan/Feb 1982): 47; Henry W. Lambright, *Shooting Down the Nuclear Airplane* (Syracuse, NY: Inter-University Case Program No. 104, 1967), 3; Susan M. Stacy, *Idaho National Engineering Laboratory: Test Area North, Hangar 629, Historic American Engineering Record ID-32-A* (Idaho Falls: Lockheed Martin Idaho Corporation, 1994), 10.
16. Susan M. Stacy, *Idaho National Engineering Laboratory, Army Reactor Experimental Area, Historical American Engineering Record ID-33-D* (Idaho Falls: Lockheed Martin Idaho Corporation, 1998), 5.
17. Hewlett, *Atomic Shield*, 196, 202-204. In 1948 the AEC research laboratories were Argonne, Chicago; Oak Ridge, Tennessee; Brookhaven, New York; and the new Knolles laboratory in Schenectady. The Los Alamos Science Laboratory in New Mexico focused on weapons research. The Radiation Laboratory at Berkeley, California, did not carry the title of "national laboratory." Other AEC production centers made plutonium and other weapons materials.
18. Pike quoted by Kevin Richert in "Original AEC Site Spawned Eastern Idaho's `Gold Rush,'" (Idaho Falls) *Post-Register*, May 15, 1994, H-20; (Hafstad) Hewlett, *Atomic Shield*, 210.
19. Hewlett, *Atomic Shield*, 196, 206.
20. Hewlett, *Atomic Shield*, 210.
21. Smith, Hinchman & Grylls, *Survey on Fort Peck, Montana, and Pocatello, Idaho, Sites* (Detroit: Smith, Hinchman & Grylls, March 1949), 1, 41 (fog).
22. Hewlett, *Atomic Shield*, 218.
23. Robert Smylie, interview with author, July 8, 1998, Boise; "Idaho Termed Top Favorite for Plant Site," (Idaho Falls) *Post-Register*, March 16, 1949, 1.
24. "Arco Area to Get West Atomic Plant," *Post-Register*, March 22, 1949, 1. See also letter to Mike Mansfield from David Lilienthal, March 29, 1949, IHS AR 2/22, Papers of Governor C.A. Robins, Box 1, Series 1, File: Arco Atomic Energy Plant/part 1; (hearings) Hewlett, *Atomic Shield*, 211.
25. "Station Manager Named," *Post-Register*, April 4, 1949, 1.

Chapter Four

1. "Who cares for letterheads?" *Arco Advertiser*, April 29, 1949, 1; "Arco Chief Wonders if Neighbor is Lacking in Brotherly Love," *Idaho Daily Statesman*, April 29, 1949; "Idaho Falls Pulls Back on Publicity as Atomic Capital," *Post-Register*, April 26, 1949.
2. "Station Manager Named," *Post-Register*, April 4, 1949, 1.
3. Because of the Navy's resistance to giving up the proving ground, the AEC discussed other locations for the MTR, EBR, and Navy reactors as late as mid-July; Hewlett, *Atomic Shield*, 218.
4. Jacqui Johnston Batie, interviews with author on October 14, 1998, and March 14, 1999; Bill Ginkel, interviews with author on October 13, 1998, and February 3, 1999; and undated news clipping supplied by Jacqui Batie, "Leonard E. Johnston, AEC Chief Here Takes New Job, Reports Say."

See Groueff, *Manhattan Project*, 381, for gaseous diffusion plant.

5. "Details Revealed for Plan to Build West Atomic Field Station," *Post-Register*, March 8, 1949, 1; "Arco Site Named for Atomic Plant," *Arco Advertiser*, March 25, 1949, 1; and "Leonard E. Johnston, AEC Chief Here Takes New Job, Reports Say," (see note no. 4 above).
6. "A Village Wakes Up," *Life* (May 9, 1949): 98-101; "Arco Site Named for Atomic Plant," *Arco Advertiser*, March 25, 1949, 1. See also Vardis Fisher, ed. *The Idaho Encyclopedia* (Caldwell, Idaho: Caxton Printers, 1938) entry for Arco.
7. "Village Alert to Problems" and "New Business Firms Move In," *Arco Advertiser*, 1; to Chet Moulton from Governor Robins, April 14, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant, part 1; and Federal Housing Administration, "A Preliminary Plan and Program for Arco, Idaho," 1949, in AR2/22, File: Arco Atomic Energy Plant, part 3.
8. (Quote) to Robins from Cy Davis, Idaho Falls Chamber of Commerce, March 28, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant, part 1.
9. (Quote) Robins from Cy Davis, March 28, 1949, cited in note above; to Robins from Joe Call, Idaho Falls Chamber of Commerce, March 28, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant, part 1. The towns were Island Park, Warm River, Ashton, St. Anthony, Rexburg, and Arco.
10. "Mayors Form Committee to Cooperate with Atomic Project," *Arco Advertiser*, April 8, 1949, 1.
11. Telegram to Robins from John Sanborn, April 12, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant, part 1.
12. "Who Cares for Letterheads?" *Arco Advertiser*, April 29, 1949, 1.
13. Robb Brady, interview with author, August 27, 1998.
14. Robb Brady, August 27, 1998.
15. "Blackfoot eyes Possibility of Atomic Future," *Post-Register*, April 3, 1949, 5. See also Ben Plastino, *Coming of Age: Idaho Falls and the Idaho National Engineering Laboratory* (Idaho Falls: Margaret A. Plastino, 1998), 7-8.
16. Marvin Walker, interview with author, March 15, 1999. Walker, Johnston's driver and document courier, heard Johnston remark several times that the NOP would have been an ideal set-up for the AEC headquarters, except for the lack of commitment from Pocatello. See also Plastino, *Coming of Age*, 17.
17. AEC news release, May 18, 1949, IHS AR2/22 Box 1, Series 1, File: Atomic Energy Plant, part 1.
18. David Lilienthal, *The Atomic Energy Years, 1945-1950, The Journals of David E. Lilienthal, Volume II* (New York: Harper and Row, 1964), 513-514.
19. "Purpose of Arco Site Explained," *Arco Advertiser*, August 5, 1949, 1.
20. Jacqui Batie, Marvin Walker, and John Ray, interviews with author, March 14 and 15, 1999.
21. "Problems Mount as City Squares Off to Big Job," *Post-Register*, May 22, 1949, 4.
22. R.L. Polk and Co., *Polk's Idaho Falls City Directory* (Omaha: R.L. Polk, 1952), 13.

Chapter Five

Epigraph: Bill Johnston to C.A. Robins, July 13, 1949. See note no. 1 below.

1. "AEC Offices in New Location," *Arco Advertiser*, July 22, 1949, 1; letter to C.A. Robins from Bill (L.E.) Johnston, July 13, 1949, IHS AR 2/22, Box 1, Series 1, File: Arco Atomic Energy Plant, part 2; (bubble rumor) Hewlett, *Atomic Shield*, 219.
2. Hewlett, *Atomic Shield*, 218-219.
3. Holl, *Argonne*, 87.
4. "Gradual Expansion of Arco Plant Planned by AEC," *Arco Advertiser*, September 30, 1949, 1.
5. Marvin Walker, interview with author, March 15, 1999; Hewlett, *Atomic Shield*, 495; William Ginkel, interview with author, February 3, 1999.
6. Jack M. Holl, "The National Reactor Testing Station: The Atomic Energy Commission in Idaho, 1949-1962," *Pacific Northwest Quarterly* (Volume 85, No. 1, January 1994): 18.
7. John Horan, interview with author, July 29, 1997.
8. "Exploratory Surveys Start at Atomic Site," *Arco Advertiser*, July 1, 1949, 1.
9. John Horan, interview with author, July 29, 1997.
10. John Horan, July 29, 1997.
11. Smith, Hinchman & Grylls, *Survey*, 54, 70, 80. Harold T. Stearns and J. Stewart Williams, consulting geologists, were subcontracted by Smith, Hinchman & Grylls to summarize their understanding of the aquifer. See "Geological and Hydrologic Features of the Pocatello Site, Idaho," in the *Survey*.
12. "Gradual Expansion of Arco Plant Planned by AEC," *Arco Advertiser*, September 30, 1949, 1; Hewlett, *Atomic Shield*, 211; "Testing Proves Ample Supply," *Arco Advertiser*, August 19, 1949, 1.
13. Marvin Walker, March 15, 1999.
14. Hewlett, *Atomic Shield*, 218-220. For a history of the hydrogen bomb, see Richard Rhodes, *Dark Sun, The Making of the Hydrogen Bomb* (New York: Simon and Schuster, 1995).
15. "Gradual Expansion of Arco Plant Planned by AEC," *Arco Advertiser*, September 30, 1949, 1.
16. Rick Bolton, "USGS technician Rodger Jensen reflects on 30 years in the sagebrush" *INEL News* (May 19, 1992); "A Village Wakes Up," *Life* (May 9, 1949): 101; (Johnston quote) "Purpose of Arco Site Explained," *Arco Advertiser*, August 5, 1949, 1.
17. "AEC Given Custody of Naval Proving Ground," *Arco Advertiser*, December 9, 1949, 1.
18. Hewlett, *Atomic Shield*, 495; "Fresh Water Test Well Contract Bid" and "Batch Plant Equipment Moved to Atomic Site," *Arco Advertiser*, October 7, 1949, 1.
19. Deslonde de Boisblanc, interview with author, January 16, 1999.
20. Marvin Walker, March 15, 1999.
21. To Robins from Johnston, August 24, 1949, and September 9, 1949; to Johnston from Robins, September 2, 1949; all in IHS AR2/22, Box 1, Series 1, Arco AE Plant—1949, part 1.
22. To James Reid, Idaho Bureau of Highways, from J. Bion Philipson, November 22, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant 1949, part 1.
23. (Robins quotation) to Johnston from Robins, November 30, 1949, IHS AR2/22, Box 1,

Series 1, File: Arco Atomic Energy Plant, 1949, part 1; also see letter to J. Bion Philipson from James Reid, November 30, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant 1949, part 1.

24. "Dworshak and Welker in Blackfoot Today, Discussion on Highway 20 Construction; Irate as Johnson Bypasses the Meeting," *Blackfoot Daily Bulletin*, September 12, 1952.
25. "Groups Ready Dedication of Idaho Falls-Arco Highway," *Post-Register*, September 21, 1951; "Deal Dedicates New Arco, Idaho Falls Highway," *Post-Register*, October 8, 1951.
26. (Quotation) Lou Haller, "Johnston Explains AEC Position on the Road, Rich Sets 1954-'55 As Completion Date; Senator Dworshak Has Asked Federal Aid," *Blackfoot Daily Bulletin*, September 23, 1952; "Dworshak and Welker in Blackfoot Today; Discussion on Highway 20 Construction; Irate as Johnston By-passes the Meeting," *Blackfoot Daily Bulletin*, September 12, 1952; Plastino, page 13.
27. "State Engineer Says Highway 26 Serving AEC from Blackfoot Should Be Given First Priority," *Blackfoot Daily Bulletin*, November 21, 1952; "Sen. Dworshak Reports AEC and Bureau of Public Roads Have Assured Construction Money Aid," *Post-Register*, December 22, 1952.
28. "Sen. Dworshak Reports AEC and Bureau of Public Roads Have Assured Construction Money Aid," *Post-Register*, December 22, 1952; "Crews Start Plotting AEC-Rexburg Road," *Salt Lake Tribune*, January 27, 1952.
29. (Bus fare) William Ginkel, interview with author, February 3, 1999.
30. To Alton B. Jones, State Superintendent of Schools, from George Green, Superintendent of Schools for Bannock County, April 26, 1949, IHS AR2/22, Box 1, Series 1, File: Arco Atomic Energy Plant, part 1. See also Holl, *The National Reactor Testing Station*; Robb Brady, interview with author, August 27, 1998.
31. "L.E. Johnston Explains Purpose and Development of Reactor Plant," *Arco Advertiser*, December 9, 1949, 1.

Chapter Six

Epigraph: The occasion for the song was an AEC announcement that Oak Ridge would not be involved further in reactor development, but that such work would be centralized at Argonne. See Hewlett, *Atomic Shield*, 126.

1. Kirby Whitham, interview with author, October 14, 1998. The test was conducted in the EBR-I reactor. An organic compound is one which contains carbon.
2. William Ginkel, interview with author, February 3, 1999.
3. Holl, *Argonne*, 68-69.
4. In reactor technology, neutrons with energies above 100,000 electron volts are called fast neutrons. EBR-I neutrons moved with two million electron volts of energy.
5. For a general overview of fast reactors see Alan M. Jacobs, et al, *Basic Principles of Nuclear Science and Reactors* (D. Van Nostrand Company: Princeton, 1960), 171-175.
6. "New Pump to Aid AEC At Idaho Falls Plants," *Salt Lake Tribune*, April 14, 1952. Engineers also installed more conventional pumps in each of the main cooling systems.
7. Hewlett, *Atomic Shield*, 496.
8. Kirby Whitham, October 14, 1998.
9. "Dr. Walter Zinn Recalls Early Days," *Idaho National Engineering Laboratory EBR-I Review*, 1. This undated reprint with no other publication data is a collection of stories about EBR-I printed some time after December 13, 1971, possibly by the INEL employee newspaper. Copy found in Bechtel Cultural Resources departmental files at INEEL. Hereafter, *EBR-I Review*.
10. John H. Buck and Carl F. Leyse, *Materials Testing Reactor Project Handbook*, Report No. TID-7001 (Lemont, Illinois: Argonne National Laboratory and Oak Ridge National Laboratory, 1951), 356. For a brief description of nuclear physics research at the MTR, see NRTS, *1965 Thumbnail Sketch*, 16-17. Beam experiments did extend outside the MTR building, but not to distances of a quarter of a mile.
11. Buck and Lehse, *MTR Handbook*, 29.
12. For general history of MTR development, see Buck and Lehse, *MTR Handbook*, 34-43.
13. Donald J. Hughes. *The Neutron Story* (Garden City, N.Y.: Doubleday Anchor Books, 1959), 41; Buck and Leyse, *MTR Handbook*, 29.
14. Buck and Lehse, *MTR Handbook*, 37; Hewlett, *Atomic Shield*, 126, 419.
15. Hewlett, *Atomic Shield*, 186-188.
16. (Groundbreaking) Buck and Lehse, *MTR Handbook*, 43; (siting) John Horan, July 29, 1997.
17. Hewlett, *Atomic Shield*, 496.
18. (Quotation in previous paragraph and extended quote) John W. Simpson, *Nuclear Power from Underseas to Outer Space* (La Grange Park, Illinois: American Nuclear Society, 1995), 22 and 26-27, respectively.
19. Simpson, *Nuclear Power*, 27; (MTR contribution to STR) *1965 Thumbnail Sketch*, 13.
20. Accounts of Rickover and the Nuclear Navy include Richard Hewlett and Francis Duncan, *Nuclear Navy 1946-1962* (Chicago: University of Chicago Press, 1974); Polmar and Allen, *op cit*.
21. (Rickover quote) Ronald Schiller, "Submarines in the Desert," *Colliers Magazine* (February 5, 1954): 90. Polmar and Allen, *Rickover*, 149. The original name of the Idaho reactor was Mark I; the *Nautilus* reactor, Mark II. Rickover referred to the development shortcut as "Mark I equals Mark II."
22. Simpson, *Nuclear Power*, 43.
23. (McGaraghan's Sea) Schiller, *Colliers*, 88; (backscatter) Dr. John Taylor, communication with author, August 6, 1999. Taylor was responsible for the backscatter research.
24. *The Bluejackets Manual*, 19th edition (Annapolis, Maryland: Naval Institute Press, 1973), 153.
25. Simpson, *Nuclear Power*, 27, 224-337.
26. Simpson, *Nuclear Power*, 50.

Chapter Seven

Epigraph: Marion Thomas, "Recollections and Reflections," *Idaho American Nuclear Society Newsletter* (June 1989), 5.

1. Deslonde R. de Boisblanc, *Idaho ANS Newsletter*, 5-6. This issue contained several tributes to Dr. Doan by former associates.
2. Fred McMillan, interview with author, February 2, 1999.

3. de Boisblanc, *ANS Newsletter*, June 1989.
4. (Architects) Fred McMillan, February 2, 1999; (welcome) see for example "Two Join Phillips Petroleum Staff," *Post-Register*, August 1, 1951, 3.
5. "Atom Pioneer Directs Phillips Project Here," *Post-Register*, August 19, 1951. See also Virginia Doan Fanger, *ANS Newsletter*, June 1989.
6. Stephane Groueff, *Manhattan Project*, 80.
7. de Boisblanc, *Idaho ANS Newsletter*, June 1989; Richard Austin Smith, "Phillips Petroleum—Youngest of the Giants," *Fortune* (August 1954): 72; and Phillips Petroleum Company, *Phillips, The First 66 Years* (Bartlesville, Oklahoma: Phillips Petroleum Company, 1983), 86, 125-140.
8. Warren Nyer, *Idaho ANS Newsletter*, June 1989, 7-9.
9. *Ibid*.
10. (Pappy) John Byrom, interview with author, August 25, 1999; de Boisblanc, Miles Leverett, Warren Nyer, *ANS Newsletter*, June 1989, 6-9.
11. *Phillips, The First 66 Years*, 86, 125-140.
12. The study is described by W. Singlevich, et al, *Natural Radioactive Materials in the Arco Reactor Test Site*, Report No. HW-21221 (cover title: *Ecological and Radiological Studies of the Arco Reactor Test Site* (Richland: General Electric Nucleonics Division, Hanford Works, 1951), 1-49. See also "AEC Sets Radioactivity Study at Idaho Site; College Gets Contract," *Post-Register*, June 19, 1950, 3.
13. John Horan, in an interview with author, indicated that Health and Safety Division personnel in particular made use of the report: Singlevich, et al, *Natural Radioactive Materials in the Arco Reactor Test Site*, Report No. HW-21221. See note 12 for full citation.
14. (Nevada test site) Hewlett, *Atomic Shield*, 535; (malfunctioning, 10 mr/hr on truck) Phillips Petroleum Company, *Survey of Fall-out of Radioactive Material in South and South-East Idaho Following the Las Vegas, Nevada Tests of October and November, 1951,* Report IDO 12000 HPO (Idaho Falls: Site Survey Section of the Health Physics Division, NRTS, 1952), 11, 8; (truck, rainstorm explanation) John Horan, "Draft of Interview" with John K. Harrop and Joseph J. Shonka in Idaho Falls, Summer 1994, 2.
15. See for example, "Press Release, May 18, 1961: Annual Summary of Environmental Monitoring Data for 1960," in records of Senator Henry Dworshak, IHS, Ms. 84, Box 122 B, File: AEC-Id-Press Releases.
16. "AEC to Employ Top Safeguards Here," *Post-Register*, May 11, 1950, 15.
17. Henry Peterson, interview with author, February 22, 1999; (NCRP standards) Elizabeth S. Rolph, *Nuclear Power and the Public Safety* (Lexington, Mass.: D.C. Heath and Co., 1979), 108; John Horan, interview with Baldwin and Bacchus, 1994. An exposure of 50 milirems per day was an allowable exposure, but alarms sounded at 80 percent of that value.
18. "AEC Sets Radioactivity Study at Idaho Site; College Gets Contract," *Post-Register*, June 19, 1950, 3; "Experts Test Weather Data," *Post-Register*, May 14, 1950, 14.
19. Idaho Department of Labor, *First Biennial Report of the Department of Labor, August 15, 1949—December 31, 1950*, 1.
20. To Governor Robins from W.L. Robison, March 22, 1950, IHS AR2/22, Box 1, File: Arco Atomic Energy Plant-1950, part II. See also "AEC to Organize Medical Program," *Post-Register*, June 21, 1950, 9.
21. (Accident rates) *First Biennial Report,* 25; (ceremony) Idaho Department of Labor, *Third Biennial Report of the Department of Labor, October 31, 1952 to October 1954*, 29.
22. "Committee to Advise AEC on Health in Area," *Arco Advertiser*, March 19, 1954, 3; "Idaho Board Approves AEC Health Safeguards, *Arco Advertiser*, March 26, 1954, 1; "State Committee Ends Meeting at AEC Plant," *Arco Advertiser*, July 22, 1955, 7.
23. (Hospitals) *Ninth Semiannual Report of the AEC*, January 1951, 31; (Idaho hospitals) Dr. Lawrence Knight, interview with author, April 20, 1999; "Mountain States Tumor Institute," supplement in *Idaho Statesman*, May 11, 1997, 2. St. Lukes Hospital in Boise organized an isotope laboratory in 1957 and began cobalt cancer therapy in 1960. (Shoes) Department of Health, Radiation Health Section, "Program for the Regulation and Control of the Use of Radiation in the State of Idaho, 1968," 5, IHS, Samuelson Papers, Box 50, File: Governor Samuelson Nuclear—Misc.
24. "Minutes of the Idaho State Board of Health, April 21-22, 1958; August 4-5, 1958," Minute Book at Idaho State Department of Health and Welfare, Director's Office, Boise, Idaho, p. 58 and 63, respectively. Among early industrial users of radioactive materials was the agricultural industry, which used tracers to help identify the uptake of pesticides or fertilizers in plants.
25. "Program for Regulation and Control... 1968," 5.
26. See, for example, letter to Smylie from Lyall Johnson, Acting Director of the Division of Materials Licensing, AEC-DC, May 13, 1964, in IHS AR2/23, Box 17, File: Atomic Energy.
27. To Governor Smylie from Terrell Carver, August 9, 1963, IHS, Smylie Papers, Box 20, File: Health Department, 1963. See also Minutes of the Board of Health, July 30-31, 1964, p. 241. The IDO/Phillips representatives were C. Wayne Bills, J. Weaver McCaslin, and Tabb O'Brien; "Minutes of the Governor's Committee on the Use of Atomic Energy and Radiation Hazards, February 19, 1964," held at the office of the Department of Labor, Boise. In IHS, Smylie Papers, Box 21, File: Labor Department 1962-1964.
28. To Clinton P. Anderson from T.O. Carver, February 18, 1959; IHS, Mss 84, Box 104, File: Legislative AEC Misc. 1959.
29. "Statement by the Honorable Robert E. Smylie, Governor of the State of Idaho, to the Natural Resources Subcommittee of the Committee on Government Operations," presented at a hearing held November 22, 1963, Seattle, Washington, IHS, AR2/23, Box 25, File: Len Jordan 1962-64. For a review of Idaho/AEC relations regarding housing, grazing, law enforcement, and other matters, see Jack M. Holl, "The NRTS: The AEC in Idaho," 85 *Pacific Northwest Quarterly* (January 1994): 15-24.

Chapter Eight

Epigraph: Idaho Department of Labor, *2nd Biennial Report*, 21. Thanks to Warren Nyer, from whom I first heard the term "reactor zoo."

1. Hewlett, *Atomic Shield*, 497. See also, Holl, *Argonne National Laboratory, 1946-1996*, 99. Holl reports the shortage as 12.5

kilograms of uranium-235, this being the amount over Zinn's original estimate of 40 kilograms exclusive of the fuel in the extra fuel rods.

2. Kirby Whitham, communication to author, July 9, 1999. According to Whitham, the re-manufactured rods were .010 inches larger in diameter.
3. Hewlett, *Atomic Shield*, 497-98. The significance of the names on the wall is uncertain. According to Richard Lindsay of Argonne-West, not all of the crew members were present during the chalk ceremony; a few added their names later but others did not. The sensibilities of the era were such that the women who ran the EBR office were not included. In 1995 the names of the women were placed on a plaque and installed in the EBR-I building, but the names of missing men have not been so identified. See IDO News Release, March 20, 1995, and "Better late than never for EBR-I women," *Post-Register*, March 24, 1995.
4. "Reactor Staff Weary, Happy" and "Materials Testing Reactor Achieves Operation Stage Here," *Post-Register*, April 4, 1952, 1; and Fred McMillan, interview with author, February 2, 1999.
5. (Squirrels) Jack Clark, interview with author, July 16, 1998; (Doan) John Byrom, August 25, 1998. "Scram" was a slang word meaning, "let's get out of here." Its use as a term for emergency reactor shutdowns originated with CP-1, the first reactor. For safety backup, a man was stationed near a rope restraining a control rod. Should other controls fail, he was to cut the rope, letting the rod fall into place. Someone devised an acronym "Safety Control Rod Ax Man." Another acronym, according to Polmar in *Rickover*, p. 151, was "Super-Critical Reactor Ax Man."
6. John Byrom, August 25, 1998; Phillips Petroleum Company, *The Materials Testing Reactor, A Light Water Moderated Reactor* (Geneva, Switzerland: International Conference on Peaceful Uses of Atomic Energy, 1955) "Research Reactors," p. 352. See also Buck and Leyse, *MTR Handbook*, 352.
7. Buck and Leyse, *MTR Handbook*, 29-30.
8. John Byrom, interviews with author, August 25, 1998, and March 26, 1999. See also E. Fast, J.P. Byrom, and J.W. McCaslin, *A Survey of the Materials Testing Reactor Shield*, Report No. (IDO-16073) (Idaho Falls: Phillips Petroleum Co., n.d.) and Blaw Knox Construction Company, *Barytes Aggregate Concrete Applied to Reactor Shielding*, Report No. IDO-24003 (Idaho Falls: Blaw Knox Chemical Plant Division, 1952).
9. John Byrom, personal communication to author, October 29, 1998.
10. Fred McMillan, interview with author, February 2, 1999.
11. John Taylor, personal communication to author, August 6, 1999.
12. Fred McMillan, February 2, 1999.
13. Simpson, *Nuclear Power*, 47.
14. Simpson, *Nuclear Power*, 53.
15. Schiller, *Colliers*, 91.
16. Polmar and Allen, *Rickover*, 151-152.
17. Polmar and Allen, *Rickover*, 152.
18. Simpson, *Nuclear Power*, 55-56.
19. Polmar and Allen, *Rickover*, 153.
20. The original telegram is located in a Naval Reactors Facility historical scrapbook, 1958.
21. Polmar and Allen, *Rickover*, 615.
22. By the time the Navy laid the keel for *USS Enterprise* on February 4, 1958, it had launched or laid the keel for the submarines *Nautilus*, *Skate*, *Seawolf*, *Swordfish*, *Sargo*, *Seadragon*, and *Triton*; and the cruiser *USS Long Beach*.

Chapter Nine

1. "Industrial Radioactive Waste Disposal," *Hearings before the Special Subcommittee on Radiation of the JCAE* 86th Cong, 1st session, Volume 1, January 28, 29, and 30; February 2 and 3, 1959 (Wash, D.C.: GPO, 1959). Hereafter, *Radioactive Waste Hearings*.
2. (Quotation) Rafe Gibbs, "The World's Hottest Garbage," *Popular Mechanics* (April 1955): 124-125; (Argonne) Holl, *Argonne*, 57-58.
3. Holl, *Argonne*, 73.
4. B.C. Anderson, et al., *A History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory* (Idaho Falls: IDO Nuclear Fuel Cycle Division, 1979), 1. Hereafter, *History of the RWMC*.
5. Anderson, *History of the RWMC*, 2; (precipitation) 1971 *Thumbnail Sketch*, 3.
6. Anderson, *History of the RWMC*, p. 4, 16.
7. Henry Peterson, interview with author, February 3, 1999.
8. Henry Peterson, February 3, 1999; (diapers) Ronald Schiller, *Colliers*, 90; (sanitary pads) Beverly Cook, interview with author, September 7, 1999.
9. Edgar Juell, *A Short History of the Expended Core Facility, 1953 to June 1990* (Idaho Falls: Naval Reactors Facility Expended Core Facility, no date), 1.
10. (General procedures, liquids) Anderson, *History of the RWMC*, 16; (irradiated metal parts) Doan remarks in *Radioactive Waste Hearing*, 601.
11. (Native grasses) Byrom, personal communication; (practices) Anderson, *History of the RWMC*, 16. In current practice, cardboard boxes are no longer used. Waste is packaged in wooden boxes or metal drums, each lined with plastic.
12. For Rocky Flats history, see www.indra.com/rfcab/ FAQ.html#4.
13. Anderson, *History of the RWMC*, 19. The Rocky Flats area was later expanded to eleven square miles. Source: www.cdphe.state.co.us, April 26, 1999.
14. (Nevada/Idaho) Anderson, *History of the RWMC*, 19.
15. John Horan, interview with author, January 15, 1999.
16. John Horan, January 15, 1999. See also Anderson, *History of the RWMC*, 21.
17. *Radioactive Waste Hearing*, 582-583.
18. Anderson, *History of the RWMC*, 21-22. Also, see photo 58-1450. See "Alpha Decay" in John F. Hogerton, *The Atomic Energy Deskbook* (New York: Reinhold Publishing Corp., 1963), 21. Plutonium is highly ionizing and presents a hazard to human health when it is inhaled or ingested.
19. Clyde Hammond, interview with author, October 15, 1998. According to D.H. Card, *Waste Management Program History of Buried Transuranic Waste at INEL*, (Idaho Falls: EG&G Report No. WMP 77-3, 1977), 9, Gulf Atomic sent 190 drums and 22 boxes of waste to the NRTS in 1962. Some drums were centered in boxes, and the boxes filled with concrete for shielding. These weighed between 12,000 to 14,000 pounds each.

20. Cass Peterson, "Rocky Flats: Risks Amid a Metropolis," *Washington Post*, December 12, 1988, 1.
21. Anderson, *History of the RWMC*, 22.
22. Clyde Hammond, October 15, 1998.
23. (Backfill) John Commander, personal communication to author, June 29, 1999; (strike) Anderson, *History of the RWMC*, 31; (efficiency) George Wehmann, interview with author, September 29, 1999.
24. Anderson, *History of the RWMC*, 28. According to EG&G, *Waste Management Program, History of Buried Transuranic Waste at INEL*, (Idaho Falls: EG&G Report No. WMP 77-3, 1977), p. 8, waste arriving at this time included contaminated materials from other governmental experimental sites around the nation.
25. (Upper limits, flooding, guidelines, Interim Burial Ground) Anderson, *History of the RWMC*, 19, 33, 30, 27.
26. Anderson, *History of the RWMC*, 30; (quotation) *Radioactive Waste Hearing*, 584.
27. Anderson, *History of the RWMC*, 35.
28. Formal definitions of "high-level," "low-level," TRU, spent fuel, and other categories of radioactive waste have changed over time and have become more complex; recent definitions are found in the Energy Policy Act of 1992, Title 10 of the Code of Federal Regulations (CFR), Part 60 and in DOE Order 5820.2A. At the INEEL, high-level waste refers to the solid and liquid wastes resulting from chemical separations done at the Idaho Chemical Processing Plant. TRU waste contains alpha-emitting transuranic elements (like plutonium-contaminated waste from Rocky Flats) with half-lives of 20 years or more and concentrated at 100 nanocuries per gram of waste or more. Low-level waste, typically disposed or stored at the Burial Ground, in general contains lower concentrations of radionuclides per gram of waste than high-level and TRU waste. See DOE, *Linking Legacies* Report No. DOE/EM-0319 (Washington, D.C.: DOE Office of Environmental Management, 1997), pp. 31-70.
29. (Handbook) *Radioactive Waste Hearing*, 581. For the general AEC philosophy on concentrating and reducing volumes of waste, see remarks by Dr. Abel Wolman in the hearing on p. 8-10.
30. *Radioactive Waste Hearing*, 581, 589.
31. *Radioactive Waste Hearing*, 581.
32. Whether to measure the concentration of a contaminant at the point of discharge or at the point of its use downstream later became the subject of regulatory definition.
33. Bruce Schmalz, interview with author, February 1, 1999. See also *Radioactive Waste Hearing*, 589.
34. John Horan, "Draft of Interview, Mr. John Horan" with John K. Harrop and Joseph J. Shonka, Summer 1994, p. 4.
35. *Radioactive Waste Hearing*, 602.
36. John Byrom, personal communication to author.
37. Arrowrock Group, *Context Plan*, 146.
38. (Pellets) Leroy Lewis personal communication to author.
39. See INEEL photos 56-3201, -3203, -3205, -3206, -3207, and -3208.
40. INEL, *Idaho National Engineering Laboratory Historical Dose Evaluation*, Volume 1, Report No. DOE/ID-12119 (Idaho Falls: IDO, 1991), pp. iii, v-vii, 6-8. Later DOE expenditures on the removal of waste from below ground were justified on the basis that these pathways should not ever find a human population at any time in the long-range future.

Chapter Ten

1. Polmar and Allen, *Rickover*, 167.
2. Bettis Plant, *Expended Core Facility, Maintenance and Operations Guide* (Pittsburgh: Westinghouse, 1958), 3. Hereafter, *ECF Guide*.
3. *ECF Guide*, v. The ECF was designed by the AEC's Bettis Atomic Power Laboratory, managed by Westinghouse. Arthur G. McKee & Co. was architect/engineer; and Paul Hardeman, Inc., general contractor.
4. *ECF Guide*, 14. Later equipment allowed for the unloading of a cask without having to plunge the cask into the water.
5. Edgar L. Juell, *A Short History of the Expended Core Facility*, (Idaho Falls: Naval Reactors Facility, 1990), 9-11 (excerpt p. 10).
6. Juell, *A Short History of ECF*, 12.
7. (Three cores) *ECF Guide*, 15; (MTR irradiated fuel) Juell, *A Short History of ECF*, 9.
8. Juell, *A Short History of ECF*, 13.
9. (Early training) "Crews Train in Idaho for A-Submarine," *Idaho State Journal*, February 22, 1953. Thanks to Kenhi Drewes and Hal Paige, interviews with author, February 4, 1999, for discussions of training program.
10. Polmar and Allen, *Rickover*, 297-301.
11. (Rickover quote) Polmar and Allen, *Rickover*, 302; (cross-training) Kenhi Drewes and Hal Paige, February 4, 1999.
12. Ronald Schiller, "Submarines in the Desert," *Colliers* (February 5, 1954): 91.
13. Kenhi Drewes, Hal Paige, February 4, 1999; (cooling pond) Mary Freund, interview with author, February 2, 1999.
14. On aircraft carriers, cargo such as tanks of lubricating oil could be located to offer shielding opportunities around shipboard reactors. *USS Enterprise* was launched on September 24, 1960.
15. Clay Condit, interview with author, August 25, 1999.
16. To Governor from Henry Dworshak, April 8, 1961, IHS Mss 84, Box 122 B, File: AEC-Idaho Plant; to Robb Brady from Henry Dworshak, April 8, 1961, IHS, Mss 84, Box 122 B, File: AEC—Idaho Plant.
17. (Criticality date) *Naval Reactors Facility* pamphlet, no date, no page numbers. For more on the U.S. Navy's quest for silent submarines and the compromises made among silence, depth, and speed, see Tyler, *Running Critical, The Silent War, Rickover, and General Dynamics* (New York: Harper and Row, 1986). See Tom Clancy, *The Hunt for Red October* (Annapolis, Md.: Naval Institute Press, 1984) for a fictionalized account of the competition between the two superpowers; and "Submarines, Secrets, and Spies," a *NOVA* television program produced by the Documentary Guild for WGBH/Boston with Sveriges Television, copyright 1999.
18. Elizabeth S. Rolph, *Nuclear Power and the Public Safety*, 24-26.
19. (Sidebar) U.S. DOE and U.S. Department of Defense, *The United States Naval Propulsion Program* (Washington, D.C.: GPO), 19.
20. Rolph, *Nuclear Power and the Public Safety*, 26.
21. Clay Condit, August 25, 1999.

22. (Steno) Mary Freund; (preparations) Henry Peterson, February 3, 1999; (legend) Hal Paige, February 4, 1999.

Chapter Eleven

1. Don Reid, in undated transcript of taped interview named "Don Reid's Early CPP History, Cassette Tape # 1," p. 9-10. A second tape was named "Cassette Tape # 2." No copies of the tape were found, nor the name of the interviewer. Transcript supplied to author by Jeff Bryant of INTEC (Chem Plant).
2. Don Reid, Cassette Tape # 1, 14, 16.
3. (AEC plans) Don Reid, Cassette Tape # 1, 14-17. In a bomb detonation, tritium undergoes a fusion reaction with deuterium, producing a generous supply of neutrons which in turn promote the fissioning of plutonium atoms.
4. TWX from C. Vanden Bulck, Oak Ridge National Laboratory, to R. Cook, USAEC, Washington, D.C., August 31, 1953, HREX Doc. No. 0709671.
5. Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon and Schuster, 1986), 574. See also "Human Studies Project Team Fact Sheet, Bayo Canyon/The RaLa Program," January 10, 1994, HREX Doc. No. 0701316, p. 1.
6. To R. Cook, Washington, D.C., from C. Vanden Bulck, acting manager ORNL, August 31, 1953, HREX Doc. no. 0709671. See also John Horan, Summer 1994 interview by John K. Harrop and Joseph J. Shonka, pp. 1-2. Iodine is taken up by the human thyroid gland.
7. General Manager's Diary entry for April 18, 1950, HREX Doc. No. 0723885; to Carroll Wilson, General Manager, AEC, from George Brown, Director of Engineering, AEC, April 25, 1950, HREX Doc. No. 0720687; to George Brown from Ray Knapp, May 3, 1950, HREX Doc. No. 0720685.
8. The hexone process was called REDOX; the tributyl phosphate process, PUREX. In the history of the Chem Plant, there were three accidental criticalities.
9. Succeeding operators were Phillips Petroleum Company, 1953-1966; Idaho Nuclear Corporation, 1966-1971; Allied Chemical, 1971-1979; Exxon Nuclear Corporation, 1979-1984; Westinghouse Idaho Nuclear Corporation, 1984-1994; Lockheed Martin Idaho Corporation, 1994-1999. The Bechtel Corporation assumed responsibility in 1999.
10. Don Reid, Cassette Tape # 2, 6-9.
11. Mark L. Sutton, "ICPP Historical Data," September 8, 1988, 1. Copy supplied to author by Jeff Bryant. This also is source for sidebar, p. 98, "Memories of an Operator Helper at the Chem Plant."
12. R.B. Lemon and D.G. Reid, "Experience With a Direct Maintenance Radiochemical Processing Plant," *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy* Volume 9 (Geneva: United Nations, 1956), 536.
13. Don Reid, Cassette Tape No. 2, 15. See also "Uranium Production—ICPP Processing Runs," Revised 10-1-75, MPH, an ICPP history of production runs; and "AEC Chemical Processing Plant Begins Operation at Arco Site," *Idaho State Journal*, March 15, 1953.
14. Reid, Cassette Tape # 2, 11.
15. Reid, Cassette Tape # 2, 12-14.
16. For a more detailed description of the ICPP's modified PUREX process, see Brewer F. Boardman, *The ICPP (A Factsheet)* (Idaho Falls: Idaho Operations Office, 1957). For a general description of the plant and its operations, see R.B. Lemon and D.G. Reid, "Experience With Direct Maintenance Plant," 532-545.
17. L.A. Decker, "Significant Accomplishments in the History of the ICPP," paper presented at the 1972 National Meeting of the American Chemical Society, San Francisco, California, September 1, 1976, p. 5. In 1969 Idaho Nuclear Corporation designed a denitration facility to convert the liquid into UO_3, a granular solid, for which, see N.J. Rigstad, "ICPP Environmental Impact Statement," 1973, a draft manuscript supplied to author by Jeff Bryant, p. 17. The change was stimulated by more stringent packaging and shipping requirements.
18. Dieter Knecht, et al, "Historical Fuel Reprocessing and HLW Management in Idaho," *Radwaste Magazine* (May 1997): 40. See also Richard K. Lester and David J. Rose, "The Nuclear Wastes at West Valley, New York, *Technology Review* (May 1977): 20-21, for discussion of neutralization of acid wastes and its cost; (quotatation) John B. Huff, *Furnace Separations for Radioactive Liquid Wastes* Report No. PTR-241 (Idaho Falls: 1957, PPCo.), 8.
19. See Cyril M. Slansky and John A. McBride, "The Case for Small Reprocessing Plants, *Nucleonics* (September 1962): 43-56.
20. Knecht, "Historical Fuel Reprocessing," 40. The ratio of ten gallons of fission product to one million gallons of stored waste was noted in a letter from John B. Huff to Henry Dworshak, August 18, 1958, IHS, Ms. 84, Box 83, File: AEC-Idaho Plant. Geneva Conference *ICPP Report*, p. 534, says low-activity waste was "discharged directly to the ground." Boron is a neutron "poison," a material that absorbs neutrons and helps prevent accidental criticalities.
21. N.J. Rigstad, "ICPP EIS," 1973, p. 7, manuscript provided to author by Jeff Bryant. For a summary of how process chemistry progressed, see Dieter A. Knecht, "Historical Fuel Reprocessing," 35-47. Between 1953 and 1988, the Chem Plant recovered 31,432 kilograms of U-235.
22. Don Reid, Cassette Tape # 2, 17-18. See also Rigstad, 12. The fuel cutting facility was at CPP-603, the Fuel Storage Facility. It had to be modified to receive and unload fuel arriving in 75-ton casks, heavier than earlier casks.
23. (Dates of RaLa program) U.S. DOE, INEL Historical Dose Evaluation Report No. DOE/ID-12119 (Idaho Falls: DOE/IDO, 1991), Vol. 1, p. A-26. The program was under design and cold testing from March 1954 to November 1956. For a description of the RaLa cell, see Cyril M. Slansky and John A. McBride, "The Case for Small Reprocessing Plants," Nucleonics (September 1962): 44-45; (Operating practices) E.R. Ebersole, "RaLa Monitoring Experience" in A Compendium of Information for Use in Controlling Radiation Emergencies, delivered at a Conference in Idaho Falls on February 23, 1958, HREX Doc. No. 704450; (procedures in early years of RaLa runs prior to addition of filtration equipment) John Horan, interview with Harrop and Shonka, Summer 1994, pp. 2, 4-6; (iodine retention), Phillips Petroleum Company, Idaho Chemical Processing Plant (Idaho Falls: PPCo, n.d., but circa 1965), 33.
24. John Byrom, note to author, June 24, 1999. See also Horan, interview with Harrop and Shonka, Summer 1994, pp. 4-5; and Horan, interview with Baldwin and Bacchus, HREX Doc. No. 0726467, pp. 26-27.

25. John Horan, interview with Burton Baldwin and Thomas Baccus, August 18, 1994, p. 5-6, “redacted version” in HREX Doc. No. 0726467.

26. John R. Horan, *Annual Progress Report, Health and Safety Division, 1962*, Report No. IDO-12033, p. 43, HREX Doc. No. 702992.

27. *INEL Historical Dose Evaluation*, iii.

Chapter Twelve

1. “Johnson Leaves Position as Idaho AEC Manager, *Arco Advertiser*, April 30, 1954, 4. Also, Jacqui Johnston Batie and William Ginkel, interviews with author, October 14, 1998, and February 3, 1999, respectively.

2. (Consolidation) “AEC Contractors Study Merger Move,” “Phillips Plans AEC Merger,” “Phillips Ends Merger Soon,” *Post-Register*, August 24, August 27, and October 8, 1953, respectively; (employee attitudes) Bernice Paige, April 8, 1999.

3. Eisenhower’s policy domination is a central theme of Richard G. Hewlett and Jack M. Holl in *Atoms for Peace and War 1953-1961* (Berkeley: University of California Press, 1989), xxi; (defense spending) Harry S. Truman, *Memoirs, Years of Trial and Hope,* Volume 2 (Garden City, N.Y.: Doubleday and Co., 1956), 306-312; (quotation) Dwight David Eisenhower, *Mandate for Change, 1953-1956* (Garden City, N.Y.: Doubleday and Co., 1965), 452; (massive retaliation) Chester J. Pach, Jr., and Elmo Richardson, *The Presidency of Dwight David Eisenhower* (Lawrence: University Press of Kansas, 1991), 76-81. The Army’s share of the budget shrank from 33 percent to 25 percent, and the Air Force’s grew from 39 percent to 47 percent.

4. (Scare the country, Atoms for Peace quotations, Operation Candor) Herbert S. Parmet, *Eisenhower and the American Crusades* (New York: Macmillan Company, 1972), 386; (national objectives) U.S. AEC, *Major Activities in the Atomic Energy Programs, January—June 1953 U.S. Atomic Energy Commission* (Washington, D.C.: U.S. AEC, 1953), 18.

5. (Quotation) Hewlett, *New World*, 5.

6. Public Law 83-703 was adopted by the Second Session of the 83rd Congress and became effective August 30, 1954.

7. J.W. Henscheid, interview with author, December 10, 1998.

8. J.R. Huffman, *MTR Technical Quarterly Report, Second Quarter 1954*, Report No. IDO-16191 (Idaho Falls: PPCo, 1954), 17; and Huffman, *MTR Technical Quarterly Report, Third Quarter 1954*, Report No. IDO-209, 12.

9. Deslonde de Boisblanc, interview with author, January 16, 1999.

10. R.L. Heath, *Scintillation Spectrometry, Gamma-Ray Spectrum Catalogue*, 2nd edition, Report No. IDO-16880-1 (Idaho Falls: PPCo, 1964). Report number for the first edition was IDO-16408. According to D.R. de Boisblanc, Heath “pushed the resolution by more than a factor of sixteen using lithium-drifted germanium and silicon, plus low noise amplifiers employing liquid nitrogen-cooled field effect transistors. He also introduced the use of digital computers to reduce the data.”

11. *1965 Thumbnail Sketch* (Idaho Falls: Idaho Operations Office, 1965), 17; de Boisblanc, July 14, 1999.

12. (Hydraulic rabbit) US AEC, *Major Activities in the Atomic Energy Program July—December 1953*. (Washington, D.C.: US AEC, January 1954), 25; (Argonne loop) L.W. Fromm, *Design Evaluation of In-Reactor Tube for Argonne Water Loop at MTR*, Report No. ANL-5403 (Lemont, Illinois: Argonne National Laboratory, 1955), 5.

13. W.E. Nyer, et al. *Proposal for a Reactivity Measurement Facility at the MTR*, Report No. IDO-16108 (Idaho Falls: PPCo, 1953), 6-8.

14. J.W. Henscheid, personal communication to author, December 10, 1998.

15. J.R. Huffman, *MTR Technical Branch Quarterly Report for First Quarter 1955*, Report No. IDO-16229 (Idaho Falls: PPCo, 1955), 24.

16. Pamphlet, *Gamma Irradiation Facility, A Fact Sheet*, no author, p. 3-5, found attached to *1957 Thumbnail Sketch*.

17. Walter C. Sparks, interview published in Susan M. Stacy, ed., *Conversations, A Companion Book to Idaho Public Television’s “Proceeding On Through A Beautiful Country)* (Boise: Idaho Educational Public Broadcasting Foundation, 1990), 266-267.

18. Walter C. Sparks, interview with author, May 13, 1999.

19. Sparks, May 13, 1999; George A. Freund, *Suitability of Potato Products Prepared from Irradiated and Chemically Inhibited Potatoes* and Freund, *Current Status and Potential of Irradiation to Prevent Potato Sprouting*, Reports No. IDO-10042 and IDO-11300-Addendum, respectively, both (Idaho Falls: Western Nuclear Corporation in cooperation with Engineering Committee, Potato Processors of Idaho, February 1965); and “Commercial Interest Increasing Rapidly in Food Irradiation, *Nucleonics* (December 1963): 23.

20. (40 megawatts) IDO-16254, 6; (questions) see series of Phillips Technical Branch quarterly reports for 1955 through 1957.

21. W.P. Connor, *MTR Technical Branch Quarterly Report*, Report No. IDO-16297 (Idaho Falls: PPCo, 1956), 5.

22. “Test Reactors—The Larger View,” *Nucleonics* (March 1957): 55.

23. Philip D. Bush, “ETR: More Space for Radiation Tests,” *Nucleonics* (March 1957): 41-42. The extra depth required for the control rods meant that a portion of the foundation had to be blasted through lava rock. See also R.M. Jones, *An Engineering Test Reactor for the MTR Site (A Preliminary Study)*, Report No. IDO-16197 (Idaho Falls: PPCo, 1954), 7.

24. *1965 Thumbnail Sketch*, 14; J.W. Henscheid, December 10, 1999. For more information on the ETR, see “ETR: More Space for Radiation Tests,” *Nucleonics* (March 1957): 41-56.

Chapter Thirteen

1. Horan, Baldwin and Baccus 1994 interview, HREX Doc. No. 0726467. Bracketed inserts within quotation are from *INEL Historical Dose Evaluation*, Volume 2, pp. A-180 to A-182.

2. (Johnston announcement) “AEC to Add Aircraft Unit Here,” *Post-Register*, July 29, 1952, 1; See “AEC Announces Preliminary Plans for Airplane Reactor Will be Ready Around November 15,” *Arco Advertiser*, November 7, 1952, 1; “AEC Sets January 30 as Bid Opening Date for $6,000,000 Facilities at Aircraft Reactor Site,” *Post-Register* (assumed), January 3, 1953, 1; “Utah Construction Low Bidder on AEC Aircraft Reactor,” *Arco Advertiser*, February

20, 1953; "Contact Let for AEC Aircraft Propulsion Reactor," *Arco Advertiser*, March 27, 1953, 1; "AEC Announced Bids for the Construction of an Access Road to the Prototype Aircraft Propulsion Reactor," *Post-Register*, August 31, 1952.

3. "Allan C. Johnson Gets Idaho AEC Post; Bowden Goes to FOA," *Post-Register*, May 13, 1954, 1; "Allan Johnson Named New AEC Manager, *Arco Advertiser*, May 14, 1954, 1.
4. William Ginkel, February 3, 1999. For detailed history of Aircraft Nuclear Propulsion Program, see Susan M. Stacy, Historical American Engineering Record, *Idaho National Engineering Laboratory, Test Area North, Hangar 629*, HAER NO. ID-32-A (Idaho Falls: LMITCO, 1995).
5. Hewlett, *Atomic Shield*, 71-74, 106.
6. John Tierney, "Take the A-Plane: The $1 Billion Nuclear Bird that Never Flew," *Science 82* (January/February 1982): 49; also Henry W. Lambright, *Shooting Down the Nuclear Airplane* (Syracuse, N.Y.: Inter-University Case Program, No. 104, 1967), 5.
7. To Senator William F. Knowland from Henry Dworshak, November 24, 1956; IHS Dworshak Papers, Box 59, File: Legis AEC Miscellaneous.
8. Among the public relations documents produced by General Electric in 1959 was *Idaho Test Station, Idaho Falls, Idaho*, a pamphlet describing GE's activities concerning the ANP program. It includes explanations and diagrams explaining the direct cycle concept. Copy in Dworshak Papers, Box 112 File: AEC Idaho Plant. Pratt and Whitney contracted to develop the indirect cycle, but got a late start due to contract disputes.
9. Carl Gamertsfelder, "Oral History of Health Physicist Carl C. Gamertsfelder," January 19, 1995, Report No. DOE/EH-467 *Human Radiation Studies: Remembering the Early Years*.
10. (ANP management structure) Kenneth Gantz, ed., *Nuclear Flight* (New York: Duell, Sloan and Pearce, 1960); John Horan, interview with author, July 14, 1998.
11. General Electric, *Nuclear Power Plant Testing in the IET*, Report No. APEX-131 (Cincinnati: Aircraft Nuclear Propulsion Program, Aircraft Gas Turbine Division, May 1953), 5.
12. For description of HTREs, see G. Thornton, A.J. Rothstein, and D.H. Culver, ed. *Comprehensive Technical Report, General Electric Direct-Air-Cycle Aircraft Nuclear Propulsion Program, Program Summary and References*, Report No. APEX-901 (Cincinnati: GE ANP Department, Atomic Products Division, 1962),
19. See also news release, "General Electric ANP Department Completes Testing of Heat Transfer Experiment No. 3," issued by AEC IDO, January 27, 1961, Dworshak Papers, Box 122-B, File: Atomic Energy Commission, Idaho Press Releases.
13. General Electric, *ANPP Engineering Program Progress Report No. 18*, Report No. APEX-18 (Cincinatti: GE ANP, 1955), 7; APEX-901, 37; Tierney, "Take the A-Plane," 50.
14. (Shield weight) Tierney, "Take the A-Plane," 50; APEX-18, 195.
15. Gamertsfelder, "Oral History," Report No. DOE/EH-0467.
16. Comptroller General of the United States, *Review of Manned Aircraft Nuclear Propulsion Program, Atomic Energy Commission and Department of Defense, Report to the Congress of the United States* (Washington, D.C.: General Accounting Office, 1963), 138. Congress authorized construction of the FET (hangar), support buildings, and a runway in July 1955. Detailed design commenced in March 1956, and groundbreaking occurred in September 1957. The facility was ready in July 1959. Hereafter, Comptroller General.
17. Richard Meservey, interview with author, October 12, 1998.
18. AEC/IDO news release, "General Electric ANP Department Completes Testing of Heat Transfer Experiment No. 3," January 27, 1961, IHS, Dworshak Papers, Box 122-B, File: Atomic Energy Commission, Idaho Press Releases. See also "HTRE - 3 Completes 120 Hours of Operation," *GE News, Idaho Test Station, Aircraft Nuclear Propulsion Department* (April 1, 1960): 1. Issue found in IHS, Dworshak Papers, Box 112, File: AEC Idaho Plant; and APEX-901, p. 50, 57.
19. John Horan, interview with Baldwin and Baccus, HREX Doc. No. 0726467, p. 7. See also Gamertsfelder, DOE/EH-0467.
20. APEX-18, 196.
21. (Runway) "Proposed ANP Runway Area," Drawing No. 7-ANP-001-2 2/2, and "ANP Runway Profile," 7-ANP-001-3, shown to author by Bud White, INEL; copies available at Record Storage Center, Central Facilities Area, INEEL; (quote), Comptroller General, 39, 52.
22. Gantz, *Nuclear Flight*, 175, 178.
23. D.J. Blevins, et al. *Flight Engine Test Facility Design Criteria*, Report No. APEX-225 (Idaho: GE ANP Department Idaho Test Station, 1955), 15-21.
24. See samples of mail to Henry Dworshak: telegram from Robb Brady, Idaho Falls *Post-Register*, January 29, 1961; letter from (Idaho State Senator) C.A. Bottolfsen, March 2, 1961; IHS Dworshak Papers, Box 122-B, File: AEC Idaho Plant.
25. David F. Shaw, "General Manager's Report" and "GE Ready to Perform First Experimental Flight in 1963,"*Aircraft Nuclear Propulsion Department News* (March 31, 1961): 1.
26. Letter to Bottolfsen from Henry Dworshak, March 7, 1961; dayletter to J. Robb Brady from Henry Dworshak, March 8, 1961; IHS Dworshak Papers, Box 122-B File: Atomic Energy Commission Idaho Plant.
27. Arthur M. Schlesinger, Jr., *A Thousand Days, John F. Kennedy in the White House* (Boston: Houghton Mifflin, 1965), 300-301, 307. See also Herbert York, *Race to Oblivion* (New York: Simon and Schuster, 1970), 29.
28. "Kennedy Asks $2 Billion Defense Insurance Hike," and "A-Plane Work Halt Asked by JFK in Defense Message," *Idaho Daily Statesman*, March 29, 1961, p. 1, 6 respectively.
29. To President John F. Kennedy from Governor Robert E. Smylie, March 29, 1961; IHS Dworshak Papers, Box 122-B, File: Atomic Energy Commission Idaho Plant.
30. "Kennedy Wants A-Plane Junked, New GE Effort," *Post-Register*, March 28, 1961, 1.
31. Jay Kunze, interview with author, February 5, 1999.
32. (Expense) Comptroller General, 113; "ANP Termination Leaves Vast Facilities, Big Technical Legacy," *Nucleonics* (August 1961): 26-27. See also letter from John W. Morfitt, Manager, ANPD, to Henry Dworshak, September 26, 1961; both in

Dworshak Papers, Box 122 B, File: AEC Idaho Plant.

Chapter Fourteen

Epigraph: "Transient Studies," *Nucleonics* (June 1960): 115.

1. Plastino, *Coming of Age*, 64; Holl, *Argonne*, 118. The acronym comes from the letters BOiling water Re Actor eXperiment.
2. Holl, *Argonne*, 118; Andrew W. Kramer, *Understanding the Nuclear Reactor* (Barrington, Illinois: Technical Publishing Co., 1970), 37, 70.
3. J.R. Dietrich and D.C. Laymans, *Transient and Steady State Characteristics of a Boiling Reactor: The Borax Experiments, 1953*, Report No. ANL-5211, February 1954; Holl, *Argonne*, 118; Plastino, *Coming of Age*, quoting Ray Haroldsen, 64.
4. Holl, *Argonne*, 118.
5. Holl, *Argonne*, 119.
6. Holl, *Argonne*, 120; (talk of dynamite), Clyde Hammond, interview with author, October 15, 1998.
7. Plastino, *Coming of Age*, quoting Haroldsen, 64.
8. For account of 1955 Geneva Conference, see Laura Fermi, *Atoms for the World: United States Participation in the Conference on the Peaceful Uses of Atomic Energy* (Chicago: University of Chicago Press, 1974).
9. Plastino, *Coming of Age*, 64-65. The addition of the generating equipment earned BORAX-II its new designation as BORAX-III. BORAX-IV was BORAX-III with a new core made of a fuel containing Thorium Oxide and Uranium Oxide.
10. "Arco First City in United States Lighted by Atomic Power," *Arco Advertiser*, August 12, 1955, 1; "Arco Gets Premier Showing of AEC Film, *Arco Advertiser*, August 19, 1955, 1; Plastino, *Coming of Age*, 65.
11. (Borax tests) Argonne National Laboratory, *Annual Report for 1959*, ANL Report No. ANL-6125 (Chicago: ANL, 1959), 94. See also J.O. Roberts, "Selected Operating Experience of Commission Power Reactors," a paper presented to the American Institute of Electrical Engineers, June 18, 1961, in IHS, Ms 84, Box 122 B, File: AEC-Press Releases; (EBWR) Holl, *Argonne*, 150; Robert L. Loftness, *Nuclear Power Plants: Design, Operating Experience, and Economics*, (Princeton, N.J.: Van Nostrand (Nuclear Science Series), 1964), 167-213; to Senator Dworshak from Francis K. McCune, GE, September 25, 1958; IHS, Ms 84, Box 104, File: Legislative AEC Misc 1959.
12. Reactor safety programs also took place at other national labs; ie, Kinetic Energy Water Boilers (KEWB) were safety tested at Los Alamos.
13. Richard L. Doan, "Two Decades of Reactor Safety Evaluation," Memorial Lecture in honor of Dr. C. Rogers McCullough prepared for Winter Meeting of the American Nuclear Society, Washington, D.C., November 15-18, 1970, p. 3. For general histories of reactor safety, see George T. Mazuzan and J. Samuel Walker, *Controlling the Atom* (Berkeley: University of California Press, 1984) and J. Samuel Walker, *Containing the Atom* (Berkeley: University of California Press, 1992).
14. Jack M. Holl, et al., *United States Civilian Nuclear Power Policy, 1954-1984: A History* (Washington, D.C., U.S. DOE, 1985), 4.
15. Warren Nyer, interview with author, February 1, 1999.
16. (Location) T.R. Wilson *An Engineering Description of the SPERT-1 Reactor Facility*, Report No. IDO 16318 (Idaho Falls: ANL, 1957), 8. (vocabulary) to Glenn Seaborg from Senator Dworshak, November 16, 1961, IHS MS 84, Box 122 B, File: AEC-Idaho Plant.
17. "SPERT-2 Features Versatility," Nucleonics (June 1960): 120; pamphlet, "Special Power Excursion Reactor Tests" (Idaho Falls: Phillips Petroleum Company, n.d.), 18.
18. Nyer, February 1, 1999.
19. "Special Power Excursion Reactor Tests," (Idaho Falls: Phillips Petroleum Company. n.d.); Warren Nyer, February 1, 1999.
20. Detroit Edison led a consortium of utility companies called the Power Reactor Development Company.
21. Holl, *Argonne*, 115-116.
22. J.O. Roberts, "Selected Operating Experience," 37.
23. Holl, *Argonne*, 141-143.
24. "AEC Tells How Reactor Failed," *Business Week* (April 14, 1956): 34; Jerome D. Luntz, "Nuclear Accidents Are Everybody's Business, *Nucleonics* (May 1956): 39.
25. Argonne National Laboratory, *Annual Report for 1957*, Report No. ANL-5870 (Chicago: ANL, 1958), 83.
26. Loftness, *Nuclear Power Plants*, 339; ANL-West, *EBR-II since 1964* (Idaho Falls: ANL-W, 1983).
27. For design and other details, see George Freund, et al, *Design Summary Report on the Transient Reactor Test Facility, TREAT*, Report No. ANL-6034 (Chicago: ANL, 1960).
28. ANL, *Annual Report 1959*, 102; Edmund S. Sowa, "First TREAT Results—Meltdown Tests of EBR-II Fuel," *Nucleonics* (June 1960): 122-124.
29. These were the Argonne Fast Source Reactor (AFSR) and Zero-Power Reactor Three (ZPR-III). ZPR-I and -II were not located at the NRTS.
30. "About the Idaho Division..." (Idaho Falls: Argonne Idaho Facilities, 1964), Fact Sheet EBR-II, page 1-2. The approach to design-level power production was gradual, attained on September 25, 1969.

Chapter Fifteen

Epigraph: Interview of George Voelz, "Remembering the Early Years," Report No. DOE/EM 0454, November 29, 1994, HREX Doc. No. 0727845.

1. Lawrence H. Suid, *The Army's Nuclear Power Program, The Evolution of a Support Agency* (New York: Glenwood Press, 1990), p. 3-8, 82. For technical detail on the SL-1 reactor and artist's renderings of DEW Line packages, barge-mounted reactors, and other applications, see "Army Reactor Program," *Nucleonics* (February 1969): 53-54 and insert. See also ANL *Annual Report 1958*, Report No. ANL-5980 (Lemont, Illinois: ANL, 1959), 53-55.
2. For a history of the Army Reactor Program at the NRTS, see Susan M. Stacy, Historical American Engineering Record, Idaho National Engineering Laboratory, *Army Reactor Experimental Area, HAER No. ID-33-D*.
3. Suid, *Army's Nuclear Program*, 83.
4. See "Description of ALPR," *Nucleonics* (February 1958), and pull-out section following p. 54.

5. Argonne had named the reactor "Argonne Low Power Reactor," or ALPR.
6. The GCRE was the eighth reactor type developed by the AEC Nuclear Reactor development program, selected for both military and civilian potential. The name of the AREA reactor complex was changed later to ARA (Army Reactor Area) and still later to ARA (Auxiliary Reactor Area). U.S. AEC press release, June 6, 1956; IHS Dworshak Papers, Mss 84, Box 55, File: AEC—Idaho Plant.
7. Norman Engineering Co., *Master Plan Study for the Army Reactor Experimental Area*, Report No. IDO-24033 (Idaho Falls: Norman Engineering, 1959), Section II (no p.n.).
8. R.T. Canfield, *SL-1 Annual Operating Report, February 1959-February 1960*, Report No. IDO 19012 or CEND-82 (Idaho Falls: Combustion Engineering, 1960), 7. SL-1 was the first power plant reactor in the country to use aluminum-clad fuel elements, which heretofore had been used only in test reactors like the MTR. A new alloy overcame the low melting point of aluminum, and after SL-1, aluminum alloys were used widely. See Suid, *Army's Nuclear Program*, 83.
9. "SL-1 Explosion Kills 3; Cause and Significance Unclear," *Nucleonics* (February 1961): 17.
10. See drawing in *Nucleonics*, (February 1969): 54 ff. The fuel zone was 27.8 inches long.
11. (Water hammer) General Electric, *Final Report of SL-1 Recovery Operation* (Idaho Falls: GE Report No. IDO-19311, 1962), p. I-6.
12. Staff of the JCAE, "Summary of the SL-1 Reactor Incident at the National Reactor Testing Station in Idaho on January 3, 1961," January 10, 1961, IHS, Dworshak Papers, Box 122 B, File: AEC Id Press Releases. Other details of the accident were reported in *Nucleonics* (February 1961): 17-23; and in a series of press releases from the Idaho Operations Office after the accident, copies in Dworshak papers.
13. "Sequence of Events Related to the SL-1 Accident at the National Reactor Testing Station, Idaho, on January 3, 1961." HREX document #0715561. No author or date. This report was an appendix to an unidentified AEC document. See also *Nucleonics* (February 1961); and "Detailed Events Chain at SL-1 Reactor Told," *Post-Register*, January 12, 1961.
14. A Class II event would impact other facilities on the site; a Class III, territory beyond the boundaries of the Site. A road block was not required. C. Wayne Bills recalled that the HPs may have stopped one or two autos in order to determine whether their tires had picked up any contamination.
15. SL-1 Report Task Force, *IDO Report on the Nuclear Incident at the SL-1 Reactor on January 3, 1961, at the National Reactor Testing Station*, Report No. IDO-19302 (Idaho Falls: Idaho Operations Office, 1962), 54.
16. "Big Hazard at Idaho Atom Site? Traffic Accidents, Says Nurse," *Post-Register*, February 23, 1961.
17. Dr. George Voelz, "Remembering the Early Years," Oral History Interview, November 29, 1994, HREX Doc. No. 0727845.
18. The men were Specialist 5 John A. Byrnes, 27, U.S. Army; Specialist 4 Richard L. McKinley, 22, U.S. Army; and Construction Electrician Richard C. Legg, 26, U.S. Navy. Byrnes had been certified at SL-1 in February 1960; Legg, in September 1960. McKinley was a trainee.
19. John Horan, interview with author, July 16, 1998.
20. Horan, July 16, 1998.
21. "Findings of the Board of Investigation," *Nuclear News* (July 1961): 15.
22. *INEL Historic Dose Evaluation, Volume 2*, p. A-83 to A-85. See also *Volume I* map, p.27.
23. (Squad rescue) Staff of the JCAE, "Summary of the SL-1 Reactor Incident," 2-3; (GCRE decontamination, logbook, neutron detector) film "The SL-1 Accident," (Idaho Falls: Idaho Operations Office).
24. The General Manager's Board of Investigation, *Report on the SL-1 Incident, January 3, 1961,* Press Release No. 61-24 (SL-1), (Idaho Falls: Idaho Operations Office, June 11, 1961), 31.
25. (Team recovery) IDO Press release, January 9, 1961, Dworshak Papers, box 122 B; (Dugway, mockup, procedures) film "The SL-1 Accident."
26. George Voelz, M.D., November 29, 1994; John Horan and Wayne Bills, "What Have We Learned? Health Physics at SL-1," *Nucleonics* (December 1961): 48.
27. (Luedecke proposal) John Horan, July 16, 1998; (caskets) "Blast Victim's [sic] Rites Await AEC Action," *Salt Lake Tribune*, January 17, 1961; (lead wrap) C. Wayne Bills, February 3, 1999; "Military Gets Bodies of NRTS Victims," *Post-Register*, January 23, 1961; "Atom Victim is Buried in Lead Vault," *Utica Observer-Dispatch*, January 25, 1961; "A Catastrophe New to Man," *New York Herald Tribune*, January 29, 1961. The AEC required that the cemeteries accepting the caskets must have perpetual care, that the graves not be disturbed without AEC permission, and that the graves be shielded with concrete and dirt.
28. Jay Kunze, February 5, 1999. The AEC contracted General Electric to disassemble and analyze the reactor on May 5, 1961; (Dugway) C.W. Bills, personal communication, June 25, 1999.
29. Kunze, February 5 and July 6, 1999.
30. Kunze, February 5, 1999.
31. (Crane) Wayne Bills, interview with author, February 3, 1999; (vessel in transit) General Electric, *Final Report of SL-1* p. II-37, II-39. See also "SL-1 Reactor Core Trucked to Hot Cell for Study," *Arco Advertiser*, December 8, 1961, 3.
32. General Electric *Final Report*, ii.

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1. (Monster quote) Robert F. Alkire, "'Monsters' Huddle in Weird Stillness," Associated Press story published in *Salt Lake Tribune*, January 8, 1961, and as "Moon-like Eastern Idaho Desert Scene of Nuclear 'Monster' Runaway," in *Idaho Daily Statesman*, same date, 5; (sleeping quote) "A-Reactors Won't Blow Us Up," *The Deseret News and Telegram*, January 6, 1961.
2. (Mishaps) "NRTS Marks First Fatal Atomic Mishap," *Idaho Daily Statesman*, January 5, 1961; (instructed) Frank Carey, "Chemical Explosion in Nuclear Reactor Potentially More Perilous than A-`Blast,' *Idaho Daily Statesman*, January 5, 1961.
3. The IDO compiled 154 press clippings from around the country in a document "The SL-1 Accident, Press Clippings." A copy is extant at the IDO public information office in Idaho Falls, Idaho.
4. (Siting) John W. Finney, "Blast Stresses A-Question," *Salt Lake Tribune*, January 5,

1961; (set back) "What Happened in Nuclear Blast," *Business Week*, January 7, 1961.

5. (Reuther quote) "Press Release from Industrial Union Department of AFL-CIO, January 5, 1961, at IHS, Ms 84, Box 122 B, File: "AEC-Idaho Plant;" (defeat) "A Month After the Idaho Accident," *Oak Ridger*, February 6, 1961.

   The forty-item list included incidents such as the MTR fuel rod with a pin-hole leak (described in Chapter 12) and similar events that had occurred in other AEC facilities across the country. The information was available for review in unclassified AEC literature.

6. To Senator Henry Dworshak from Donald E. Seifert and George Dragich, May 11, 1061, in IHS, Mss 84, Box 122 B, File: AEC-Idaho Plant.
7. To Senator Dworshak from John T. Conway, June 20, 1961, IHS, Mss 84, Box 122 B, File: AEC Miscellaneous.
8. (Wilson) To Senator Dworshak from John T. Conway, acting executive director of JCAE, June 1, 1961, in IHS, Mss 84, Box 122 B, File: AEC-Idaho Plant.
9. Atomic Energy Commission Investigation Board, *SL-1 Accident* (Washington, D.C.: Joint Committee Print, U.S. Government Printing Office, 1961), ix.
10. "Johnson Resigns at AEC," *Arco Advertiser*," December 8, 1961, 1; John Horan, C. Wayne Bills interviews with author, July 16, 1998, and February 2, 1999, respectively.
11. To Ramey from A.R. Luedecke, January 12, 1961, in IHS, Mss 84, Box 122 B, File: AEC-Idaho Press Releases; "AEC Surveys Safety of Licensed Reactors," *Post-Register*, January 13, 1961; "Safety Survey Launched for all Reactors Licensed by AEC," *Idaho Daily Statesman*, January 13, 1961; "AEC Asks U. Bolster Reactor Safety," *Salt Lake Tribune*, January 13, 1961.
12. J.W. Henscheid, interview with author, December 10, 1998.
13. David Okrent, *On the History of the Evolution of Light Water Reactor Safety in the United States* (Los Angeles: University of Los Angeles, 1978), pp. 6-102 to 6-106. Okrent reproduces a letter from the ACRS to A.R. Luedecke, December 31, 1962.
14. (Greenland) To Ramey from Luedecke, January 12, 1961, op cit.; (ML-1) AEC/Idaho Operations press release, February 11, 1961, IHS, Dworshak Papers, Box 122 B, File "AEC—Press Releases." Also, Hogerton, *Atomic Energy Desk Book*, 33. The Army operated SM-1 at Fort Belvoir; SM-1A at Fort Greeley, Alaska; PM-2A at Camp Century, Greenland; PM-1 at Sundance Air Force Base, Wyoming; PM-3A at McMurdo Sound, Antarctica; PL-3 at Byrd Station; and *Sturgis*, a barge.
15. (Power dates) Suid, *Army's Nuclear Program*, 91.
16. T.L. Murphy, *Final Disassembly and Examination of the ML-1 Reactor Core*, IDO-171-90, (Idaho Falls: PPCo, 1966), 110-111; "Economic Military Power Arrives, But Pentagon Hesitates," *Nucleonics* (April 1960): 27; Suid, *Army's Military Reactors*, 92-93. See also Stacy, *Army Reactor Experimental Area, HAER No. ID-33-D*.
17. The SL-1 Burial Ground was regraded and recontoured in 1997 after a 1996 "Record of Decision" signed by the Department of Energy, the Environmental Protection Agency, and the State of Idaho. The new natural-material "cap" was to improve the isolation of hazardous materials from humans and the surrounding environment. Erik Simpson, "Agencies agree to cap reactor burial grounds," *INEL News* (February 6, 1996): 7.
18. "Reactor Safety: Accident Control Study," *Nucleonics* (April 1964): 28. See John R. Horan and C. Wayne Bills, "What Have We Learned? Health Physics at SL-1," *Nucleonics* (December 1961): 48; Voelz, November 29, 1994. The film, "The SL-1 Accident," produced by Idaho Operations Office circa 1962, was in three parts, Phase 1, 2, and 3. All were converted to video format.
19. C. Wayne Bills, personal communication to author, June 25, 1999.
20. (Exposures) *IDO Report on the Nuclear Incident at the SL-1*, 27; John R. Horan and C. Wayne Bills, "What Have We Learned? Health Physics at SL-1," *Nucleonics* (December 1961): 43.
21. "Rescue, Control Crews Honored for Service After SL-1 Blast," *Post-Register*, March 6, 1962, 12; "AEC Honors Participants in SL-1 Reactor Emergency," March 6, 1962, IDO Press Release, IHS, MS 84, Box 124, File: AEC Idaho Plant.
22. See for example Harvey Wasserman and Normon Solomon, *Killing Our Own, The Disaster of America's Experience with Atomic Radiation* (New York: Delacorte Press, 1982); John Fuller, *We Almost Lost Detroit* (New York: Reader's Digest Press, 1975); John May, *The Greenpeace Book of the Nuclear Age* (New York: Pantheon Books, 1989); Leslie J. Freeman, *Nuclear Witnesses: Insiders Speak Out* (New York: W.W. Norton and Co., 1981).

Chapter Seventeen

Epigraph: William Ginkel, *EG&G Bulletin*, July 19, 1985, 1.

1. "Johnson Resigns at AEC," *Arco Advertiser*, December 8, 1961, 1; C. Wayne Bills, interview with author, February 3, 1999.
2. William Ginkel, interview with author, October 13, 1998.
3. Warren Nyer, "Recollections and Reflections," *Idaho ANS Newsletter* (June 1989): 9.
4. The following quotations and information regarding the ATR not otherwise noted are from Deslonde de Boisblanc, interviews and personal communications with author, August-September 1999.
5. D.R. de Boisblanc, *The Advanced Test Reactor—ATR—Final Conceptual Design*, Report No. IDO-16667 (Idaho Falls: Phillips, 1960), 11-13; and Deslonde de Boisblanc, personal communications.
6. Deslonde de Boisblanc, personal communications to author, August 23 and September 2, 1999.
7. Deslonde de Boisblanc, communication to author, August 23, 1999.
8. For additional information on the ATR, see D.R. de Boisblanc et al, *The Advanced Test Reactor—ATR Final Conceptual Design*, Report No. IDO-16667 (Idaho Falls: PPCo, 1960). See pamphlet, *Advanced Test Reactor* (Idaho Falls: Idaho Nuclear Corporation, no date) for addition description of the reactor.
9. "Idaho Rites Start Record Atom Job," *Post-Register*, no date, p. 1, 12, clipping in IHS, Ms. 84, Box 124, File: AEC-Idaho Plant, 1961.
10. Letter to Senator Dworshak from Richard Donovan, November 7, 1961, IHS, Ms. 84, Box 122 B, File: AEC Miscellaneous; (Geneva) IDO Press Release, September 11, 1958, at IHS, Ms. 84, Box 83, File: AEC-

Idaho Plant; R.L. Doan, "MTR-ETR Operating Experience," *Nuclear Science and Engineering* (January 1962): 23-24, 26; Idaho Operations Office, *1965 Thumbnail Sketch* (Idaho Falls: Idaho Operations Office, 1965), 15.

11. R.L. Doan, "MTR-ETR Operating Experience," 24.
12. *1965 Thumbnail Sketch*, 16-18.
13. "Bid opening for AEC Tech Services Center," *Arco Advertiser*, June 5, 1962.
14. J.O. Roberts, "Selected Operating Experience of Commission Power Reactors," 32 (full citation in Chapter 14).
15. *November 1958 Thumbnail Sketch*, 23; (gauges) Jack Clark, interview with author, July 16, 1998.
16. For more on OMRE and EOCR, see Arrowrock Group, *Context History*, 85-88.
17. (Melting point) C. Wayne Bills, communication to author, circa August 20, 1999. Piqua was one of the "Second Round" of demonstrations initiated by AEC invitation in September 1955. See Holl, Anders, and Buck, *Civilian Nuclear Power Policy,* 5; *Controlled Nuclear Chain Reaction: The First 50 Years* (La Grange Park, Illinois: American Nuclear Society, 1992), 41; and numerous editions of *Thumbnail Sketch*.
18. William R. Corliss. *SNAP Nuclear Space Reactors* (Washington, D.C.: U.S. AEC Division of Technical Information, 1966), 11.
19. *July 1971 Thumbnail Sketch*, 34.
20. Richard Meservey, interview with author, October 12, 1998. See also letter to J.W. McCaslin from G.L. Cordes, January 20, 1965, "Monthly Report of TAN-SPERT HP Section for December 1965," HREX Doc. No. 0721415.
21. "Idaho's Atom Mission in Space," *Post-Register*, April 14, 1965, 4; Corliss, *SNAP Nuclear Space Reactors*, 35-38. *1965 Thumbnail Sketch*, 32. See also AEC/ID news release No. 63-11, "AEC Schedules Deliberate Reactor Destructive Test for November," September 17, 1963, HREX Document No. 721416. See also John Horan, "Memo to File," January 14, 1966, HREX Document No. 727305. The tests were named SNAPTRAN (SNAP Transient).
22. R. (Dick) Smith, "The Breeder Reactor Concept," Idaho National Engineering Laboratory *EBR-1 Review* (cited in Chapter Six notes.)
23. "EBR-II Fact Sheet," copy found in IHS, Ms. 400, Box 43, File: Legislative JCAE—20th Anniversary.
24. *EBR-II since 1964*, 24. The first loading of fuel was enriched to 48 percent U-235.
25. For more detailed description, see *EBR-II Since 1964*, 67-70.
26. (Burnup rate), *EBR-II since 1964*, 26. Burnup rate reached 2.6 percent in 1975.
27. Holl, Anders, and Buck, *Civilian Nuclear Power Policy*, 10.
28. Holl, *Argonne,* 230; "AEC Kills Argonne's FARET in favor of Fast Flux Test Facility," *Nucleonics Week*, December 2, 1965.
29. J. Newell Stannard, *Radioactivity and Health, A History*, Report No. DOE/RL01830-T59 (Hanford: Pacific Northwest Laboratory, 1988), 1299; C.A. Hawley, et al, *Controlled Environmental Radioiodine Tests, National Reactor Testing Station*, Report No. IDO-12035 (Idaho Falls: IDO, 1964), 1; John Horan, interview with author, January 15, 1999.
30. Clyde Hawley, interview with author, September 22, 1999.
31. John Horan, July 14, 1998; Hawley, *Controlled Environmental Radioiodine Tests*, 2.
32. (Location), C.A. Hawley, ed., *Controlled Environmental Radioiodine Tests at the National Reactor Testing Station 1965 Progress Report*, Report No. IDO-12047 (Idaho Falls: IDO, 3; (grid) D.F. Bunch, *Controlled Environmental Radioiodine Tests Progress Report Number Two*, Report No. IDO-12053 (Idaho Falls: IDO), 3; (bids) IDO News Releases, April 21, 1966; April 25, 1967; May 6, 1967; April 2, 1970; April 13, 1970; in BSU, Ms. 6, Box 155, File 1.
33. George Voelz, "Remembering the Early Years," HREX Doc. No. 0727845. Other sources indicate that from six to ten people were involved in the experiments. See U.S. DOE, *Human Radiation Experiments: The Department of Energy Roadmap to the Story and the Records*, Report no. DOE/EH-0445 (Washington, D.C.: DOE, 1995), 239.
34. In a 1994 interview with researchers investigating human radiation experiments, John Horan expressed his belief that the NRTS might have been the only AEC laboratory to follow the protocol of obtaining approval of the AEC and developing consent forms. See transcript of interview by Baldwin and Baccus, HREX Doc. No. 0726467, p. 16. For a summary of CERT test dates, see *INEL Historical Dose Evaluation*, Volume 2 (Idaho Falls: Idaho Operations Office Report No. DOE/ID 12119, 1991), page A-72 through A-77. A copy of the Nuremburg Code was found at www.geneletter.org/0197/nuremburg.htm.
35. (Sensitive counters) Hawley, *Controlled Environmental Radioiodine Tests*, 14; for an account of personal experiences, see *Idaho Press Tribune*, January 19, 1987.
36. Stannard, *Radioactivity and Health, A History*, 1,300, 1,302; (laboratory experiments) J.D. Zimbrick and P.G. Voilleque, *Controlled Environmental Radioiodine Tests at the National Reactor Testing Station Progress Report Number Four*, Report No. IDO-12065 (Idaho Falls: IDO, 1969), 2.
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39. See C.E. Stevenson, et al, *Waste Calcination and Fission Product Recovery Facilities—ICPP, A Conceptual Design*, Report PTR-106 (Idaho Falls: PPCo, 1956); and D.R. Evans, *Pilot Plant Studies with a Six-Inch Diameter Fluidized Bed Calciner*, Report No. IDO-14539 (Idaho Falls: PPCo), 2.
40. Argonne National Laboratory, *Annual Reports* for 1955 (p. 21-23), 1956 (p. 65), 1957 (p. 95-97). See also C.E. Stevenson, et al, *Waste Calcination and Fission Product Recovery Facilities—ICPP, A Conceptual Design*, Report PTR-106 (Idaho Falls: PPCo, 1956); and D.R. Evans, *Pilot Plant Studies with a Six-Inch Diameter Fluidized*

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41. See INEEL photos NRTS-59-709 and NRTS-59-925. For a history of the old Waste Calcining Facility, see Susan M. Stacy, *Idaho National Engineering and Environmental Laboratory, Old Waste Calcining Facility HAER No. ID-33-C*, Report No. INEEL-97-01370 (Idaho Falls: LMITCO, 1997).
42. L.T. Lakey, et al, *Development of Fluidized Bed Calcination of Aluminum Nitrate Wastes in the Waste Calcining Facility*, Report No. IDO-14608 (Idaho Falls: PPCo, 1965), pp. ii-5.
43. (Merit badge sidebar) "Boy Scouts Atomic Energy Merit Badge," *Nuclear News* (August 1963): 34; to Len Jordan from Robert L. Shannon, March 14, 1966, BSU, Ms. 6, Box 148, File 1.
44. D.R. Evans, *Pilot Plant Studies*, 3. See also Robert D. Thompson, *Ruthenium Behavior during Fluidized Bed Calcination of Radioactive Waste Solutions: Problem Review and Program Suggestions*, Report No. PTR-743 (Idaho Falls: PPCo, 1965). The calciner's first waste feed came from aluminum-clad fuel. With the aluminum nitrate from the waste stream and aluminum nitrate from the process, most of the nitrate salt being processed was aluminum nitrate. Calcining turned this into aluminum oxide, which is known as the mineral *alumina*. The calcined product of zirconium-clad fuel is *zirconia*.
45. Stacy, *Old Waste Calcining Facility HAER No. ID-33-C*.
46. (500 years) Allied Chemical, *The Waste Calcining Facility, Idaho Chemical Processing Plant* (Idaho Falls: Idaho Chemical Programs, circa 1974), 13. Towards the end of life for the WCF, the bends in the pipe did become a concern. The abrasion of the calcine particles eroded a hole in an elbow of the transport line; Leroy Lewis, personal communication to author, August 31, 1999.
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Chapter Eighteen

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1. J.W. Henscheid, interview with author, December 10, 1998. See also *Nuclear News* (October 1969): 17, which described a failure of the primary coolant heat exchangers early in the hydraulic testing program (1965) from excessive tube vibrations and which had to be rebuilt.
2. J.W. Henscheid, December 10, 1998.
3. (Shaw quotation) William Lanouette, "Dream Machine," *Atlantic Monthly* (April 1983): 45. For a summary of safety philosophy, see Elizabeth Rolfe, *Nuclear Power and the Public Safety*.
4. Chuck Rice, interview with author, October 15, 1998.
5. Joint Committee on Atomic Energy, *Hearings on AEC Authorizing Legislation, Fiscal Year 1968* (Washington: Government Printing Office, 1967), 762.
6. (Shaw views) Robert Gillette, "Nuclear Safety (I): The Roots of Dissent", *Science* (September 1, 1972): 774-776.
7. "Martin, U.S. Rubber to Run Hanford '200 Area,' Build Isotope Plant; Diversification at NRTS," *Nucleonics* (March 1965): 21; "A New Contractor to Manage NRTS in place of Phillips," *Nuclear Industry* (February 1965): 12.
8. (Thirty companies) "NRTS Breakup: AEC Seeks New Contractor," *Nucleonics* (June 1965): 27; "AEC Invites Proposals for Operation of Certain Facilities at Idaho Site," May 3, 1965, BSU Ms. 6, Box 141, Folder 10; (titan firms) "Titan Firms to seek Idaho AEC Contract," *Post-Register*, circa May 9, 1965, in BSU Ms. 6, Box 141, Folder 10; "General Atomics Here to Study Contract," *Post-Register*, undated clipping, BSU Ms. 6, Box 141, Folder 9; Bill Ginkel, "Welcome. The NRTS—What It Is and What It Does...," remarks at "Pre-Proposal Information Meeting," Elks Club, May 20, 1965.
9. (AEC liked Aerojet) Aerojet Nuclear Company, *A Historical Brief of the LOFT Reactor at the Idaho National Engineering Laboratory* Report No. ERDA/IDO CI-1275 (Idaho Falls: ANC, 1975), 14; (Aerojet investments) Robert Gillette, "Nuclear Safety (II): The Years of Delay," sidebar "The Fall of Phillips Nuclear," *Science* (September 8, 1972): 868; "Aerojet Commemorates 25th Anniversary March 20," *Idaho Nuclear News* (March 1967): 1; (Johnson) to Jordan from Allan C. Johnson, February 22, 1966, BSU Ms. 6, Box 148, Folder 1. Aerojet was a subsidiary of the General Tire Company; Charles Rice, interview with author, October 15, 1998.
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11. (Quotation) Robert Gillette, "The Fall of Phillips Nuclear" sidebar, *Science* (September 8, 1972): 868.
12. For discussions of the "Bandwagon Market" that began with the Oyster Creek project, see Richard Rhodes, *Nuclear Renewal* (New York: Viking, 1993); Elizabeth Rolfe, *Nuclear Power and Public Safety*; J. Samuel Walker, *Containing the Atom*.
13. The Brookhaven Study was WASH-740, a report originally prepared in 1957, when the JCAE was preparing the Price-Anderson Act and contemplating the monetary value of severe accidents.
14. Aerojet Nuclear Company, *A Historical Brief of the LOFT Project*, 1.
15. Aerojet Nuclear Company, *A Historical Brief of the LOFT Reactor*, 1.
16. Roger Anders, unrevised preliminary unpublished manuscript, "Safety Research: An Impossible Task," copy supplied to Stacy by author, p. 48.
17. Walker, *Containing the Atom*, 147.
18. (Zircaloy) Aerojet Nuclear Company, *A Historical Brief of the LOFT Project*, 2; (gas pressure) Anders, "Safety Research," 6.

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22. (Breeder) Robert Gillette, "Nuclear Safety (III): Critics Charge Conflicts of Interest," *Science*, (September 15, 1972): 970; (quotation) to Jordan from T.G. Taxelius, September 18, 1970, BSU, Ms. 6, Box 174, File 31; to Edward J. Bauser from Donald Kull, November 17, 1970, BSU Ms. 6, Box 174, File 31.
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25. Walker, *Containing the Atom*, 177. U.S. DOE, *Comprehensive Facility and Land Use Plan, INEL*, Report No. DOE/ID-10514 (Idaho Falls: IDO, 1995), 185.
26. Gillette, "Nuclear Safety (III): Critics Charge Conflicts of Interest," *Science*, 974.
27. Rolfe, *Nuclear Power and the Public Safety*, 93. See also letter to Robert Hollingsworth from Orval Hansen, Nov 19, 1971, IHS Ms. 400, Box 16,21, File: Dept Atomic Energy Commission. The Union of Concerned Scientists attacked the Interim Criteria and the Semiscale tests that supported them because they were not conservative enough.
28. Aerojet Nuclear Company, *A Historical Brief of the LOFT Reactor*, 4.
29. (No fabricators) Gillette, "Nuclear Safety (II): The Years of Delay, *Science*, 870; Aerojet Nuclear Company, *A Historical Brief of the LOFT Reactor*, 5; to John Hough, governor's office, from Nolan Hancock, Oil, Chem and Atomic Workers International Union, Dec 30, 1971, BSU Ms. 141-3, Box 91, File 6.
30. (Blame Phillips) Gillette, "Nuclear Safety (II): The Years of Delay," 869; (early research independence) Rolph, *Nuclear Power and the Public Safety*, 68.
31. (Stake) Bill Ginkel, personal communication to author, July 13, 1999; (name change) Gillette, "The Fall of Phillips Nuclear," 868.
32. (Gillette quotation) "Nuclear Safety (I): The Roots of Dissent," *Science*, p. 773; (Leeper quotation), same article, p. 774. In addition to the four-part series published in *Science* on September 1, 8, 15, and 22, 1972, Gillette wrote "Nuclear Reactor Safety: At the AEC the Way of the Dissenter is Hard," which appeared in *Science* (May 5, 1972):492-498, and discusses the hearing underway at the time on LOCAs and ECCS.
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2. Holl, Anders, Buck, *Civilian Nuclear Policy*, 6. The Price-Anderson amendment to the Atomic Energy Act capped the coverage for a nuclear accident at $560 million. The government supplied $500 million of the insurance at a nominal cost, while private companies supplied the remaining $60 million at standard rates.
3. See *EBR-II Since 1984*, p. 26-29 for operating data on EBR-II reactor. According to Richard Lindsay, a water cooled reactor can make plutonium, but not with enough efficiency to make recycling economic for more than about one recycle.
4. William Lanouette, "Dream Machine," *Atlantic Monthly* (April 1983): 45.
5. There were several types of breeders. Using combinations of uranium and thorium, the concepts had in common the conversion of otherwise useless metals into new fissionable fuel. See Lanouette, "Dream Machine," 36.
6. Holl, *Argonne*, 230-231.
7. Holl, *Argonne*, 231.
8. "AEC Reports on Current Fast Reactor Technology," *Nucleonics* (April 1966): 19.
9. Holl, *Argonne*, 231-32.
10. (Brady editorials), Orval Hansen, interview with author, July 1, 1998.
11. Telegram to Frank Church, Len B. Jordan, and Ralph Harding from Governor Robert Smylie, April 16, 1964, IHS, Ms. AR2/23, Box 17, File: Atomic Energy 63-64.
12. IDO news release, September 15, 1965, BSU, Ms. 6, Box 141, File 9; (long shot) "The Research Yeast," editorial, *Post-Register* (May 9, 1965), 4.
13. To Governor Smylie from N.K. Sowards, Asst. Mgr, Aerojet, June 7, 1965; and to Governor Smylie from Fred Rooney, May 25, 1965, IHS, Papers of Gov. Samuelson, Box 50, File: Nuclear File from Smylie, 1965.
14. Robb Brady, "The Research Yeast," *Post-Register*, May 9, 1965, 4; "Additional NRTS Siting Information for the 200 Bevatron Accelerator," June 11, 1965, and letter to W.L. Robison from Senator Leonard Jordan, August 5, 1965, in BSU Ms. 6, Box 141, File 10; IDO Press Release, September 15, 1965, and letter to Idaho Accelerator Committee from F.S. Rooney, September 20, 1965, in BSU Ms. 6, Box 141, File 9; AEC Press Release, March 22, 1966, in BSU Ms. 6, Box 148, File 1.
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17. Industrial Development Division of the Department of Commerce, *Idaho Industrial Opportunities* (Boise: Department of Commerce, 1966), 4; "Legislature Studies Idaho's New Atomic Mission," *Post-*

Register, January 26, 1967, 16. See also Department of Commerce, *An Action Program for Industrial Progress in Idaho* (Boise: Dept of Commerce, 1968).

18. To Jordan from R.R. Smith, July 1, 1966, BSU Ms. 6, Box 147, Folder 136.
19. To Smylie from Lloyd Howe, July 8, 1966, IHS, Samuelson Papers, Box 13, File: Commerce and Development—Nuclear Advisory Committee; (new platform quotation) to Jordan from Robb Brady, April 26 and July 14, 1966, BSU, Ms. 6, Box 147, Folder 36; and R.R. Smith to Jordan, July 1, 1966, op cit.; to Jordan from Brady, June 3, 1966, BSU Ms. 6, Box 148, Folder 1.
20. To Chet Holifield from Glenn Seaborg, January 23, 1967, BSU Ms. 6, Box 154, Folder 30; (strenuous protest) to Seaborg from McClure, February 2, 1967; "Idaho Loses Another Atomic Race," editorial, *Post-Register*, January 25, 1967, 4.
21. Idaho Code 39-3004 established the Idaho Nuclear Energy Commission, created by S.B. 115, 39th Session, Idaho Legislature (1967).
22. INEC, *Annual Report of the Idaho Nuclear Energy Commission, Report No. 3*, 1969 (Boise: INEC, 1969), 1.
23. Bill Ginkel, "Remarks at Chamber of Commerce Breakfast Meeting," Westbank Motel, Idaho Falls, May 16, 1967, p. 3.
24. Other members were Donald McKay, Wallace C. Burns, Perry Nelson, Albert E. Wilson, see *INEC Annual Report Number Two, 1968*.
25. J. Shifferdecker, "Idaho Nuclear Panel Directed by Chemist," *Idaho Daily Statesman*, August 6, 1967.
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28. "Atomic Food Unit to be Shown," *Times-News*, April 18-19, 1968, 3; "Peaceful Use of Nuclear Power to be Shown in Buhl," *Times-News*, April 22, 1968, 1; "Gov. Samuelson Slates Buhl Visit to AEC Irradiator," *Buhl Herald*, April 25, 1968, 1; photograph, *Times-News*, April 26-27, 1968, 3.
29. "Bill may be Significant in Efforts to Develop Atomic Energy Uses," *Post-Register*, February 4, 1968; "AEC Approves Pact with Idaho," *NRTS News* (August 1968): 1; "Idaho to Become Atom 'Agreement' State," *Post-Register* (August 11, 1968), 10.
30. (Research grants) INEC Report No. 3; (compact) "Western Interstate Nuclear Board Annual Report, 1969-1970," in BSU Ms. 6, Box 174, Folder 31; "An Act Authorizing entry of the State into the Western Interstate Nuclear Compact" and "An Act Appropriating Moneys from the General Fund to the INEC for...paying the State's share of expenses to the Western Interstate Nuclear Compact," in BSU Ms. 6, Box 167, Folder 8; to John Conway, JCAE, from R.E. Hollingsworth, GM AEC, April 26, 1968, BSU Ms. 6, Box 162, Folder 4.
31. To INEC from MTR Study Committee, March 3, 1968, in IHS, Samuelson Papers, Box 23, File: State AEC/Nuclear Energy Commission; to Glenn Seaborg from Samuelson, April 19, 1968; to Steele Barnett from Seaborg, April 8, 1968, in IHS, Samuelson papers, Box 50, File: Nuclear 1968.

Chapter Twenty

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1. Ben Plastino, *Coming of Age*, 46; Bill Ginkel, interview with author, October 13, 1998.
2. Robb Brady, "12,000 Hear LBJ at Site," *Post-Register*, August 26, 1966, 1.
3. (Policy address) John Horan, interview with author, October 14, 1998; (quotation) Robb Brady, "12,000 Hear LBJ at Site," *Post-Register*, August 26, 1966, 1.
4. Through November 1999, President Lyndon Johnson was the only president of the United States to visit the Site.
5. Commemorative booklet produced by NRTS, "President's Visit, August 26, 1966," copy found at IHS; Bill Ginkel, interview with author, October 13, 1998.
6. "Governors Back Idaho Reactor," *Post-Register*, May 17, 1968; "Idaho Views Fund Use for Reactor, *Post-Register*, June 7, 1968.
7. "Remarks by Wilfrid E. Johnson, US AEC Commissioner, August 15, 1968, Rotary Club," IHS, Samuelson Papers, Box 50, File: Nuclear 1968.
8. Pamphlet "MTR, Today an Irradiation Facility, Tomorrow...Western Beam Research Reactor, The Hub for Neutron Research in the Western United States,"in BSU Ms. 6, Box 167, Folder 10.
9. See "In preparation for KIFI Channel 8 program in Idaho Falls, November 8, 1968," IHS, Samuelson Papers, Box 23, File: State AEC/Nuclear Energy Commission; "Nuclear Council Advances Member Drive; MTR Role Scoped," *Post-Register*, December 8, 1968, 12; to Dr. Lee Dubridge from Orval Hansen, January 27, 1969, IHS, Ms. 400, Box 1, File: 9/I/A/5 Atomic Energy; to Jordan from Samuelson, April 9, 1969, BSU Ms. 6, Box 167, Folder 11; to Chet Holifield from Orval Hansen, May 3, 1969, BSU Ms. 6, Box 167, Folder 10; *Congressional Record* (Volume 115, No. 73, Tuesday May 6, 1969):E 3666-7.
10. To Ginkel from Samuelson, December 26, 1968, IHS Samuelson Papers, Box 23, File: State AEC/Nuclear Energy Commission.
11. To Frank Church from Robert D. O'Neill, AEC, September 15, 1969, BSU Frank Church Papers, Series 3.2.1, Box 3, Folder 1; to Wallace F. Bennett from Seaborg, May 20, 1969, BSU Ms. 6, Box 167, Folder 10.
12. "A Proposal to Sustain the MTR as the WBRR for a Two-Year Period," in BSU Ms. 6, Box 167, Folder 10; "AEC Denies Universities' Bid for Arco Materials Reactor," *Idaho Statesman*, October 11, 1969; (commercial business) to William Ginkel from Joseph Rosenbuerg, January 27, 1970, BSU Ms. 6, Box 174, Folder 32; to Jordan from Rutledge, February 10, 1970, BSU Ms. 6, Box 174, Folder 32.
13. To Jordan from Robert O'Neill, AEC Congressional Relations, April 27, 1870, BSU Ms. 6, Box 174, Folder 32.
14. To Rutledge from Donald F. Kline, Executive Director for Higher Education, May 28, 1970, BSU, Ms. 6, Box 174, Folder 32. See also "Application for Funding for a Proposed Study of Mercury Poisoning in Idaho," May 28, 1970, and related documents in same folder.
15. (August critical) to Edward Bauser from R.E. Hollingsworth, August 27, 1970, IHS Ms. 400, Box 43, File: JCAE-MTR; "Governor Sees MTR Still Displays Class," *Post-Register*, August 25, 1970, 2.

16. To Samuelson from Hollingsworth, August 19, 1970, BSU Ms. 6, Box 174, Folder 32.

17. To James Schlesinger from Donald J. Mackay, March 28, 1972, BSU Ms. 141-3, Box 91, Folder 7. The *Post-Register* speculated that the AEC refused to help with the MTR because it was protecting General Electric, which it had encouraged to build a test reactor at Vallecitos, California, to produce radioisotopes for private industry. See R.C. Russell, "'Chess Game' Continues Over Future of MTR," *Post-Register*, September 13, 1970, 16; (population) Cartography Students, University of Idaho, *The Compact Atlas of Idaho* (Moscow, Idaho: Cart-O-Graphics Laboratory, 1938, 61.

18. To Hansen from Edward E. David, Jr., February 18, 1972, IHS, Ms. 400, Box 34, File: AEC-General.

19. C. Wayne Bills, personal communication to author,
September 2, 1999.

20. (NRAD reactor) Richard Lindsay, personal communication.

21. 21. Peter H. Metzger, *The Atomic Establishment* (New York: Simon and Schuster, 1972), 150; Lawrence E. Davies, "Fire Cleanup Keeps Plutonium Plant Busy" *New York Times*, June 17, 1969, 10.

22. Bill Ginkel to Robert Erkins, Sept. 12, 1969, IHS, Ms. 400, Box 16, File: Atomic Energy.

23. (Ginkel quote, previous paragraph) "Radioactive Wastes Disposal Not Hazardous, AEC Claims," *Post-Register*, September 11, 1969; (Lee) "Thorough Investigation Needed," September 15, 1969, and "National Atomic Dump," circa October, 1969, p. 4, both from *South Idaho Press*.

24. To Doug Bean from Ginkel, Oct. 21, 1968, IHS, Samuelson Papers, Box 50, File: Nuclear-1968; "Official Thinks AEC Tries to Avert Contaminating Ground Water" and "AEC Wastes Miss Goals Set by Idaho," *Idaho Daily Statesman*, September 12, 1969.

25. To T.O. Carver from Samuelson, October 21, 1969, IHS Ms. 400, Box 16, File: Atomic Energy.

26. News release, September 12, 1969, BSU Frank Church, Series 3.2.1, Box 2, Folder 12.

27. Bob Smith, "AEC Scored on Storing Waste," (possibly from *New York Times*) March 7, 1970; "Burial Hazards Denied by the AEC," *Post-Register*, March 16, 1970, 1. Both items found in IHS, Samuelson Papers, Box 50, File: Nuclear 1970.

28. Bill Ginkel sent the report to Samuelson's Task Force as well as a more current update. See National Academy of Science, "Radioactive Waste Management: An Interim Report of the Subcommittee on Radioactive Waste Management" February 17, 1970, and "Geological Aspects of Radioactive Waste Disposal," 1966, referred to in letter from Ginkel to Samuelson, March 17, 1970, IHS Samuelson Papers, Box 3, File: Health: General. See also *The Atomic Establishment*, p. 151-154.

29. "Meeting of the Governor's Task Force Committee for Investigation of Possible Atomic Pollution to the Snake River Aquifer," Boise, October 29, 1969, IHS Samuelson Papers, Box 50, File: Nuclear 1969.

30. "AEC, State Scan Waste Disposal," *Post-Register*, November 1969 (copy in clipping file IHS, Samuelson Papers, Box 50 in pamphlet file); "Why Idaho Haste on Waste Study?" *Times-News*, September 30, 1969; "AEC Commissioner Backs Idaho AEC Officials, Idaho Nuclear on Issues," *Post-Register*, November 25, 1969.

31. Unsigned memo regarding Howard Tuckner visit to Idaho Falls, January 21, 1970, IHS Samuelson Papers, Box 50, File: Nuclear-1970.

32. "AEC Scientist Raps Safety Standards," *Idaho State Journal*, January 13, 1970.

33. U.S. Department of Health, "Public Health Aspects of the NRTS Radioactive Burial Grounds," copy in *Congressional Record*, March 6, 1970, p. S 3142.

34. To Samuelson from Terrell Carver, November 12, 1970; "Minutes of Meeting of Governor's Task Force on Disposal of Radioactive Wastes in Idaho," October 17 (or Oct. 27, record is ambiguous), 1970, in IHS Samuelson Papers, Box 50, File: Nuclear-1970; (within the decade) to Frank Church from Glenn Seaborg, June 9, 1970.

35. (Salt mine) to Orval Hansen from John A. Erlewine, June 19, 1970; and AEC Press Release, June 17, 1970, IHS, Ms. 400 Hansen, Box 16, File: Atomic Energy Commission; (uniform AEC policies) Anderson, *History of the RWMC*, 36.

36. (New thinking) George Wehmann, interview with author, September 29, 1999; (AEC directive) Anderson, *History of the RWMC*, 42. The directive was Immediate Action Directive (IAD) No. 0511-21, "Policy Statement Regarding Solid Waste Burial."

37. This area eventually became known as Pad A, the only asphalt pad used for above-ground storage within the boundaries of the original 88-acre Burial Ground.

38. (Winter/spring moratorium) Anderson, *History of the RWMC*, p. 37-38. After January 6, 1970, Rocky Flats waste was no longer buried, but stored above the ground.

39. Note: George Wehmann, September 29, 1999.

40. the IDO conducetd several studies of the feasibility and economics of barrel retrieval. See Anderson, *History of the RWMC*, 54-60; (air support buildings) John Commander, interview with author, July 14, 1998.

41. *Technical Site Information*, 1993, Radioactive Waste Management Complex, p. 13.

CHAPTER TWENTY ONE

1. To Syd Duncombe, University of Idaho, from Cecil Andrus, July 7, 1972, in BSU Ms. 141-3, Box 91, File 7.

2. BSU Ms. 141-3, Box 92, File 2 contains marked and highlighted articles on the potentials of hydrogen fuel including "Hydrogen and Other Synthetic Fuels, A Summary of the Work of the Synthetic Fuels Panel," prepared for the Federal Council on Science and Technology; "When Hydrogen Become's the World's Chief Fuel," *Business Week* (September 23, 1972): 98; Lawrence Lessing, "The Coming Hydrogen Economy," *Fortune* (November 1972): 138-145.

3. C.C. Warnick, W.P. Barnes, E.L. Michaelson, et al, *A Conceptual Study of a Nuclear Energy Park for the State of Idaho* (Moscow: University of Idaho, November 1972); "$150,000 U.S. Revenue Earmarked for NRTS," newsclip with no date or name in BSU Ms. 141-3, Box 91, File 2 (Agrocarbon Hydrogen Study).

4. To Cecil Andrus from Gene Rutledge, February 22, 1073; to Andrus from Alfred T. Whatley, Western Interstate Nuclear Board; both in BUS Ms. 141-3, Box 91, File 8.

5. Drs. John Howe and Maynard Fosberg, *A Study of the Unitization of Water from a*

Nuclear Reactor to Grow Trees and Ornamentals (Moscow: University of Idaho, 1973.) The water was non-radioactive cooling water from the Chem Plant condenser.

6. To Dixy Lee Ray from Cecil Andrus, July 31, 1973; to Andrus from Ray, September 6, 1973; BSU Ms. 141-1, Box 62, File 14.
7. To Governor Andrus (and others) from Michael Christie, August 28, 1973, BSU Ms. 141-3, Box 91, File 8; "AEC Eyes Nevada Site as Dump for A-Wastes," *Washington Post*, August 28, 1973.
8. To Dixy Lee Ray from Frank Church and Cecil Andrus, October 9, 1973, BSU Ms. 141-3, Box 9, File 8.
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25. (Quotation) Beverly Cook, interview with author, September 7, 1999.

Acronyms

630-A	High Temperature Marine Propulsion Reactor
710	Fast Spectrum Refractory Metals Reactor
A1W	Aircraft carrier, first prototype, Westinghouse (Also known as the Large Ship Reactor A and B)
A/E	architect/engineering
ACRS	Advisory Committee on Reactor Safeguards
AEC	Atomic Energy Commission
AFSR	Argonne Fast Source Reactor
AI	Atomics International
ANC	Aerojet Nuclear Corporation
ANP	Aircraft Nuclear Propulsion
ARA	Army Reactor Area, (Later Auxiliary Reactor Area)
AREA	Army Reactor Experimental Area
ARMF	Advanced Reactivity Measurement Facility
ATR	Advanced Test Reactor
ATRC	Advanced Test Reactor Critical Facility
ATWS	Anticipated Transients Without Scrams
BORAX	Boiling Water Reactor Experiment
BPA	Bonneville Power Administration
CE	Combustion Engineering
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERT	Controlled Environmental Radioiodine Tests
CET	Critical Experiment Tank
CFA	Central Facilities Area
CFRMF	Coupled Fast Reactivity Measurement Facility
CP-1	Chicago Pile Number One
CPP	Chemical Processing Plant
CRADA	Cooperative Research and Development Agreement
CRCE	Cavity Reactor Critical Experiment
DEW	Distant Early Warning System
DoD	Department of Defense
DOE	Department of Energy
DOE-ID	Department of Energy-Idaho Operations Office
EBR	Experimental Breeder Reactor
EBOR	Experimental Beryllium Oxide Reactor
EBWR	Experimental Boiling Water Reactor
ECCS	Emergency Core Cooling System
ECF	Expended Core Facility
EINIC	East Idaho Nuclear Industry Council
EIS	Environmental Impact Statement
EOCR	Experimental Organic Cooled Reactor
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
EROB	Engineering Research Office Building
ETR	Engineering Test Reactor
ETRC	Engineering Test Reactor Critical Facility
FARET	Fast Reactor Test Facility
FCF	Fuel Cycle Facility
FET	Flight Engine Test
FFTF	Fast-Flux Test Facility
FLECHT	Full-length Emergency Core Heating Tests
FPC	Federal Power Commission
FRAN	Nuclear Effects Reactor
FRAP	Fuel Rod Analysis Program
FWPCA	Federal Water Pollution Control Administration
GCRE	Gas Cooled Reactor Experiment
GE	General Electric
HOTCE	Hot Critical Experiment
HP	health physicist
HTRE	Heat Transfer Reactor Experiment
ICPP	Idaho Chemical Processing Plant
IDO	Idaho Operations Office
IDWR	Idaho Department of Water Resources
IET	Initial Engine Test
IFR	Integral Fast Reactor
INC	Idaho Nuclear Corporation
INEC	Idaho Nuclear Energy Commission

INL	Idaho National Laboratory
INEL	Idaho National Engineering Laboratory
INEEL	Idaho National Engineering and Environmental Laboratory
INFCE	International Nuclear Fuel Cycle Evaluation
INTEC	Idaho Nuclear Technology and Engineering Center
IRC	INEEL Research Center
ISC	INEEL Supercomputing Center
ISU	Idaho State University
JCAE	Joint Committee on Atomic Energy
KAPL	Knolls Atomic Power Laboratory
LMFBR	Liquid Metal Fast Breeder Reactor
LOCA	Loss-of-Coolant Accident
LOFT	Loss of Fluid Test
MIT	Massachusetts Institute of Technology
ML-1	Mobile Low-Power Reactor
MTR	Materials Testing Reactor
NaK	eutectic alloy of sodium (Na) potassium (K)
NAS	National Academy of Science
NASA	National Aeronautic and Space Administration
NEPA	National Environmental Policy Act
NERI	National Energy Research Initiative
NERP	National Environmental Research Park
NOAA	National Oceanic and Atmospheric Administration
NPG	Naval Proving Ground
NPR	New Production Reactor
NRAD	Neutron Radiography Facility
NRC	Nuclear Regulatory Commission
NRF	Naval Reactors Facility
NRTS	National Reactor Testing Station
NSF	National Science Foundation
NWCF	New Waste Calcining Facility
OAC	operating area confinement
OMRE	Organic Moderated Reactor Experiment
OU	operable unit
PBF	Power Burst Facility
RAF	Remote Analytical Facility
RaLa	radioactive lanthanum
RIA	reactivity-initiated accidents
REM	roentgen equivalent man
RMF	Reactivity Measurement Facility
RWMC	Radioactive Waste Management Complex
S5G	submarine reactor, 5th prototype, General Electric (Also known as the Natural Circulation Reactor)
SCRCE	Spherical Cavity Reactor Critical Experiment
SDI	Strategic Defense Initiative
SIS	Special Isotope Separations
SL-1	Stationary Low-Power Reactor
SM-1	Stationary Medium-Power Reactor
SMC	Specific Manufacturing Capability
SNAP	Systems for Nuclear Auxiliary Power
SPERT	Special Power Excursion Reactor Test
STEP	Safety Test Engineering Program
STR	Submarine Thermal Reactor (Also known as S1W or, Submarine reactor, 1st prototype, Westinghouse)
STR	Split Table Reactor
SUSIE	Shield Test Pool Facility
TAN	Test Area North
THRITS	Thermal Idaho Reactor Test Station
TMI	Three Mile Island
TRA	Test Reactor Area
TSA/B	Technical Support Building
TREAT	Transient Reactor Test
TRU	transuranic
U of I	University of Idaho
UAW	United Auto Workers
UP&L	Utah Power and Light
USGS	United States Geological Survey
USSR	Union of Soviet Socialist Republics
WAG	Waste Area Group
WBRR	Western Beam Research Reactor
WCB	Willow Creek Building
WCF	Waste Calcining Facility
WERF	Waste Experimental Reduction Facility
WIPP	Waste Isolation Pilot Plant
WOW	Woman Ordnance Worker
ZPR	Zero Power Reactor
ZPPR	Zero Power Physics Reactor (Previously known as the Zero Power Plutonium Reactor)

Glossary

Activation product

Upon bombardment with neutrons, some materials absorb neutrons into their nuclei, forming new and usually radioactive isotopes.

Alpha particle

A positively charged nuclear particle identical with the nucleus of a helium atom. It consists of two protons and two neutrons. Alpha particles can be stopped by a sheet of paper.

Anti-Cs

Slang speech meaning “anti-contamination,” referring to special clothing worn by people requiring protection from radiation.

Atom

The smallest particle of an element that can exist either alone or in combination with other elements. Atoms are made up of electrons, neutrons, and protons.

Atomic energy

Energy that can be liberated by changes in the nucleus of an atom, such as by fission or fusion. Contemporary scientists prefer to use the term “nuclear energy.”

Atomic number

A characteristic of an element, the number of protons in the nucleus.

Aquifer

A water-bearing stratum of permeable rock, sand, or gravel.

Background radiation

The radiation in an ambient environment. It includes cosmic rays from outer space, radon gas, and other forms of radiation from natural sources (such as granite) and human-made sources (dental X-rays, fallout from nuclear explosions).

Beta particle

An electron or positron ejected from the nucleus of an atom during radioactive decay. The mass of an electron is equal to 1/1837 that of a proton. It can be stopped by an inch of wood or a thin sheet of aluminum.

Bin set

A cluster of storage containers at the Idaho Nuclear Technology Engineering Center built to store solid calcine waste. The waste is highly radioactive, and the bin sets are heavily shielded.

Blowdown

A term used to describe sudden depressurization upon the breaking of a pipe carrying pressurized water.

Boiling water reactor

A nuclear reactor concept in which the coolant, water, is permitted to boil as it absorbs the heat of the nuclear reaction. The resultant steam drives a turbine and generates electricity.

Breeder reactor

A nuclear reactor concept in which the operation produces a net increase in fissionable material. That is, more fissionable material is produced than is consumed.

Calcine

As a noun, the dry solid (grainy or granular) product of a chemical process removing liquids from a solution. As a verb, the heating of a material at a high temperature to drive off volatile materials.

Cerenkov radiation

A blue-white light produced when gamma rays hit electrons in water. The energy of the gamma rays is sufficiently great that the electrons move through the water faster than light moves through water.

Cesium-137

A radioactive isotope of the element cesium, which emits gamma radiation. It is an important fission product.

Chain reaction

A self-sustaining sequence of events occurring when a neutron splits a fissionable atom (of uranium, for example) and releases sufficient neutrons to cause other atoms to split in the same way.

China Syndrome

A figure of speech referring to a theoretical melting of nuclear reactor fuel which would occur upon a loss of coolant to the fuel. The fuel would melt, penetrate the reactor vessel, drop to the concrete floor of the building, and reach the soil below. The phrase comes from the expression "dig a hole all the way to China," a fantasy of (American) children who believe China to be on the opposite side of the globe from their own playground.

Chicago Pile-1

The name of the first nuclear reactor to go critical, so called because graphite blocks were piled upon each other to construct the reactor.

Cladding

The outer layer of metal over the fissionable material in a nuclear fuel element, typically aluminum or zirconium. Cladding promotes the transfer of heat from the fuel to the coolant and contains fission products and activation products within the fuel element.

Cold run

A test of a chemical process and equipment using non-radioactive materials.

Cold shutdown

A reactor condition in which the coolant temperature has been reduced to 200° F or below, the pressure has been reduced to atmospheric pressure, and the chain reaction has stopped.

Cold War

A conflict over ideological differences between the United States and the Soviet Union and their respective allies lasting from the late 1940s until early in the 1990s. It was carried on by means other than sustained or direct military action.

Containment building

A safety feature of most commercial nuclear reactor power plants. The airtight building, typically engineered to contain gases and pressures that might be released in an accident, houses the reactor, pressurizer, coolant pumps, and other equipment.

Control rod

A device within a nuclear reactor made of materials which absorb neutrons. Control rods help dampen or permit the reactor's chain reaction.

Contamination, radioactive

Unintentional or undesirable contact of a person, object, or material with radioactive substances.

Control room

The operating center of a nuclear reactor from which the reactor is operated and monitored.

Coolant

In a nuclear reactor, a gas or fluid (such as water or liquid metal) sent past the fuel elements to collect and carry away the heat generated by the nuclear reaction.

Core

That part of the nuclear reactor consisting of the fuel and control elements, the coolant, and the vessel containing these.

Criticality

The point at which a nuclear reactor is just capable of sustaining a chain reaction.

Critical mass

The minimum amount of nuclear fuel necessary to sustain a chain reaction.

Curie

A measure of radioactivity, a curie is that quantity of material that decays at a rate of $3.7\text{x}10^{10}$ disintegrations per second.

D&D

An abbreviation for "decontamination and decommissioning," particularly of a building or structure that once housed active nuclear activities and may have been contaminated in the process. Historic uses of the term may also have referred to "dismantling" or "demolishing."

Decontaminate

A process removing radioactive materials from a person, place, or object.

Decay

The spontaneous ejection of particles by radioactive materials. Synonym for radioactive disintegration.

Depleted uranium

Uranium that, through the process of enrichment, has been stripped of most of the uranium-235 it once contained. It has more uranium-238 than natural uranium, but is referred to as "depleted."

Dose

A specific amount of ionizing radiation or a toxic substance absorbed by a living being.

Glossary

Dosimeter

A device such as a film badge which can be worn by a person (or placed somewhere in the environment) and is used to measure the radiation dose received over a period of time.

Electron

An elementary particle consisting of a charge of negative energy. Electrons are said to circle the nucleus of an atom.

Emergency Core Cooling System

An emergency backup system designed to inject cooling water into the core of a reactor in the event that the normal cooling system fails. This safety requirement is intended to prevent the overheating of the fuel and subsequent melting.

Enriched uranium

Uranium which has been modified from its natural state to contain a higher concentration of the isotope uranium-235 than natural uranium.

Excursion

A term used to describe an unexpected or accidental increase in the power level of a nuclear reaction.

Fallout

Radioactive particles and gases resulting from a nuclear explosion which gradually descend to earth.

Film badge

A piece of masked photographic film worn by nuclear workers. The film is darkened by radiation and can be analyzed to indicate how much exposure the film and the badge wearer received over a period of time.

Fission

The splitting of an atomic nucleus resulting in the creation of lighter elements, heat, free neutrons, and other particles.

Fission product

Any of several lighter elements or particles created by the nuclear fission of a heavy element such as uranium.

Flux

The flow or stream of neutrons emanating from nuclear fission.

Fossil fuels

Coal, oil, and natural gas are referred to as "fossil" fuels because they are the remains of plants and animals that lived on earth millions of years ago.

Fuel cycle

The life cycle of a fuel including the complete sequence of steps beginning with mining and refining an ore and ending with the disposition of the waste products after the fuel has been beneficially used.

Fuel reprocessing

A chemical process, usually involving several steps, that recovers uranium-235 and other fissionable products from spent fuel.

Fuel assembly

An arrangement of nuclear fuel and its cladding material into a particular form and shape for use in a nuclear reactor. Fuel may be assembled in plates, rods of various diameters, or other shapes.

Fusion

The union of atomic nuclei to form heavier nuclei resulting in the release of enormous quantities of energy. The process usually requires conditions of extreme heat and pressure.

Gamma radiation

High-energy, high penetrating electromagnetic radiation emitted in the radioactive decay of many radionuclides. They are similar to X-rays.

Geiger counter

An instrument used to detect and measure beta and gamma radiation.

Half-life

The time it takes for one-half of any given number of unstable atoms to decay (disintegrate). Half-life is unaffected by temperature, pressure, or chemical conditions surrounding the substance.

Hot cell

A specialized shielded laboratory in which radioactive materials may be handled with the aid of remotely operated manipulators. The walls and windows of the laboratory are made of materials designed to protect workers from gamma and other radiation.

Hot run

An operational (or test) run of a chemical process and equipment using radioactive materials.

Hot settlement Pond

An outdoor basin, usually lined at the bottom with clay, in which liquids containing radioactive particles are sent to evaporate. Solids settle to the bottom, where they are adsorbed onto the clay.

Interim storage

A concept in the management of nuclear waste in which the waste is moved to an intermediary location between its point of origin and its "final" or ultimate storage location.

Iodine-131

Also called radioiodine or radioactive iodine, an isotope of the element iodine, which has a half-life of about eight days. This (and other iodine isotopes) are released when the cladding surrounding spent fuel is dissolved or breached.

Ion exchange

A chemical process in which a substance dissolved in water is exchanged with another.

Ionization chamber

A device used to measure radioactivity.

Irradiate

To expose a substance to ionizing radiation in a nuclear reactor. The substance so exposed may be referred to as the target.

Isotope

Any of two or more species of atoms of a chemical element distinguished by different quantities of neutrons in their nuclei. For example, hydrogen has three isotopes: protium (one proton), deuterium (two protons), and tritium (three protons).

Linear accelerator

A device in which charged particles are speeded up in a straight line by successive impulses from a series of electric fields.

Manhattan Engineer District/Manhattan Project

Created by President Roosevelt in 1939, the Manhattan Engineer District of the U.S. Army Corps of Engineers was commissioned to build an atomic bomb. The effort was referred to as the Manhattan Project.

Maximum permissible dose

A regulatory limit on the radiation exposure that a nuclear worker or a member of the general public may legally receive due to radioactive releases from a nuclear power plant or other nuclear activity.

Megawatt

A measure of electrical power equal to one million watts.

Meltdown

The accidental melting of nuclear reactor fuel caused by a failure of the coolant to carry away heat.

Millirem

A unit of radiation equal to one thousandth of a "rem." See rem.

Microcurie

A measure of radioactivity equal to one millionth of a curie.

Mixed waste

Waste that contains both chemically hazardous and radioactive waste.

Moderator

A material used in a nuclear reactor to reduce the natural speed of neutrons ejected from fissioning atoms. Typical moderators are water or graphite.

Natural uranium

Uranium that has not been through an enrichment process to separate its uranium-235 isotopes. It is made of uranium-238 (99.3 percent) and uranium-235 (0.7 percent).

Neutron

An uncharged particle, a part of an atomic nucleus, having a mass nearly equal to that of a proton. One or more neutrons are present in every known element except hydrogen.

Noble gases

Elemental gases which do not generally combine chemically with other materials. They are helium, neon, argon, krypton, xenon, and radon.

Nuclear power plant

An electrical generating facility using nuclear fuel.

Nuclear energy

Energy released in a nuclear fission or fusion reaction.

Nuclear reactor

A complex device designed to contain a controlled nuclear fission chain reaction. A reactor may function for testing and experimentation (Materials Test Reactor), for the generation of electricity (any commercial nuclear power plant), for the production of weapons-related materials such as tritium or plutonium (N Reactor at Hanford), as a breeder of nuclear fuel (Experimental Breeder Reactor), for propulsion (Submarine Thermal Reactor), or as a combination of these functions.

Nuclear waste

A general term including high-level, transuranic, low-level, mixed low-level, and byproduct material. Each of these terms is further defined for regulatory purposes.

Nucleus

Center of an atom consisting of a cluster of neutrons and protons. It contains nearly all of the mass of the atom.

Plutonium

A metallic element most typically created by irradiating uranium in nuclear reactors (although small amounts have been found in nature). The fissionable isotope plutonium-239 can be used as reactor fuel.

Pressurized water reactor

A reactor concept in which water is used to cool the reactor core. It is pressurized to prevent it from boiling. Heat is transferred from a "primary" coolant pipe to a "secondary" pipe.

Primary loop

A closed system of piping through which coolant flows past the nuclear fuel in a reactor.

Prompt critical

A state of criticality derived from the fact that a small percentage of neutrons in a chain reaction are not emitted as soon as the atom splits, but are "delayed" for as long as a few minutes. "Prompt" neutrons are emitted immediately upon fission. If a reactor goes "prompt critical," it indicates that reactivity has increased to the point that prompt neutrons alone are sufficient to maintain the chain reaction. Rapid multiplication of neutrons can occur after this point. In the SL-1 reactor accident, the rapid withdrawal of the control rod is presumed to have brought about a state of prompt criticality, in which the chain reaction did not require the emission of the "delayed" neutrons to begin or continue.

Proton

An elementary atomic particle that is identical with the nucleus of a hydrogen atom. Along with neutrons, it is a constituent of all other atomic nuclei.

PUREX

An acronym for plutonium-uranium extraction, the name of a chemical process used to reprocess spent nuclear fuel and irradiated targets.

R&D 100 Award

Research and development awards presented by *R&D Magazine*. Only one hundred R&D innovations are recognized in the country each year.

Radiation

Energy transferred through space or some other media in the form of particles or waves. If the particles or waves are capable of breaking up atoms or molecules, then the radiation is said to be ionizing radiation.

R

An abbreviation meaning "roentgen." One roentgen (R) measures the power of gamma or X-rays to produce ionization (ie, strip an electron from an otherwise stable atom) in one gram of air.

Radioactive waste

By-products of nuclear processes which are radioactive and have no useful recyclable purpose.

Radioactivity

The spontaneous emission of particles or waves from the nucleus of an atom. The emissions may include alpha and beta particles, and gamma rays.

Radionuclide

A radioactive species of an atom. For example, strontium-90 is a radionuclide (also called a radioisotope) of strontium.

RaLa

An abbreviation for Radioactive Lanthanum, one of the fission products of a nuclear reaction. It was useful to scientists developing a plutonium bomb.

Reactor vessel

A cylindrical steel container enclosing the fuel elements, control elements, coolant piping, and other structures that support the core of a nuclear reactor.

Reflector

Part of the structure of some nuclear reactors designed to reflect neutrons back toward the core of the reactor.

Rem (or REM)

An abbreviation meaning "roentgen equivalent man," a measure of the amount of exposure (dose) of radiation that takes into account the biological effectiveness of the exposure on the particular organ exposed.

Retention basin

An outdoor basin (of any of several designs) in which liquid solutions are deposited and held pending evaporation or the precipitation of solids.

Roentgen

An international unit of measurement of gamma or X- radiation. See "R" above.

Secondary loop

In a reactor coolant system, heat carried away from the reactor core in a "primary" system is transferred to a second loop. Water in the second loop does not become radioactive and its steam is used to spin turbines for electrical generation.

Semiscale

The informal name of a scale model of a nuclear reactor operated as part of the Nuclear Reactor Safety Test Engineering Program at the NRTS/INEL. Instead of using nuclear fuel, the "core" simulated the heat of a nuclear reaction by electrical means. The device was used to study the behavior of water and steam in accidents involving the loss of coolant caused by a broken pipe.

Scram

A sudden shutting down of a nuclear reactor, usually by dropping safety rods, when a predetermined neutron flux or other dangerous condition occurs.

Shielding

Material such as lead, concrete, water, paraffin, and other materials used to prevent the escape of radiation into the ambient or working environment of people and equipment.

Spent nuclear fuel

Nuclear fuel containing fission and activation products that can no longer economically sustain a chain reaction and is withdrawn from a reactor.

Spent fuel storage basin

A pool or pit made of reinforced concrete containing water and used to store spent nuclear fuel. The water acts as a shield preventing radiation from harming workers near the pool.

Transuranic waste (TRU)

Waste materials contaminated with human-made elements heavier than uranium, such as plutonium. Also called TRU (transuranic waste). This term also implies a regulatory definition in which the waste contains substances with a half-life over twenty years in concentrations of more than one ten-millionth of a curie per gram of waste.

Triga

The brand name of a small, low-power reactor manufactured by General Atomics for use in universities and laboratories. The reactor was in a small pool of water used as both coolant and moderator. Similar reactors are often called "triga-type" reactors.

Tritium

An isotope of hydrogen containing three protons. Tritium gas is produced in nuclear reactors and used to boost the explosive power of most modern nuclear weapons. It is also a constituent of irradiated water associated with reactor operations.

Uranium-235

A fissionable isotope of the metallic element, uranium. In nature, only 0.7 percent of all uranium mined from the ground consists of this isotope.

Uranium-238

The most common isotope of uranium. It does not generally fission, but can be irradiated in a reactor and transformed to an isotope of plutonium which does fission.

Uranium oxide

A metallic compound of uranium and oxygen, a useful form of uranium for use as nuclear fuel because it has a higher melting point than metallic uranium and can survive the high temperatures inside a reactor more readily. However, its heat transfer properties are not as efficient as those of metallic uranium.

Water-moderated reactor

A reactor concept which is designed so that water slows down the speed of neutrons ejected from fissioning atoms. Includes boiling water and pressurized water reactor concepts.

Warm run

The operation of a chemical process using materials that are slightly radioactive. A "warm" run is contrasted with "cold" or "hot" runs.

Waste storage tank

A holding tank for liquid or gaseous wastes which may or may not be radioactive.

Zirconium

A metallic element highly resistant to corrosion and used to make cladding for nuclear fuel elements. It is sometimes alloyed in small amounts in the fuel itself.

Zero power

Also called "low power," a mode of operating a reactor so that it maintains a chain reaction at extremely low power levels. It produces very little heat. Zero power reactors are used as sensitive laboratory tools to pre-test experimental loadings of test reactors and for other analytical purposes.

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About the Author

Educated at Georgetown University and the University of Pittsburgh, Susan M. Stacy became a resident of Boise, Idaho, in 1973, She became interested in historical research while serving the City of Boise as director of the Boise City Planning Department from 1979 to 1986. She returned to school, obtained a Master of History at Boise State University, and began a career as a research historian and author. *Proving the Principle* is her fourth book, the others being *When the River Rises, Flood Control on the Boise River, 1943-1985*; *Conversations, A Companion Book to Idaho Public Television's Proceeding On Through a Beautiful Country*; and *Legacy of Light, A History of the Idaho Power Company*. In addition to writing full-length books, she does historical research for reports, biographies, photographic exhibits, National Register nominations, Historic American Engineering Record and Historic American Building Survey reports, and other historical research for public, corporate, legal, and private clients.

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