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ACRONYMS AND ABBREVIATIONS

$\kappa^{\pm}$	kaon, plus and minus, or κ meson, fundamental particles
$\pi^{\pm}$	pion, plus and minus, or π meson, fundamental particles
A	ampere
AEC	U.S. Atomic Energy Commission
AGHCF	Alpha Gamma Hot Cell Facility
ANL-E	Argonne National Laboratory-East
APS	Advanced Photon Source
ATSR	Argonne Thermal Source Reactor
ATLAS	Argonne Tandem Linear Accelerator System
Bq	becquerel
CP-1	Chicago Pile 1
CP-2	Chicago Pile 2
CP-3´	Chicago Pile 3 Prime
CP-3	Chicago Pile 3
CP-5	Chicago Pile 5
D&D	decontamination and decommissioning
EBR-II	Experimental Breeder Reactor No. 2
EBWR	Experimental Boiling Water Reactor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ENE Area	East Northeast Area
ESH	Environment, Safety and Health
ft	feet
g	gram
GeV	giga electron volt; 1 billion electron volts
ha	hectare
HVEM	High-Voltage Electron Microscope
hr	hour
Hz	hertz
in	inch
IPNS	Intense Pulsed Neutron Source
IVEM	Intermediate Voltage Electron Microscope
keV	kilo electron volt; 1,000 electron volts
kW	kilowatt
lb	pound
LINAC	linear accelerator
LMFBR	Liquid Metal Fast Breeder Reactor

m	meter
mA	milliampere
MARS	Microcosm for Acid Rain Studies
mCi	millicurie
MeV	mega electron volt; 1 million electron volts
MHz	megahertz
mi	mile
min	minute
millirem	millirem
mm	millimeter
mR	milliroentgen
n	neutron
nC	nanocoulomb
NEC	National Electrostatics Corporation
NIOSH	National Institute for Occupational Safety and Health
NRTS	National Reactor Testing Station
ns	nanosecond
PAR	Positron Accumulator Ring
pps	pulses per second
RCS	Rapid Cycling Synchrotron
s	second
SNM	Special Nuclear Material
TBD	technical basis document
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
yr	year
ZGS	Zero Gradient Synchrotron
ZPR-I	Zero Power Reactor No. 1
ZPR-II	Zero Power Reactor No. 2
ZPR-IV	Zero Power Reactor No. 4
ZPR-IV´	Zero Power Reactor No. 4 Prime
ZPR-V	Zero Power Reactor No. 5
ZPR-VI	Zero Power Reactor No. 6
ZPR-VII	Zero Power Reactor No. 7
ZPR-IX	Zero Power Reactor No. 9
µA	microampere
µg	microgram
§	section

2.1 INTRODUCTION

Technical basis documents (TBDs) and site profile documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute for Occupational Safety and Health (NIOSH) in the completion of the individual work required for each dose reconstruction.

In this document, the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the [probability of causation] guidelines established under subsection (c) …." [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all radiation exposures in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

Argonne National Laboratory was established on July 1, 1946 and this TBD is intended to cover since that date. The work was a continuation of that done by the Metallurgical Laboratory of the University of Chicago beginning in 1941 which is an Atomic Weapons Employer under EEOICPA. The job locations did not change until land and buildings were acquired for the laboratory.

The purpose of the Argonne National Laboratory-East Site Profile is to provide information to assist in the evaluation of occupational radiation dose associated with ANL-E operations during the period applicable under the EEOICPA, which is from 1946 to the present. The information provided is selected based on the need to evaluate monitored and unmonitored worker exposure, as well as missed dose, using the methodology in *External Dose Reconstruction Implementation Guideline* (NIOSH 2002a) and *Internal Dose Reconstruction implementation Guideline* (NIOSH 2002b). This TBD describes the ANL-E site, facilities and processes, and other historical information about routine and accidental releases of radioactive contaminants, accidental worker exposures, and access control, for use if relevant worker data is not available.

2.2 SITE ACTIVITIES AND PROCESSES

2.2.1 Location and History

ANL-E was established as the first national laboratory on July 1, 1946, as a result of the Atomic Energy Act of 1946, which created the U.S. Atomic Energy Commission (AEC) and the national laboratory system. The University of Chicago has operated ANL-E since its creation. The research that ANL-E carried out in the early years as a national laboratory began under the university's Metallurgical Laboratory, which built the first nuclear reactor, Chicago Pile 1 (CP-1), under the West Stands of the university's Stagg Field. CP-1 successfully achieved the world's first man-made nuclear chain reaction in 1942. Before 1946, the University dismantled CP-1 and rebuilt it as CP-2 at Site A in the Palos Forest Preserve about 25 mi southwest of Chicago in the Argonne Woods (Site A in Figure 2-1). The 7.9-ha (19-acre) site became known as Argonne Laboratory in 1943.

The present site of the ANL-E (Site D in Figure 2-1) is on the central 607 ha (1,500 acres) of a 1,514-ha (3,740-acre) tract in Dupage County, Illinois, about 27 mi southwest of downtown Chicago and 5 mi west of Site A (Wescott and O'Rourke, 2001a). This site was acquired in 1947 and was called Site D (*D* for Dupage County). Much of the 907-ha (2,240 acre) Waterfall Glen Forest Preserve around the site was part of ANL-E before being deeded to the Dupage County Forest Preserve District in 1973 (Golchert and Kolzow 2004).

2.2.2 Development of Site A

In March of 1943, the CP-1 reactor was moved from the West Stands to Site A (Figure 2-2) and renamed CP-2 (ANL 1979a). The CP-1 and CP-2 reactors used natural uranium metal fuel and a graphite moderator. The CP-2 was surrounded by 5' of concrete shielding. In May of 1944, CP-3 began operation at Site A; this second reactor was cooled and moderated with 1500 gallons of heavy water and was surrounded by an 8' thick concrete octagonal wall (Holl 1997 p 113). It is believed both CP-2 and CP-3 were located in Building A at Site A. In 1953, CP-3 was updated by replacing the natural uranium fuel with enriched uranium and was redesignated as CP-3´. These research reactors operated until 1954 (Wescott and O'Rourke 2001a). Among the programs carried out at this site during and after World War II were fission product separation, reactor physics studies, tritium recovery from irradiated lithium and radionuclide metabolism studies in laboratory animals (Golchert and Sedlet 1977).

In 1943, low-level radioactive waste burial began in 1.8-m deep trenches in a 0.4-ha (1-acre) area 600 m north of Site A called Plot M. At first, ANL-E used glass or metal to contain radioactive materials, both solid and liquid, placed them at the bottom of the trenches, and then covered them with sufficient soil to keep external exposure rates at acceptable levels. Additional layers of waste and soil were placed until the trenches were full. This type of disposal continued through 1947. Sometime in 1948, the material for trench disposal was placed into steel bins, then into the trenches, and covered with

soil. In June of 1949, burial at Plot M was discontinued, and the bins were removed and shipped to Site D. The area was covered with additional soil and seeded with grass (ANL 1979a).

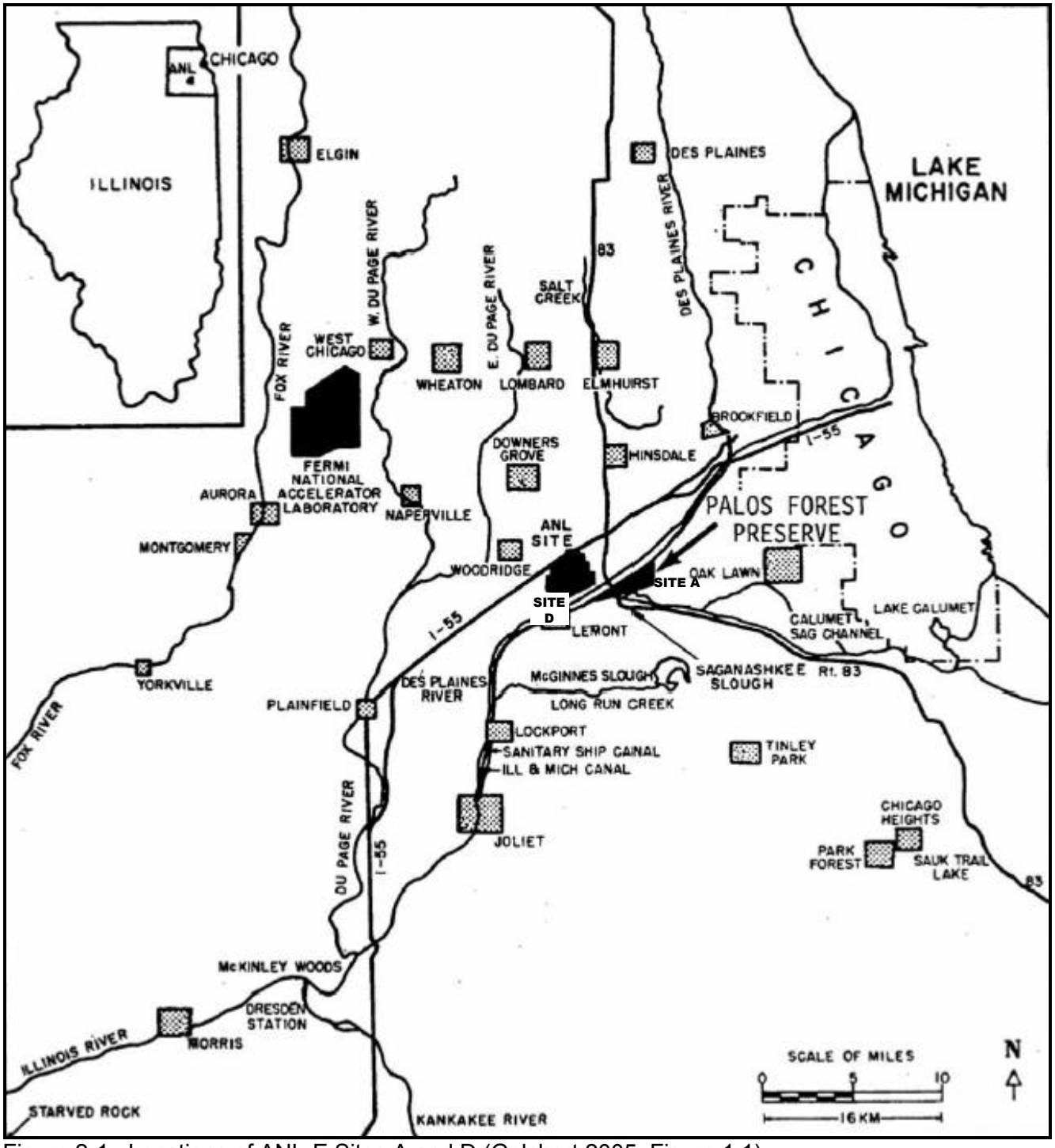

Figure 2-1. Locations of ANL-E Sites A and D (Golchert 2005, Figure 1.1).

2.2.3 Development of Site D

In 1947 and 1948, several temporary structures were erected in the far western portion of Site D for construction contractors. This area became known as the 800 Area and was apparently intended as the construction headquarters. These structures were later reused for other purposes, and additional permanent buildings were constructed there in the 1950s and 1960s. All the buildings have since been demolished (Wescott and O'Rourke, 2001a).

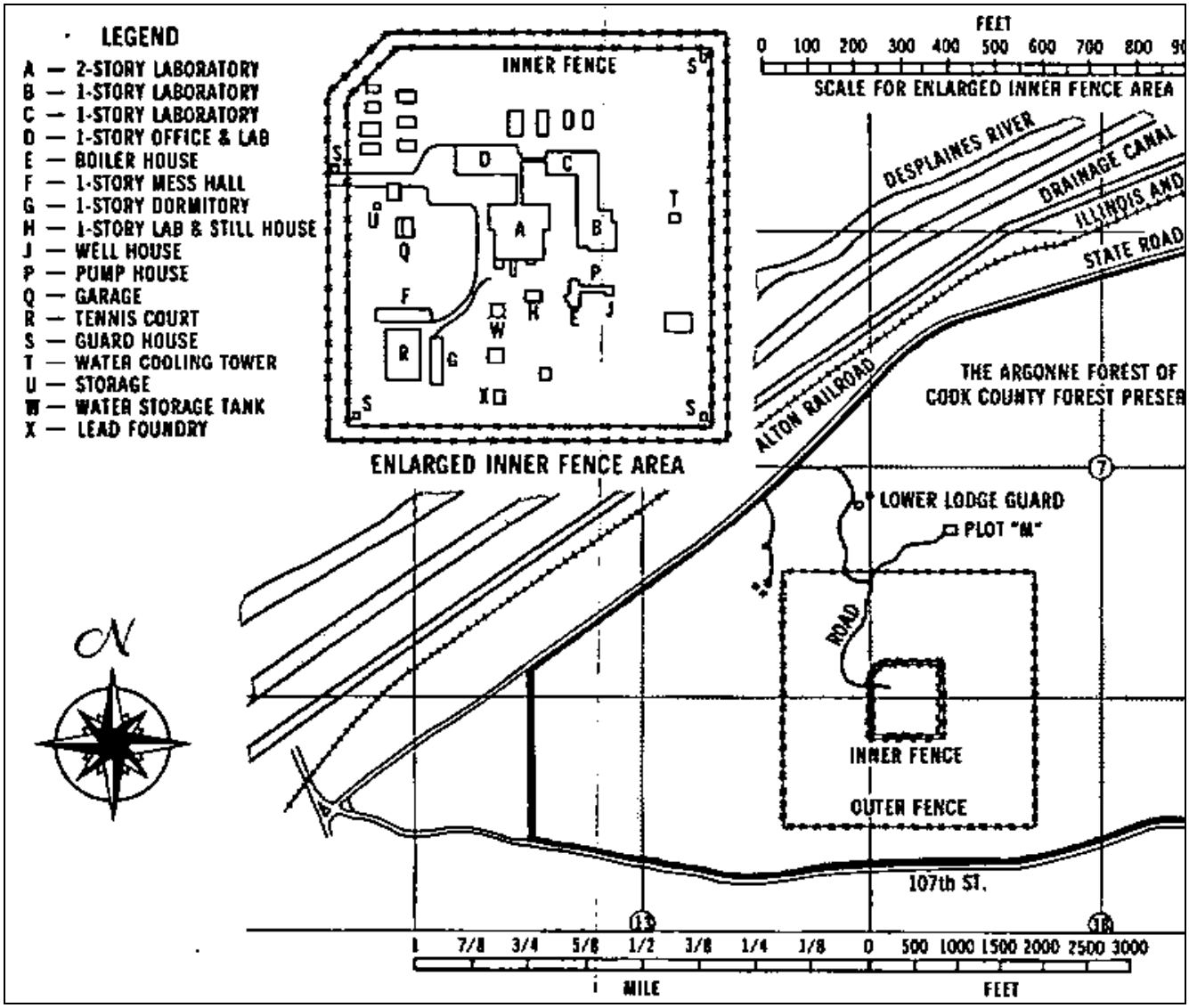

Figure 2-2. Site A (Jobst, Houk, and Mohr 1978).

Construction of working facilities began at Site D in 1948 with quickly built Quonset huts to house research divisions while more permanent buildings were built. These huts were in the East Area (far right in Figure 2-3), which housed portions of the Reactor Engineering group, Metallurgy, Central Shops, Remote Control Engineering, Electronics, Administration, and certain other support functions. Facilities used in support of operations involving radioactive materials, and constructed in the early 1950s, included a nuclear material storage vault (Building 16F), a hot machine shop (Building 17) and associated dust collector structure (Building 41), and an industrial waste treatment plant (Building 34) (Kline, Fassnacht, and Moe 1987). A landfill in the East Northeast (ENE) Area (northeast of the 319

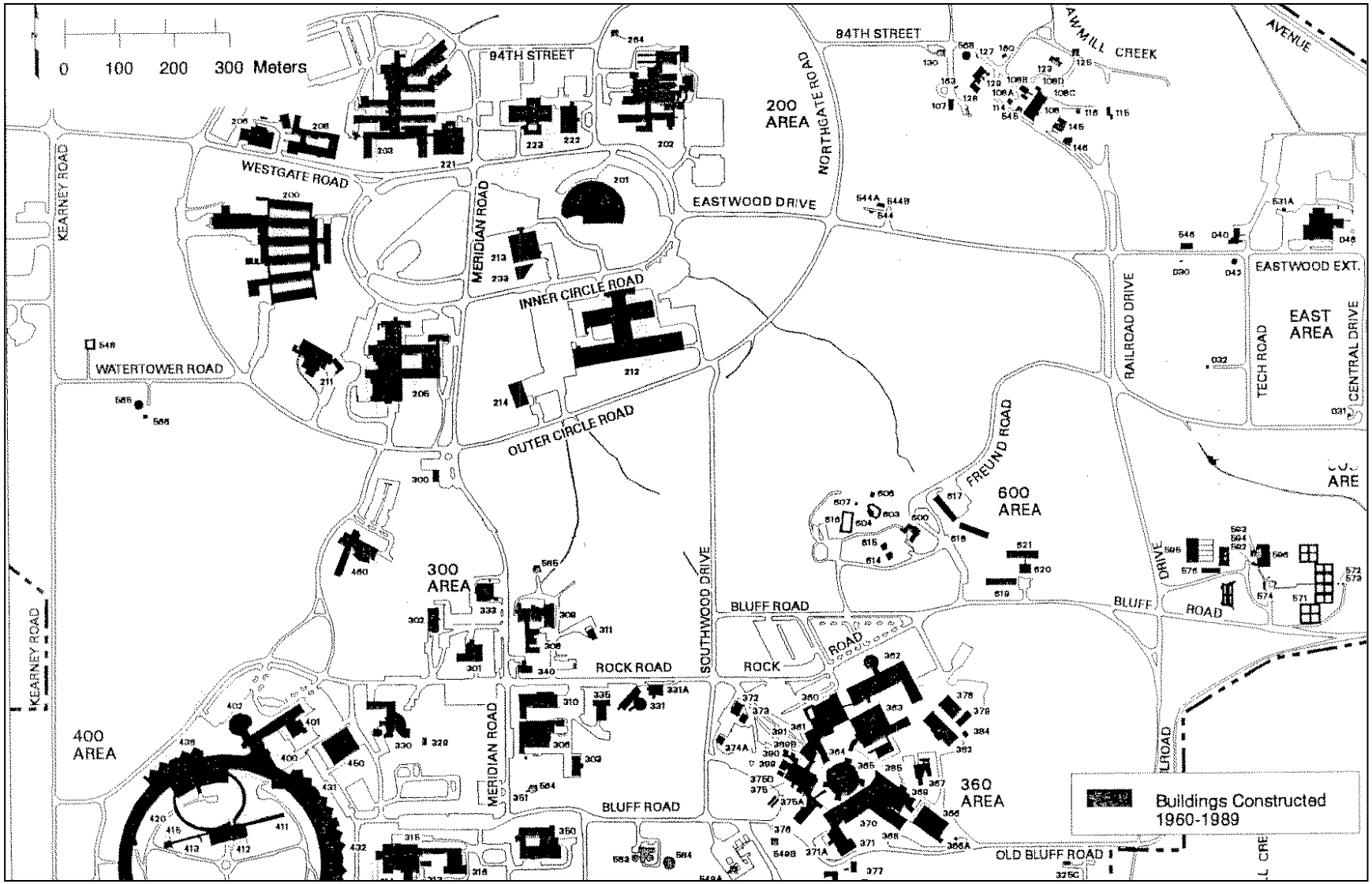

Figure 2-3. Site D (Wescott and O'Rourke 2001b, Figure 4.5).

Area) was used between 1951 and 1956 (DOE 1997). The only masonry building built in the East Area was the Building 40 Chemistry hot laboratory. In 1957, Buildings 15 and 22 of the East Area housed ANL-E's International School of Nuclear Science and Engineering, which used the Argonaut (Argonne Nuclear Assembly for University Training) demonstration research reactor in Building 25. Twenty-five support buildings were built including a coal-fired power plant. Buildings necessary for water, steam, and electricity distribution were built in the 100 and 500 Areas in the early 1950s and 1960s. A holding basin was constructed in the 570 Area in the 1950s as part of a laboratory wastewater treatment plant (DOE 1997). A waste ion exchange facility was constructed as Building 579 (renumbered as Building 594 in 1997) in the 1950s in the East Area to process waste fluids from a collecting lagoon (Wiese 1998). Sludge drying beds were used in this area from the 1940s to 1994.

The 600 Area is used for housing of visiting scientists, recreation, and housing administration. The Freund estate (Buildings 600, 603, 604, 606, and 616) was built in the 1930s. Buildings 614 and 615 were built in 1954; buildings 617-619 were built in 1957; and buildings 620 and 621 were built in 1964. Building 460, which was built approximately in 1995 near the APS, is the current Guest House.

Construction of the first permanent buildings for the laboratory's missions at Site D began in 1948 in the 300 Area. Table 2-1 summarizes ANL-E buildings and their periods and purposes of operations. Buildings 301 (Physics and Metallurgy Hot Laboratory), 306 (Decontamination Shop), 310 (Experimental Waste Processing, Storage, and Shipping), and 316 [Zero Power Reactor (ZPR) Assembly] were completed in 1950 and served specialized functions. Caves 1 to 5 were added to Building 301 in 1950, 1951, 1954, 1958, and 1960, respectively. Facilities completed in 1951 in the 200 Area included Buildings 200 (Chemistry), 205 (Chemical Engineering), and 211 (Cyclotron). Additional facilities were added to the 200 and 300 Areas in 1952, including Buildings 202 (Biology), 203 (Physics), 208 (Reactor Engineering), 340 (Experimental Animal Quarters), and 350 (Fuel Fabrication Facility). Building 330 was built in 1953 to house the CP-5 reactor, which became operational in 1954 and was ANL-E's primary research reactor. Once CP-5 was operational, the CP-2 and CP-3´ reactors at Site A were dismantled and the lease of Site A ended. A half-scale mockup of the Experimental Breeder Reactor-II (EBR-II) was housed in Building 206, which was also built in 1953. Building 308 was constructed in 1956 to contain a partial mockup of the EBR-II. The full-scale EBR-II was eventually built in 1964 at ANL-West in Idaho and was operated there until 1994. Building 331 constructed in 1956 housed the Experimental Boiling Water Reactor (EBWR), which became operational in 1957 and generated part of ANL-E's electricity supply during the 1960s. The 319 Landfill and French Drain operated from the mid-1950s until 1968.

During the 1960s, several new facilities were added (Wescott and O'Rourke, 2001b). Construction of the Janus reactor for biological studies in Building 202 started in 1959. A 10-MeV Van de Graaff accelerator was added in Building 203 in 1960 for physics research. Van de Graaff and linear accelerators (LINACs) were added in Buildings 203 and 211 in 1962 for chemistry research. Also in 1962, a hot cell wing was added to Building 200 (Chemistry), and ZPR-VI and ZPR-IX were built in a new Building 315. Building 335 was also constructed in 1962 to house the Juggernaut Reactor, which was intended to relieve some of the CP-5 workload. The Zero Gradient Synchrotron (ZGS), a complex of 16 buildings in the 360 Area, was completed in 1963. Also in 1963, Building 212 (Fuels Technology Center) was constructed to contain the Alpha Gamma Hot Cell Facility (AGHCF). Building 221 was built in 1964 to house computer personnel from various divisions. A new cafeteria (Building 213) and a building for nuclear rocket testing (Building 311) were constructed in 1964. In 1966, Building 309 was constructed to serve as storage space. Building 325C is a prefabricated waste storage building constructed in 1966. Building 314 was constructed in 1968 to house the Fast Neutron Generator. Building 223 was built in 1968 for the expanding Material Science Division. Building 214, housing offices for the EBR-II project, was completed in 1970.

Table 2-1. Summary of facilities and operations.[a]

Facility	Constructed	Closed[b]	Operations
Palos Park Site A	1942	1954	Primary site of ANL-E until Site D opened in 1948
CP-2	1943	1954	Moved and reconstructed CP-1 reactor; Pu production research
Plot M	1943	1949	Shallow trench burial of radioactive wastes associated with reactor program
CP-3	1944	1950	Heavy-water moderated Pu separation research
CP-3'	1950	1954	Natural U fuel from CP-3 replaced with enriched U
Site D	1947	Present	Present site of ANL-E
800 Area	1947	1992	Initially temporary structures for construction contractors; no indication how area was used between 1950 and 1966; converted to site sanitary landfill in 1966
East Area	1948	Mid- to late 80s	Temporary residence while main campus was constructed to the west; included 11 Quonset huts, Chemistry hot lab, 25 support structures (including coal power plant)
40	1948	Present	Chemistry hot lab
570 Area	1940s	1994	Part of laboratory wastewater treatment plant – holding basin (until 1978), sludge drying beds (until 1994)
16F	1950s	1980	Vaults for storage of SNM
17, 41	1950s	early 1980s	Hot machine shop; used to fabricate or modify items which were radioactive or were components of radioactive systems (Building 41 was a sheet metal structure supported 9 ft above ground to trap graphite dust from Building 17)
34	1950s	1978	Industrial waste treatment plant
100 Area	1950	Present	Distributed systems (buildings related to the boiler house in Building 108, steam distribution, well houses)
500 Area	1950s, 1960s	Present	Distributed systems (buildings related to electrical and water)
300 Area	1950	Present	Special nuclear facilities
301	1950	Present	Physics and metallurgy hot lab, Caves 1–5 added in 1950, 1951, 1954, 1958, 1960; remote handling, fuel rod analysis
306	1950	Present	Decontamination shop. Waste management operations.
310	1950	Present	Experimental waste processing, storage, and shipping; irradiation source facility added (1954 - ?)
316	1950	Present	ZPR-I (rebuilt as ZPR-IV in 1953, ZPR-IV´ in 1957), ZPR-II (1952-1954), ATSR (rebuilt version of ZPR-I in 1960), ZPR-V and ZPR-VII (1950s and 1960s)
ENE Landfill	1951	1956	Landfill for construction debris and miscellaneous waste
600 Area	1951-1980s	Present	Freund estate taken over by AEC; buildings used for housing visiting scientists, recreation, housing administration
200 Area	1951	Present	Core buildings
200	1951	Present	Chemistry, M-Wing caves with unique containment (1961–present), hot cell wing added (1962–present)
205	1951	Present	Chemical Engineering, fuel processing and recovery studies, concrete-shielded cells
211	1951	Present	Cyclotron, Van de Graff accelerator (1962), LINAC (1962)
202	1952	Present	Biology, Janus reactor (200 kW) (1963–1992), gamma irradiation rooms, kennels
203	1952	Present	Physics, Tandem Van de Graff accelerator (1960), ATLAS accelerator (1982–present)
208	1952	Present	Reactor engineering; Stationary Low Power Reactor (1958–1961), mostly office space, Van de Graaff accelerator wing added in 1956
340	1952	Present	Experimental animal quarters (1952–1980), vacant and office space (1980–1998), post office (1998–?)
350	1952	Present	Fuel fabrication facility (1952–1979), renamed Plutonium facility, Uranium facility added (1970s), New Brunswick Laboratory (1974–present)
330	1953	1979	CP-5 reactor (5,000 kW)
206	1953	1994	Half-scale mockup of EBR-II
579 (594)	1950s	2003	Waste Ion Exchange Facility (operated only a short time; no exact shutdown date)
317 Area	mid-1950s	Present	Liquid waste disposal in French Drain in mid-1950s; later temporary storage of containerized solid radioactive and mixed waste; treatment of surface contaminated metal mixed waste
319 Area	mid-1950s	1968	Liquid waste disposal in French Drain until 1968, landfill until 1968
308	1956	1994	Second partial mockup of EBR-II
331	1956	Present	EBWR (20–100 MW) (1956–1960s; removed in 1990s), low-level waste and transuranic storage (1990s–present)

Table 2-1 (Continued). Summary of facilities and operations.[a]

Facility	Constructed	Closed[b]	Operations
25	1957	1965	Argonaut demonstration reactor (10 kW)
15,22	1957	1965	International school for nuclear science and engineering
315	1962	Present	ZPRs VI and IX
335	1962	Present	Juggernaut Reactor (250 kW, 1962–1970), Flow Induced Vibration Test Facility (1976–1990s)
212	1962	Present	AGHCF (1963–present), HVEM Tandem Accelerator facility (1985–2001), IVEM (1995–present)
360-390, 360 Area	1961	Present	ZGS (1963–1979), rapid cycling synchrotron (1976–1981), IPNS (1981–present)
221	1964	Present	House computer personnel
213	1964	Present	New cafeteria
311	1964	Present	Nuclear rocket tests; experimental facility for miscellaneous projects
309	1966	Present	Storage space
325C	1966	Present	Prefabricated, hydrogen storage (1966–1979), waste storage
314	1968	Present	Fast Neutron Generator (1970–1995)
223	1968	Present	Materials Science Division
214	1970	Present	Offices for EBR-II project. Facility engineering offices.
486	1970	?	MARS facility
300	1975	Present	Gas station. Tanks removed 2005.
485	1975	Present	Greenhouse (1975–1990), bioreclamation and biodiversity studies (1990s)
320	1976	~2000	Shooting range
333	1977	Present	Emergency services building
201	1982	Present	Central administrative building
302	1985	Present	Security division
320	1985	Present	Building next to shooting range for security division
222	1986	Present	Graphic arts and electronics
291	1987	Present	Guard post at north gate
487	1987	?	Atmospheric studies
233	1988	Present	Argonne credit union
400 Area	1995	Present	APS facility
207	?	?	Offices in mobile structure

a. Acronyms identified in text; ? = date unknown.
b. Present = not closed.

Construction in the 1970s involved only two permanent buildings: Building 300 (a gas station), and Building 333 (an emergency services building). With the heightened U.S. Department of Energy (DOE) emphasis on environmental studies, a temporary frame structure (Building 486) known as the Microcosm for Acid Rain Studies (MARS) facility was erected in 1970 for performing acid rain studies. Building 485, a prefabricated greenhouse, was erected in 1975 for study of acid rain, ozone, plant ecology, and other biological experiments.

In 1982, a new administration building (Building 201) was built for DOE and ANL-E. The Argonne Tandem Linear Accelerator System (ATLAS) was added to the north side of Building 203 in the same year. Other buildings constructed during the 1980s include Building 302 in 1985 (Security Division), Building 320 in 1985 (next to shooting range), Building 222 in 1986 (graphic arts and electronics), Building 291 in 1987 (guard post at north gate), Building 487 in 1987 (facility in support of atmospheric studies), and Building 233 in 1988 (Argonne Credit Union).

In 1990, ground was broken for the $0.5-billion Advanced Photon Source (APS) facility in the 400 Area, and the facility was completed in 1995.

2.2.4 Overview of Missions and Programs

2.2.4.1 Production, Power, and Research Reactors

When ANL-E was established in 1946, military projects were the top priority (Wescott and O'Rourke 2001a). Of first and most importance was the naval Propulsion Project, which was transferred to ANL-E in 1947. Argonne's task was development of control rods and fuel elements for a nuclear reactor to power a submarine. The ZPR-I in Building 316 was the prototype submarine reactor. Nautilus, the first nuclear submarine, was launched in January 1954. The role of ANL-E in this project ended in 1956.

Reactors for plutonium production were studied at ANL-E. Fuel-processing studies for the production reactors at Hanford were carried out in Buildings 205 and 310 in the early 1950s. The ZPR-II reactor in Building 316 was designed for ANL-E's part in developing the plutonium and tritium production plant constructed at the Savannah River Site in 1954.

Beginning in 1946, ANL-E's mission encompassed research on power reactor design and development including breeder and boiling-water reactors. The Experimental Boiling Water Reactor (EBWR), which developed the BWR technology for power reactors, was built at Argonne in 1956 in Building 331 and was operational between 1957 and 1967. Two partial mock-ups of the EBR-II were constructed in Buildings 206 and 308 in the 1950s. In 1965, ANL-E devoted a considerable effort toward design of the Liquid Metal Fast Breeder Reactor (LMFBR), but it was never built. Beginning in 1961, ANL-E scientists devoted about 6 years to a higher-powered version of the CP-5, but the project ended in 1967 before construction. Beginning in 1985, ANL-E was involved in development work for the Integral Fast Reactor, which is a breeder reactor with onsite facilities to reprocess the fuel and reinsert it in the reactor. Research on fuel reprocessing was conducted at ANL-E. The project was canceled in 1994.

Reactors were used at ANL-E for basic research. The CP-2, CP-3, and CP-3´ research reactors were operated at Site A until 1954. The CP-5 reactor, which was the first research reactor at ANL-E Site D, went on line in 1954 and operated until 1979. Research was conducted at CP-5 by most divisions, and technicians for Illinois' first commercial power plants were trained at CP-5. ZPR-VI and ZPR-IX were constructed in Building 315 in the 1960s to relieve the workload of the ZPR-III at the National Reactor Testing Station (NRTS) in Idaho and were used to test core loadings for the nuclear rocket program and the LMFBR project. This type of reactor was very efficient in reactor development studies, specifically for study of core loadings. The Zero Power Reactor Program that began in the 1950s was also involved in basic research. The original ZPR-I was modified and rebuilt numerous times for different applications. In 1960, it was modified again and renamed the Argonne Thermal Source Reactor (ATSR) for development of sensors and detectors for other reactors.

Argonne built the Argonaut reactor in the East Area in 1957 as a demonstration tool for use by the International School of Nuclear Science and Engineering and it was used until 1965. In 1958, an Argonaut reactor was assembled and operated during the Second International Conference on the Peaceful Uses of Atomic Energy in Geneva Switzerland (Holl 1997). In 1962, the Juggernaut reactor was built in Building 335 based on the Argonaut design. This reactor relieved some of the load on the CP-5 reactor but was quickly overshadowed by the Janus reactor that went online in 1964. The Janus reactor was built specifically for research into the biological effects of ionizing radiation. Janus was shut down in 1992.

2.2.4.2 Accelerators

During the 1960s, high-energy physics research requiring particle accelerators was one of the most important areas of investigation at ANL-E. Before this time, the laboratory had four accelerators. The 60-Inch Cyclotron, built in 1951 and housed in Building 211, was used for nuclear solid-state physics, chemistry, isotope production, and biological studies. Two Van de Graaff accelerators housed in Buildings 208 and 203 were used in basic research similar to that conducted with the Cyclotron. A Dynamitron accelerator housed in Building 203 was used in basic physics experiments. An electron linear accelerator (LINAC) was installed in 1962 in Building 211. The most elaborate accelerators in the 200 Area are those associated with the ATLAS, which was the world's first superconducting heavy ion accelerator and remains one of ANL-E's premier facilities for high-energy physicists. The ZGS in the 360 Area operated from 1963 to 1979. Together with bubble chambers, the ZGS put ANL-E at the forefront of subatomic structure and neutrino research in the 1960s and 1970s. The Intense Pulsed Neutron Source (IPNS), which went on line in 1981 and continues to be used in materials research, utilizes many of the buildings occupied by the ZGS in earlier years as does the Argonne Wakefield Accelerator (AWA). The Advanced Photon Source in the 400 Area began operation in 1995.

2.2.4.2.1 60-Inch Cyclotron

The 60-Inch Cyclotron in Building 211, owned by the Chemistry department, was built in 1951 and accepted on July 10, 1952. The facility was operated for research and medical radioisotope production through November 1992 (Ramler and Parker 1959, Collins et al. 2001). Decontamination and decommissioning (D&D) of the facility occurred in 2000. The accelerator provided about 200-μA beams of protons, deuterons, ^{3}He, and ^{4}He ions at energies of 11, 21, 34, and 45 MeV, respectively, for irradiations in the cyclotron vault as well as of lower intensities for a 60-in. scattering chamber in the Experimental Tunnel. The vault is at a negative pressure of 0.1 in. of water and has an air change every 8 min. The Nuclear Medicine Group used the cyclotron to produce ^{211}At, ^{18}Fl, ^{44}Sc, ^{46}Sc, ^{47}Sc, ^{47}Ca, ^{64}Cu, ^{62}Zn, ^{114}In, ^{205}Bi, and ^{206}Bi. Other groups produced ^{56}Co, ^{178}Hf, and ^{237}Pu. After irradiation, the water-cooled targets would read up to 200 rad/hr (beta and gamma) at 33 in. (Okolowitz and Jezik 1954). Target failure or handling accidents could lead to contamination situations.

The cyclotron vault walls were constructed of 7-ft normal density concrete (150 lb/ft^3), and the roof was 4 ft of the same material. Two hydraulic doors (38 ton and 120 ton) provided access when lowered and closure when raised.

The hot laboratory was a room exhausted through high-efficiency particulate air (HEPA) filters that contained a junior cave (installed in 1954), senior cave, three fume hoods, radioactive material storage tubes, and a viewing window to the main vault. The junior cave with 3-in. steel walls and a 9-in. lime glass window was 20 by 48 in. inside and exhausted through HEPA filters. The senior cave had 24-in. high-density (300 lb/ft^3) concrete walls and had a 6 by 10 ft working area. Both had master-slave manipulator arms.

2.2.4.2.2 Tandem Van de Graaff

A High Voltage Engineering Corporation Model EN Tandem accelerator was installed at the rear of Building 203 in 1960. The target rooms were separated with 5.5-ft concrete walls from the accelerator vault and a corridor outside. A shielding study used 3 μA of 12-MeV deuterons on a beryllium target and resulted in dose rates outside the shielding but in inaccessible areas up to about 20 mrem/hr consisting mostly of neutrons (Dyer and Mundis 1966). In 1968, the EN was traded for an FN Tandem that could produce somewhat higher energy beams. With a maximum of 9 MV on the terminal, 18-MeV proton or deuteron beams and 27-MeV helium beams were available. For a

tandem, the deuteron beams would have the highest dose rate. Beam currents usually range up to a maximum of a few microamperes.

2.2.4.2.3 Argonne Tandem Linear Accelerator System

Superconducting split-ring resonators were tested in 1977 and then developed into a LINAC. ATLAS uses the FN tandem Van de Graff, a booster LINAC, and the ATLAS LINAC to accelerate beams of hydrogen up to uranium to an energy up to 17 MeV/nucleon. In 1992, a positive-ion injector was developed that uses an electron cyclotron resonance source and a LINAC as an alternative to the tandem accelerator. ATLAS is a heavy ion accelerator designed for use in basic research and especially for physics experiments with low-energy heavy ion beams. Radiation levels around the heavy ion beams are low so that target rooms can often be occupied with the beam on.

Small (μCi) sealed sources are mainly used for calibrating gamma-ray detectors and are kept in safes in the experimental hall. Open sources are typically used to calibrate charged-particle detectors. Other sources occasionally used at ATLAS are ^{252}Cf fission sources (open and sealed), and neutron sources (Pu–Be and Pu–^{13}C). Because these sources contain Special Nuclear Materials (SNMs), their use is restricted to Physics Division personnel.

2.2.4.2.4 Zero Gradient Synchrotron

Construction of the ZGS in the 360 Area began in 1961. It generated 12.5-GeV protons for high-energy physics experiments beginning in 1963 until 1979 (ANL 1974). The source was a 750-keV Cockcroft-Walton accelerator that injected into a 50-MeV LINAC accelerator. The synchrotron magnets (almost 5,000 tons of steel) produce a magnetic field that increases from about 0.0025 to over 2.2 tesla in 1 s. The frequency in the ferrite-loaded radio frequency cavity ranges from 4.4 to 14 MHz to accelerate the proton beam of 2.5×10^{12} protons/pulse from 50 MeV to 12.5 GeV.

The beam could be extracted at two locations or strike an internal target to generate secondary beams to the Meson facility in Building 370. The proton beams sent to Buildings 369/365 or 372/374 could be used directly or in secondary beams in up to 23 beam lines. Beams of $\pi^{\pm}$-mesons, $\kappa^{\pm}$-mesons, neutrons, protons, and antiprotons were available with energies above 1 GeV. A 12-ft-diameter liquid hydrogen bubble chamber in a superconducting magnet was available in Building 374, and a streamer chamber was available in Building 365. Beam line halls were built with concrete and iron shielding up to about 10 ft thick.

Inside the shielding, all these particles were present and resulted in complex radiation fields. Outside the shielding, neutrons and gamma radiation was available in low intensities. This facility generated activated materials, but the loose contamination should have been very low with the possible exception of near a failed target. Airborne releases of ^{11}C, ^{13}N, and ^{15}O probably existed at levels comparable to those from the more recent Intense Pulsed Neutron Source (IPNS).

2.2.4.2.5 Intense Pulsed Neutron Source

The IPNS was developed using some of the ZGS facilities after the latter was turned off in 1979. The system consists of a negative hydrogen ion source, a Cockcroft-Walton preaccelerator, a 50-MeV Alvarez LINAC, a 450-MeV Rapid Cycling Synchrotron (RCS), beam transport lines, a spallation target, and neutron beam lines to experiments. Unlike a reactor, the IPNS neutrons are in pulses about 100 ns long, so energy can be measured with the time of flight of the neutrons. The RCS was built in the mid-1970s as a booster for the ZGS to increase its beam current. The injector and Alvarez LINAC have been used since 1961 for the ZGS program. The preaccelerator and LINAC are in

Building 361, the RCS is in Building 391, and the spallation target and neutron beam lines are in Building 375. When in operation, 3×10^{12} protons at 450 MeV are delivered to the uranium (was enriched, but is no longer) target 30 times a second and generate about 1.3×10^{15} n/s leaving the target (Carpenter, Price, and Swanson 1978).

Recent thermoluminescent dosimeter (TLD) measurements around the outside of the buildings in a posted area have shown neutron leakage up to about 420 mrem/yr (Golchert and Kolzow 2004). The airborne releases of ^{11}C (20-MeV neutron production threshold with a 20-min half-life) attributed to the IPNS were likely a mixture of ^{11}C, ^{15}O, and ^{13}N.

2.2.4.2.6 Advanced Photon Source

The APS in the 400 Area was begun in 1990, commissioned in 1995, and continues to operate as the world's leading source of photons in the kilo electron volt energy region; it generates about 1 MW of photons. A 100-mA, stored, 7.5-GeV positron beam generates synchrotron radiation for many users simultaneously. As a charged particle travels in a circle, the centripetal acceleration results in photon emission (similar to stopping in an X-ray generator) called synchrotron radiation, which is particularly important for electrons or positrons. Undulator insertion devices in the straight sections of the magnetic lattice provide X-ray beams in the kilo electron volt energy region about 1×10^{21} times as bright as those from a conventional X-ray generator. Research is conducted in many areas of materials, biological, and nanostructure sciences.

All APS accelerators are in concrete-shielded buildings. A 250-MeV, 2-A (30-ns pulse at 60-Hz repetition rate) electron LINAC bombards a 7-mm tungsten target to generate positrons. A pulsed (10 kV, 6,000 A) magnetic solenoid collects the positrons into a 450-MeV positron LINAC that accelerates them to the Positron Accumulator Ring (PAR). Local shielding around the production target protects equipment and workers outside the interlocked tunnel. Twice a second the 6-nC positron beam is transferred from the PAR into the 450 MeV to 7,500 MeV injector synchrotron (368-m circumference) where they are accelerated and transferred into the 7.5-GeV positron storage ring. The positron converter was removed in 1999, so that the storage ring now stores electrons and simplifying the injector system.

The storage ring (1,100-m circumference) has 40 sectors, each with two dipoles, other magnets, and a long straight section mounted on 5 girders. Synchrotron radiation is used from 35 of the dipoles and insertion devices are used in 35 straight sections. Energy loss to synchrotron radiation is about 5.5 MeV/revolution (insertion devices generate additional loss), and this is supplied by radio frequency cavities so the beam remains at the same energy. The storage ring tunnel has a 1-m normal density concrete roof and a 0.8-m inner wall of the same material. The outer wall is a ratchet design to allow passage of the beam lines and is 22-in. high-density concrete to reduce interference with the beam lines.

The experiment hall for the 70 beam lines is outside the storage ring. Experiments are conducted in experiment stations constructed of lead 2 in. thick on the back walls and up to 1 in. thick on the sidewalls with roofs up to 0.5 in. thick. Transport pipes between the experiment stations are shielded with 1-in. lead to protect against the intense radiation from the synchrotron.

2.2.4.2.7 Argonne Wakefield Accelerator

The newest ANL-E accelerator (1993 to present) is the Argonne Wakefield Accelerator in Building 371. Its emphasis is on studies of high-gradient (about 100 MeV/m) wakefield acceleration; the AWA uses a 20-MeV electron drive bunch to accelerate a witness beam, which the wakefield then

accelerates further. The safety operating envelope for the facility is 400 nC at 30 pps with energy of 20 MeV. The accelerator is housed in a concrete and steel bunker 6 to 8 ft thick. The electron beams are generated from laser-driven photocathode guns. Radiation fields are primarily from an electromagnetic cascade, but a few photoneutrons are generated.

2.2.4.2.8 Electron Microscope Tandem Facility

The Material Science Division operates the High-Voltage Electron Microscope (HVEM), which is a combination electron microscope and particle accelerator in the G Wing of Building 212. It uses either a 2-MV National Electrostatics Corporation (NEC) tandem accelerator or a 650-kV NEC ion implanter to change a material being bombarded. The material changes are studied using an electron microscope. A high-voltage electron microscope was available until 2001, and an intermediate voltage electron microscope became available in 1995. Radiation levels around this facility are generally well below 1 mrem/hr.

2.2.4.2.9 Small Accelerators

Building 203 (Physics) contained a Dynamitron in the northeast corner. In 1951, a Van de Graaff accelerator was added. There was a vertical 3-MeV Van de Graaff accelerator in Building 211 in 1954 that resulted in a nonpenetrating exposure (Okolowitz and Jezek 1954). A Van de Graaff accelerator was installed in Building 211 in 1962. Small Van de Graaff accelerators could also have been used in Buildings 203, 208, and 212, as well as at Site A. There is a 22-MeV electron LINAC in Building 211. Two Febetrons in Building 200 were used to produce 600-keV and 2-MeV X-ray beams (DOE 1982).

The Applied Physics Division used a 3-MV Van de Graaff (possibly in Building 203) until they built the Fast Neutron Generator (FNG) in Building 314 in 1968. The FNG used a tandem 4-MV Dynamitron that could also be operated as a single-ended accelerator. As a tandem it could generate over 50 μA of 8-MeV protons or deuterons. In single-ended mode, particle beams over 1 mA can be accelerated to 4 MeV.

2.2.4.3 Basic Research

While research in the 1950s at ANL-E largely involved reactor projects, there were other types of basic research. Research addressing radioactive waste management issues was conducted in Building 310, which contained a test incinerator for destruction of dry radioactive wastes. Retention tanks in the basement of this building held contaminated water for use in development of treatments for liquid wastes, mostly involving solidification. Work in Building 205 involved the processing of used nuclear fuels. Air quality studies occurred in Building 200 along with a variety of other types of research into radiochemical issues. Physicists were looking at the basic properties of the atom and the radioactive effects on molecules during these early years. Irradiation of foods in a gamma irradiation pool occurred in Building 310 involving spent fuel rods from the Material Testing Reactor in Idaho to investigate the effects of radiation on bacteria in food.

ANL-E conducted basic research into hazardous radioactive materials such as uranium and plutonium. This required sophisticated containment facilities to provide a safe environment for researchers and to limit contamination outside the research zone. Construction of the M-Wing caves in Building 200 occurred in 1961 and 1962 to allow experimentation with minimal exposure to radiation. In 1963, the AGHCF was opened in F Wing of Building 212. Similar to the M-Wing caves, the AGHCF used a nitrogen atmosphere to stabilize pyrophoric materials for examination. Major fuel studies for reactor programs of the 1960s and 1970s were conducted at the AGHCF.

In the 1950s, ANL-E scientists studied the effects of radiation on humans from occupational or medical exposures to radium. For biological studies on the effects of radiation on animals and plants, the Biology Division focused on whole-body experiments using gamma irradiation facilities and the Janus reactor during the 1960s to early 1980s. After that time, the focus shifted to studies at the cellular and molecular level.

The Material Science Division conducted a large amount of research on superconductors. The majority of this work occurred in Buildings 223 and 212 and involved close collaboration with the High-Energy Physics Division and use of the ZGS facility. Research in the Material Science Division was aided by the addition of the HVEM tandem accelerator facility in Building 212. This allowed study of the effects of radiation at the atomic level. The building was modified to incorporate an Intermediate Voltage Electron Microscope (IVEM) in 1995, which is still in use. The HVEM was dismantled in 2001.

Beginning in the early 1950s, radioactivity measurements in air, water, soil, and biota were made both on and off the site to evaluate the potential impacts of ANL-E. Measurements of fallout were an important part of this early program because it was important to understand the dynamics of anthropogenic radionuclides from atmospheric testing in comparison to potential contributions from the site. In the late 1960s, environmental studies officially became an important mission of the laboratory.

2.2.5 Support Operations

The following discussion addresses only those operations supporting the ANL-E operations that involved the use or production of radioactive materials. The Fuel Fabrication Facility at ANL-E began operation in 1952 in Building 350 to support various reactor studies. It was later renamed the Plutonium Fabrication Facility. In 1959, it was dedicated as the nation's first large-scale plant for making nuclear reactor fuel elements from plutonium. It processed hundreds of kilograms of ^{239}Pu in metallic and ceramic form (ANL 1979b). The facility also processed lesser amounts of ^{233}U and ^{235}U.

The New Brunswick Laboratory operated by DOE was relocated from New Jersey to Building 350 in 1977. The Laboratory developed and provides reference materials for calibrating nuclear fuels and sensors, and scientists verify the properties of radioactive material bought or sold for use in reactors, not only for ANL-E but also for organizations around the world (Wescott and O'Rourke 2001b).

Treatment and storage of radioactive materials or radioactively contaminated waste began in East Area in Building 16F (Nuclear Materials Storage Vault) and Building 34 (Industrial Waste Treatment Plant). The ENE Area (from 317 and 319) landfill was used for disposal of waste between approximately 1951 and 1956, but no documentation of waste disposal activities at this area is available (DOE 1997). Therefore, DOE has assumed that waste potentially contaminated with radioactive materials was disposed of here and labeled the landfill a "suspect material dump." The Waste Ion Exchange Facility in Building 579 in East Area (later named Building 594) was used for a short period in the 1950s to process waste fluids from a collecting lagoon. The 570 Area unlined holding basin used between the 1950s and 1978 infrequently accepted waste with both radioactive and hazardous contaminants. The sludge drying beds were used between 1940s until 1994 (DOE 1997). These units were part of the laboratory wastewater treatment plant during those years. The Map Tube Facility in 317 Area was a concrete structure with 129 cast-iron storage pipes cast vertically into the concrete (Wescott and Moos 1995). This facility stored small, highly radioactive objects such as nuclear fuel elements and assemblies or irradiated metal objects. There were also concrete vaults in the 317 area for storage of remote- and contact-handled radioactive waste. These vaults drained to an outfall into the adjacent Waterfall Glen Forest Preserve until 1987 (DOE 1997).

2.2.6 Summary of Nuclear Materials on Site

The missions at ANL-E over the years since 1946 have been varied, and some of them were classified. Therefore, it is extremely difficult to define precisely the types and amounts of nuclear materials on the site in any given year. In 1982 prior to a cleanup, ANL-E had approximately 2400 batches of SNM representing approximately 2700 kg of fissile material (Beckjord 1982). However, generalized observations can be made about the likely types of materials used or produced based on the known periods of operations of certain facilities, reports describing contamination, and limited bioassay results. Table 2-2 provides a limited summary of this information.

Table 2-2. General description of radioactive materials by location.

Area/Building	Acquired/ constructed	Closed[a]	Program	Types of radioactive materials used	Types of radioactive materials produced
Site A					
Site A (non-reactor buildings)	1943	1954	Research reactors	Sources (e.g., Sb)	
CP-2	1943	1954	Production reactors	Natural U	Fission products
Plot M	1943	1949	Production reactors	Fission products	H-3 in groundwater
CP-3	1944	1950	Production reactors	Natural U	Fission products, tritium
CP-3´	1950	1954	Production reactors	Enriched U	Fission products, tritium
East Area					
40	1948	Present	Specialized		
16F,17,34,37,38,41	Late 1940s to early 1950s	Early 1980s	Support	Natural U, natural Th, Cs-137, Co-60	U-234, U-235, U-238, Th-232, Ac-228
25	1957	1965	Research reactors	U	
15,22	1957	1965	Education	U, Th (Building 22)	
200 Area					
200	1951	Present	Basic research	Irradiated Th-232, Sr-90, Pu-238, Pu-239/240, Pu-242, Am-241, Am-243, Cm-243, Cf-252	Rn-220
202	1952	Present	Basic research	S-35, highly enriched uranium fuel	Fission products
203	1952	Present	Accelerators	Ra-226	Uranium
205	1951	Present	Basic research	H-3, Pu-239/240, Am-241 (1972–1995); U-233 (1994); Am-243, Cf-252 (1995)	
206	1953	1994	Power reactors	Depleted U	
208	1952	Present	Accelerators, power reactors		
211	1951	Present	Accelerators	Co-60, Sr-90, Cd-109, In-114, Cs-137, Ra-226, Th-228/230, U-230/232/234/235/238, Pu-239, Am-242/243, Cm-244/245, specialized nuclear medicine isotopes	
212	1962	Present	Basic research	Pu in metallic form, H-3, Cs-137, Sr-90	Pu-238, Pu-239/240, Am-241 (D&D)
223	1968	Present	Basic research		
300 Area					
301	1950	Present (Hot Cell Facility inactive since 1992)	Specialized	Highly radioactive materials in two heavily shielded caves	Large amounts of nuclear fuel materials in 1950s and 1960s (Pu, U), Cs-137, Co-60, Am-241, Bi-214, Eu-154, Eu-155
306	1950	Present	Specialized	Pu-238, Pu-239/240, Am-241	
308	1956	1994	Power reactors		
310	1950	Present	Basic research		
311	1964	Present	Basic research		
314	1968	Present	Research reactors		
315	1962	1982	Research reactors	Pu, enriched and depleted U	U-238, Th-234, Cs-137

Area/Building	Acquired/ constructed	Closed[a]	Program	Types of radioactive materials used	Types of radioactive materials produced
316	1950	Present	Production/research reactors	Highly enriched U	Co-60, Eu-152, Cs-137, other fission products
317 Area	mid-1950s	Present	Support	H-3, Co-60, Sr-90, Cs-137, Pu-239, Am-241, Cm-244, plus fuel elements	
319 Area	mid-1950s	1968	Support	H-3	
325C	1966	Present	Support		
330	1953	1979	Research reactors	Enriched U	Fission products, H-3, Ar-41, Sr-90, Co-60, Cs-137 (D&D)
331	1956	Present	Power reactors	Enriched U	Fission products, Am-241, Cs-137, Co-60 (D&D)
335	1962	Present	Power reactors		Ar-41, Co-60, Eu-152, Eu-154, K-40, Cs-137, Am-241, Bi-214, Ra-226
340	1952	Present	Basic research, support		
350	1952	Present	Specialized	Plutonium in metallic form and other fissile materials (1952–1974);	Residual glovebox contamination including Am-241, Am-243, Pu-238, Pu-239/240, Pu-241, Np-237, Cm-243, Pa-233, U-235, Cs-137 (1974–1979)
360-390, 360 Area	1963	Present	Accelerators		Activation products, C-11, O-15, N-13
400 Area					
400 Area	1990	Present	Accelerators		Activation products, C-11, O-15, N-13
485	1975	Present	Basic research		
500 Area					
570	1940s	1994	Support		
579 (594)	1950s	1950s	Support	Co-60, Am-241, Cs-137	

a. Present = not closed.

2.2.7 Site Remediation Activities

D&D of reactors and other research and support facilities has been ongoing since the 1950s at ANL-E. Environmental restoration of inactive waste sites under DOE's Environmental Restoration and Waste Management Program began in 1990 with characterization of areas contaminated with hazardous and radiological wastes. Table 2-3 lists these activities in the order of initiation of characterization and provides available completion dates.

2.2.7.1 Site A

The first D&D project was the CP-2 and CP-3´ reactors (Site A) and the associated low-level radioactivity waste disposal trenches in Plot M. To return Site A and Plot M to the Cook County Forest Preserve District as planned for 1956, Site A and Plot M required remediation to the extent possible for return to their original use (ANL 1979a). In 1955, work began on surveying and decontaminating empty buildings before razing them. The reactors were dismantled, the heavy water was removed, and the fuel was shipped to Oak Ridge National Laboratory for reprocessing. The heavy water tank and its containment shell were filled with concrete and tumbled into a 12-m-deep pit with the use of explosives. The tank and shell were covered with building rubble and soil that was then graded. The top of the reactor shell is 7 m below the surface (Sedlet 1980). A nearby inscribed granite marker marks the location of the buried reactor.

In 1956, an inverted concrete box 0.3 m in thickness was constructed to cover the burial trench area (about 43 by 46 m) in Plot M. The concrete was then covered with approximately 0.5 m of soil and seeded with grass. An inscribed granite marker was placed in the center of Plot M (ANL 1979a).

A radiation survey of the site in the summer of 1956 indicated no detectable surface contamination, at which point personnel were removed from Site A and Plot M. Radiological monitoring occurred on a limited basis (DOE 1978) approximately every other year through 1975.

Table 2-3. Schedule of D&D and remediation projects.

Facility	Building or location	Year initiated	Year completed
CP-2 & CP-3´ research reactors	Site A	1955	1956
Low-level radioactive waste disposal trenches	Plot M	1955	1956
Pu Fuel Fabrication Facility	350	1974	1985
East Area Surplus facilities	16, 17, 22, 34, 37, 38, 41, 55	1983	1985
EBWR	331	1986	1996
Radioactive waste storage area and landfill	317/319 Area	1990	2003
Unlined holding basin	570 Area	1990	2003
CP-5 research reactor	330	1990	2000
M-Wing Hot Cell Facilities (Building 200)	200	1990	1996
Pu Glovebox Facility	212	1992	1996
Fast Neutron Generator	314	1992	1995
Map Tube Facility	317 Area	1993	1994
JANUS reactor	202	1996	1997
Waste Ion Exchange Facility	594	1996	1998
ATSR	316	1997	1998
60-Inch Cyclotron	211	1997	2001
Building 301 Hot Cells	301	1998	In progress
Juggernaut reactor	335	2001	2005
ZPR facilities	315	2002	In progress

2.2.7.2 Site D

Decontamination and decommissioning of the Fuel (Plutonium) Fabrication Facility in Building 350 began in 1974. Operations at this facility had been moved to Building 212 in 1973 to make room for the New Brunswick Laboratory. Sixteen gloveboxes were removed and either put into use in Building 212 or placed in controlled storage. Seven gloveboxes remained in Building 350 until further decontamination began in 1979. D&D work involved dismantling and removal of interior equipment followed by decontamination of the remaining equipment and rooms. Ventilation ductwork, filter banks, utility systems, and associated equipment were removed (ANL 1979b). Documentation cited the Argonne-Illinois Health and Safety Manual as providing the basic policy and practice for worker safety, but no citation was given for that manual (ANL 1979b). This D&D was complete in 1985.

D&D operations at the East Area Surplus Facilities including Buildings 16, 17, 22, 34, 37, 38, 41, and 55 began in 1983 and were complete in 1985. The work involved dismantling of all process equipment and associated plumbing, ductwork, drain lines, etc., packaging of contaminated materials and soil, and shipping them off the site. Each building was then torn down, and the site was landscaped (Kline, Fassnacht, and Moe 1987).

The EBWR was used in research on boiling-water reactor design and technology between 1956 and 1967. The fuel was removed shortly thereafter, and the residual activity was allowed to decay (Baker et al. 1996). D&D activities began in 1986 and were complete in 1996. Work involved removing the reactor vessel, cutting up the reactor internals using remote-handling techniques, decontaminating the containment shell to the extent possible, and shipping mixed and radioactive wastes for offsite storage and disposal. Air monitoring and bioassay were used routinely for workers with the potential for

internal exposure. Whole-body TLDs were augmented with extremity TLDs, and electronic dosimeters were also used routinely for these workers (Baker et al. 1996).

The Radioactive Waste Storage Area refers to the portions of the 317 Area used historically for processing and storage of radioactive wastes generated at ANL-E. An inactive landfill in the 319 Area was not explicitly intended for disposal of radioactive waste but the report entitled *Environmental Assessment, Environmental Remediation at Argonne National Laboratory-East* (DOE 1997) states that it is suspect based on lack of adequate documentation to describe the wastes placed in this location. The 317 Area is currently an active radioactive waste processing and storage area and includes the North Vault, which has been empty since 2001. Two 317 Area South Vaults contaminated with radioactive materials were demolished in 1995 and 1996 (ANL 1996), and the Deep Vault, used for remote-handled storage of transuranic waste, was demolished and backfilled during 2002 (Golchert and Kolzow 2005). Contaminants of the South Vaults were determined to be primarily ^{90}Sr and ^{137}Cs with small amounts of ^{60}Co and ^{241}Am (ANL 1996). The Deep Vault was contaminated with alpha emitters, while the still-existent North Vault is likely contaminated with mixed fission products (Richards, Badger, and Kittinger 1993).

Characterization of the Map Tube Facility in the 317 Area began in 1993, and decommissioning began in March of 1994 (Wescott and Moos 1995). The objectives of D&D were to remove the remaining radioactive objects stored in the facility and the contaminations to prevent further releases of radionuclides to the subsurface environment from this facility. This required removal of water that had seeped into the storage pipes of this structure and scrubbing of the pipe interiors. Removal of the still-contaminated pipes required a concrete coring rig. The coring operation generated a significant amount of concreted fines during the procedure, some of which were contaminated, and thus created a significantly larger quantity of radioactive waste to be disposed than was originally thought. The D&D project was complete in October of 1994.

The 319 Area is contaminated with ^{3}H, and possibly to a minor extent with ^{90}Sr, in the mound area where the bulk of the waste was buried. Cleanup of the 317/319 Areas has been underway since the late 1980s (Golchert and Kolzow 2005) and has been carried out as a series of interrelated actions that ultimately removed or contained the contaminants to prevent further migration to groundwater. Capping and leachate collection has been used in addition to vault removal, sealing of an underground vault drain, installation of groundwater extraction wells, and phytoremediation.

The 570 Area unlined holding basin was part of the laboratory wastewater treatment plant until 1978 (DOE 1997). Excavation was proposed under the Resource Conservation and Recovery Act corrective action process (DOE 1997). This remedial action was accomplished in 2003 (Golchert and Kolzow 2004).

The CP-5 reactor was shut down in 1979. In 1980, the fuel and all of the heavy water that could be drained was removed from the reactor and shipped off the site for reprocessing. D&D of this facility began in 1990. By 1996, all of the reactor systems were removed, and removal of reactor internals was begun (Baker et al. 1996). Since then, decontamination of the hot cell facility and fuel pool was accomplished, and associated radioactive wastes were removed (ANL 2005). Decommissioning was complete by July 2000.

D&D operations for the M-wing (Building 200) Hot Cell Facilities began in 1990 and ended in 1996. Five hot cells were cleaned including four used in the proof-of-breeding experiments for production of ^{233}U and ^{232}Th (Baker et al. 1996; Cheever and Rose 1996a). All five hot cells required remote disassembly and decontamination work prior to protected-entry decontamination. All worker radiation exposures were maintained below regulatory guidelines (Cheever and Rose 1996a). The main goals

of cleanup were to remove the source of ^{220}Rn emissions from that area and to restore the hot cells to an empty restricted-use condition.

The Building 212 Plutonium Glovebox Facility, which consisted of 61 plutonium gloveboxes in nine laboratories, was decommissioned by January of 1996. D&D work began in 1992 (Cheever and Rose 1996b). The objectives were to remove the glovebox systems, decontaminate the laboratories to meet unrestricted-use criteria, and dispose of the resultant radioactive waste. In the process of meeting these objectives, radioactive materials were removed from the gloveboxes (with full-face respiratory protection), large equipment was removed, and the gloveboxes were decontaminated, disassembled, and packaged for disposal.

The Fast Neutron Generator in Building 314 operated from 1970 to 1991 (Baker et al. 1996). D&D efforts began in 1992 and were complete in 1995. No other information about the nature of the D&D work completed was available.

The JANUS reactor (mainly J Wing of Building 202) was used to produce short-lived isotopes by neutron absorption and to irradiate plants and animals for research activities by the Biology and Medicine Divisions. The reactor fuel was removed in 1993, and a radiological characterization was conducted in 1996 (Fellhauer, Garlock, and Clark 1997). Approximately 99% of the total estimated activity inventory of 1×10^8 Bq (28 mCi) was in the graphite around the reactor tank. The predominant radionuclides were ^{60}Co, ^{152}Eu, ^{154}Eu, and to a lesser extent ^{239}Pu. The major tasks during D&D included removal of miscellaneous components, demolition of the high-dose irradiation room, removal of the reactor, removal of shutter systems, removal of other support structures and systems, and area decontamination. D&D was complete in November of 1997.

Characterization of the Waste Ion Exchange Facility in Building 594 (Building 579 until 1997) occurred in 1996; ^{60}Co, ^{241}Am, and ^{137}Cs were the identified contaminants (Wiese 1998). D&D activities began in June 1998 with the objectives of removal of radioactive and hazardous materials from the facility, decontamination to unrestricted-use levels, and demolishment of the building. The ion exchange system and the resin in it were the primary areas of concern from a safety perspective. The ANL-E *Environment, Safety & Health Manual* (ESH Manual; ANL 2005[1]) served as a guide for implementing the radiation safety program for the D&D project. Personal protection equipment was used, access was controlled to keep unauthorized personnel from entering contamination areas, and continuous air monitors were used near the D&D work areas. Building 594 was demolished in September of 1998 to complete D&D.

The Argonne Thermal Source Reactor operated in Building 316 until the late 1980s and characterization for D&D began in December of 1997 (Fellhauer, Mathieson, and Garlock 1998). Most of the D&D work occurred in Room E-111 of Building 316, which involved removing and packaging activated graphite piles, the reactor assembly, miscellaneous equipment, a contaminated fume hood, and cleanup of residual radioactivity in the area so the facility could be returned to unrestricted use. The ESH Manual (ANL 2005) served as a guide to the contractor performing the work in implementing the radiation safety program. D&D was complete by October of 1998.

Characterization of the 60-Inch Cyclotron facility began in 1997 (Collins et al. 2001). The D&D objectives were to remove radioactive materials from the facility and the site and to decontaminate the facility to unrestricted-use levels. The primary concern for the project was the safe removal of material activated by operations; the primary radionuclide of concern for that was ^{60}Co. Cleanup of

[1]The ESH Manual is an electronic compendium of independent sections. According to the ANL-E Web site, each section of the manual is reviewed every three years and revised as appropriate. Therefore, information from the ESH Manual at a particular time might not match the current version.

the associated hot laboratory and senior cave was part of this effort, in which the primary nuclide of concern was ^{137}Cs. All areas were continuously monitored for airborne contamination during D&D, which was completed in February of 2001.

Three D&D projects are in progress and awaiting funding. Characterization of the 301 Hot Cell Facility was complete in 1998 (ANL 1998). The scope of this project includes cleaning and dismantling contaminated equipment and disposing it. Characterization of the Juggernaut reactor in Building 335 was complete in 2001, and characterization of the ZPR facilities in Building 315 was complete in 2002.

In addition to the listed D&D activities, there have been numerous other small-scale D&D projects at ANL-E over the last 15 years. These include decommissioning of a kennel facility, multiple glovebox facilities, and plutonium-contaminated equipment.

2.3 RELEASES TO THE OUTDOOR ENVIRONMENT

No estimates of the quantity of effluents release are available for 1946 to 1972. Annual environmental reports for 1973 to 2004 provide annual airborne releases of radionuclides. Table 2-4 summarizes the airborne releases of gaseous radionuclides estimated from measured stack releases at reactors and other buildings where gaseous releases were known to occur. Until 1979, ^{3}H and ^{41}Ar from the CP-5 reactor constituted most of the gaseous releases. Once the CP-5 reactor was shut down in 1979, airborne releases were dominated by ^{3}H, ^{41}Ar, and ^{85}Kr from the Janus reactor and the accelerators until the breeding verification work began in Building 200 in the mid-1980s. Then ^{220}Rn dominated the total releases in terms of activity. Although the proof-of-breeding program ended in 1987, the stored wastes from this and nuclear medicine studies in Building 200 continued to contribute to ^{220}Rn releases. In 2004, the ^{220}Rn releases were less than 1% of their 1986 peak. Short-lived neutron activation products from the IPNS and APS have dominated releases since the 1990s.

Table 2-5 lists estimated annual waterborne effluent radionuclides from ANL-E to Saw Mill Creek. Wastewater discharges to this creek, which also drains surface water from much of the site, and flows into the Des Plaines River about 500 m downstream of the outfall (Golchert and Kolzow 2005). Tritium is the most common radionuclide released in water. Tables 2-4 and 2-5 include all radionuclides for which the estimated release quantity was greater than 3.7×10^{7} Bq/yr (1 mCi/yr).

2.4 ACCIDENTS

The Draft Environmental Impact Statement for ANL-E (DOE 1979) summarizes the accidents on the site. The accidents summarized were those that could "have resulted in significant offsite consequences," but the effects of which "were localized on the ANL site, and generally within the immediate vicinity of the accident location." DOE (1979) does not explicitly identify the locations of the accidents; where possible, the locations were determined from other information:

Criticality accident, June 2, 1952 (Building 316) – A power excursion in the ZPR-1 occurred when a control rod was manually withdrawn before water had been removed from the assembly. Four employees were exposed to radiation doses ranging from 12 to 190 rem. There were no detectable consequences beyond the facility fence. Rose and Novak (1952) describe the event in detail.

Radium release, June 13, 1952 (Building 203) – A platinum capsule containing 50 µg of radium sulfate powder was breached when a technician attempted to transfer it pneumatically from its storage cave. The technician had difficulty positioning the capsule in the transfer tube and, when air pressure

Table 2-4. Estimated annual activity of airborne effluent radionuclides (Bq/yr).[a]

Year	Rn-220	Rn-222	Ar-41	C-11	N-13	O-15	F-18	H-3 (HT)	H-3 (HTO)	Kr-85	Pu-241
1946–1972	No estimates available										
1973			9.8E+14						1.4E+13		
1974			1.6E+15					2.2E+12	1.7E+13	8.9E+10	
1975			1.7E+15					2.6E+10	1.6E+13	1.6E+11	
1976			1.5E+15	4.8E+10				7.0E+10	1.3E+13	2.7E+11	
1977			1.5E+15					1.5E+10	1.3E+13	5.6E+11	
1978			1.2E+15						3.5E+13	4.8E+11	
1979			2.6E+14						2.4E+13	3.3E+11	
1980			3.0E+10						3.3E+11	1.9E+11	
1981			1.5E+10							2.4E+11	
1982			2.1E+10	3.7E+12						3.1E+11	
1983			2.8E+10	4.4E+12						8.1E+10	
1984	2.8E+12		3.3E+10	3.2E+12					2.3E+12	2.6E+12	
1985	1.0E+14		9.6E+10	5.6E+12					1.7E+12	4.7E+12	
1986	2.6E+14		5.6E+10	3.3E+12					1.9E+12	6.3E+10	
1987	2.4E+14		6.3E+10	7.5E+12					1.6E+12	1.5E+11	
1988	1.4E+14		1.0E+11	3.2E+12	4.8E+10	3.0E+11		3.4E+11	1.5E+12	2.6E+11	
1989	6.9E+13		4.1E+10	3.6E+12	7.8E+10	4.0E+11		1.3E+11	1.3E+12	1.5E+11	
1990	9.6E+13	3.3E+09	1.3E+11	3.2E+12	3.6E+10	2.1E+11	7.4E+08	1.9E+11	5.4E+11	1.9E+11	7.1E+07
1991	1.1E+14	9.6E+09	1.9E+11	3.0E+12	3.7E+10	2.8E+11	7.4E+08	7.0E+11	1.0E+12	2.5E+11	
1992	1.1E+14	1.0E+10	1.8E+11	6.9E+12	1.0E+11	4.7E+11	3.1E+09	9.8E+11	4.1E+11	1.7E+11	
1993	7.5E+13	3.7E+09	3.5E+11	1.2E+13	2.3E+09	2.6E+08		9.7E+11	3.1E+11	4.8E+11	
1994	6.5E+13		1.6E+11	1.1E+13	1.5E+12	1.6E+11		1.5E+12	2.5E+12	7.8E+11	
1995	3.8E+13		2.0E+11	1.6E+13	2.0E+12	2.1E+11		1.4E+13	2.4E+12	1.1E+13	
1996	1.4E+13		3.5E+11	2.6E+13	7.9E+11	8.1E+10		1.3E+13	2.9E+12	6.2E+11	
1997	1.1E+13		3.7E+11	2.4E+13	1.4E+11	1.5E+10		4.6E+12	4.7E+11	3.9E+10	
1998	8.8E+12		3.1E+11	2.1E+13	1.4E+11	1.5E+10		5.8E+12	1.6E+12	1.1E+11	
1999	7.1E+12		5.9E+10	4.3E+12	1.2E+11	1.3E+10		4.8E+12	4.2E+11	5.0E+10	
2000	1.7E+12		4.2E+11	5.9E+13	1.3E+11	1.4E+10		4.4E+12	3.9E+11	1.7E+11	
2001	1.3E+12		3.0E+11	4.6E+13	2.4E+11	2.7E+10		2.7E+12	2.1E+11	4.9E+11	
2002	1.1E+12		3.5E+11	5.4E+13	4.0E+11	4.4E+10		3.4E+12	3.5E+11	9.6E+11	
2003	9.4E+11		3.3E+11	8.2E+13	4.0E+11	4.4E+10		2.9E+12	3.5E+11	5.0E+11	
2004	1.1E+12		2.4E+11	8.7E+13	4.0E+11	4.4E+10		1.0E+12	5.1E+11	2.8E+11	

a. Blank = not applicable; includes radionuclides estimated to be released at greater that 3.7×10^{7} Bq/yr (1 mCi/yr).

Table 2-5. Estimated annual activity of waterborne effluent radionuclides at Saw Mill Creek (Bq/yr).[a]

Year	H-3	Sr-90	Cs-137	Np-237	Pu-239	Am-241
1946-1972	No estimates available					
1973	1.3E+11					
1974	9.3E+11	2.1E+08		8.1E+07		
1975	6.3E+12	1.5E+08				
1976	5.2E+11					
1977	3.7E+11					
1978	1.4E+11					
1979	1.4E+11					
1980	5.9E+10					
1981	3.3E+10					
1982	4.4E+10					
1983	5.2E+10					
1984	3.7E+10	5.9E+07				
1985	2.7E+11					
1986	1.1E+12					
1987	3.3E+10	2.6E+08	4.4E+08			
1988	7.0E+10	1.1E+08	3.0E+08			
1989	3.2E+09		2.2E+08			
1990	1.3E+10	5.2E+07	1.1E+08			
1991	5.2E+10		3.0E-03			
1992	9.3E+10					
1993	6.9E+11	3.0E+09	2.2E+10		4.4E+07	3.7E+07
1994	4.2E+10	1.2E+09	3.1E+08			
1995	1.9E+10	8.1E+08	2.2E+08			
1996	2.8E+10	9.6E+07				
1997	2.7E+10	9.6E+07				
1998	4.7E+10	1.3E+08				
1999	1.6E+11	1.4E+08				
2000	4.3E+09					
2001	3.7E+09					
2002	3.7E+09					
2003	3.0E+09					
2004	3.3E+09					

a. Blank = not applicable; includes estimated radionuclide releases greater than 3.7×10^{7} Bq/yr (1 mCi/yr).

was applied, a puff of white smoke appeared. Much of the (undisclosed) building was contaminated; the facility was decontaminated over a period of several months. The technician's radium body burden was determined from whole-body counting and ranged from 0.3 µg at 3 days to 0.04 µg at 235 days after the incident.

Filter fire, May 20, 1959 (Building undisclosed) – A HEPA filter in a chemical laboratory was 99% destroyed by fire, but no activity was detected either near the fire or downwind of the exhaust stack.

Radioiodine release, March 14 to May 1, 1961 (Building 205) – Elements of irradiated EBR-II fuel were melted in a furnace filled with inert gas in Building 205. Iodine-131 was adsorbed onto the surfaces of a bell jar for collection of noble fission gases. When the system was opened and exposed to air, the iodine desorbed and was exhausted to the atmosphere through HEPA filters and a short stack on the roof. A contractor employee on the roof received approximately 50% of the allowable body burden. Other nearby workers received smaller doses.

Plutonium release, March 12, 1965 (Building undisclosed) – A 5.7-g sample of plutonium hexafluoride was accidentally released inside a glovebox. Air sampling indicated that 2.4 µg of an undisclosed isotope of plutonium was released to the atmosphere, but air and surface concentrations of plutonium at sampling points beyond the exhaust stack were below detection limits.

Polonium contamination at CP-5, April 9, 1970 (Building 330) – While the reactor was shutdown, a researcher performed a pressure test on a reactor horizontal through-tube. An unclad bismuth shield plug, which had been present in the reactor since 1954, was inside the tube. Polonium-210 was present in the shield plug as a product of neutron activation. A temporary seal plug was dislodged during the test, and ^{210}Po was ejected from the tube and dispersed throughout the building. Substantial decontamination of the reactor building was required, but no individual lung exposures in excess of 10% of the limit were calculated. No contamination above background levels was found on the reactor roof or on nearby buildings, stored equipment, soils, and grasses.

Plutonium glovebox explosion, October 17, 1972 (Building 205) – An explosion occurred in a glovebox that contained mixed plutonium and uranium oxides. The normal nitrogen atmosphere had accumulated a flammable mixture of hydrogen and air, which a spark ignited. Of 15 employees who could have inhaled plutonium, two had detectable amounts of plutonium that would result in lifetime lung dose commitments of less than 2 rem. No contamination was found outside the building, but plutonium was dispersed inside the building both by the blast and by subsequent tracking by evacuees and emergency personnel.

Glovebox fire, March 25, 1974 (Building 212) – Materials were being removed from a glovebox where they had been stored. The materials, including "powdered urania, thoria, and tungsten," were placed in a plastic pouch that was being sealed with a dielectric sealer. During this operation, the tungsten overheated and caused the fire. There was no contamination of personnel and downwind air samples and surface smears outside the building were negative.

Solid waste drum explosion, December 2 to 3, 1976 (Building 306) – A steel drum containing dry active waste including flammable organic solvents absorbed on a desiccant was stored overnight in a truck. The following morning, it was discovered that the drum lid had blown off and contents were scattered inside the truck. There was no evidence of contamination in either the truck or the surrounding area.

Miscellaneous small fires over a 30-yr period – A few small outdoor fires involving depleted uranium were reported. In all cases, contamination was limited to the area immediately surrounding the fire.

Other accidents involving potential nonroutine exposures of ANL-E personnel have been documented over the years in various monthly or annual health physics division reports as well as in personnel dosimetry files when nonroutine dosimetry procedures were instituted based on review of the accident. Details of routine surveys, minor contamination events, and abnormal radiological conditions are described. The accidents appear to fall into three major categories: Industrial accidents, spills of radioactive materials and associated contamination events, and reactor incidents. Some of the available incident reports estimate the dose to specific workers. Others note that decontamination occurred and give some detail of personnel contamination if it occurred.

2.5 HEALTH PROTECTION PRACTICES

The potential for occupational doses from working with radioactive materials was recognized at ANL-E from its beginnings as a national laboratory. Hilberry (1947) characterized the hazard situation as "one of tremendous complexity," and recognized that the ANL-E "health services must be prepared to

guard against damage from any or all of [the exposures to radioactive materials] and must be prepared to act swiftly in case an accident does occur." At the time this letter was prepared, the health protection organization at ANL-E had both medical and a health physics divisions. The medical division carried out all bioassay analyses and consulted with the health physics and biological research divisions to establish permissible levels for exposure. The health physics division maintained the personnel radiation meters and film badge records as well and hand and foot count records, a continuous monitoring service in all active areas including both air and external exposure monitoring, and the marking of contaminated areas. According to this letter, in which the organization of the health and biological program at the laboratory was described, a program for bioassay for plutonium and other radioactive materials had been developed and was being applied. Internal contamination from wounds was a major concern in the 1940s, and means of mitigating this potential were under investigation. Beginning in the early years, the personnel monitoring and access control activities of the laboratory evolved to the current procedures. The following sections provide overviews of personnel monitoring and access control as an introduction to the more detailed information provided in other ANL-E TBDs.

2.5.1 Personnel Monitoring and Protection

As noted above, the need for personnel monitoring was recognized at the inception of ANL-E. Bioassay monitoring for plutonium and other isotopes was being carried out to an unspecified extent, a system of continuous air monitoring of laboratory air was being developed, and pocket meters and film badges were being used regularly (Hilberry 1947). A means of reliably measuring slow and fast neutrons was also being investigated.

In 1956, the Radiation Safety Guide (Novak 1956) formally set forth the procedures for personnel monitoring. In specific, all individuals required to work in the vicinity of radioactive materials were required to wear film badges and self-reading dosimeters. The dosimeters were to be worn only in areas in which radioactive materials were located in such amounts that they constituted a potential personnel hazard. Wrist badges were required for some operations. The Radiation Safety Guide outlined precautions to protect workers from external and internal radiation and described when to use respiratory equipment and protective clothing. Myers et al. (1952) addressed selection of personnel for bioassay.

The Radiation Safety Guide (Novak 1956) was not revised, but procedures it covered continued to be revised as missions at the laboratory changed and techniques improved. The ANL-E Health and Safety Manual (ANL 1984) replaced this guide sometime in the early 1970s as the policy and procedures document to describe personnel monitoring and protection. The Health and Safety Manual provided considerably more detail in many areas of personnel protection including radiation safety; it specifically required that personnel monitoring devices (film badges, pocket dosimeters, wrist badges, finger monitors, etc.) be worn at all times when working with radiation and that protective clothing and equipment be worn when necessary. The Health and Safety Manual provided guidelines to determine the necessity.

The ANL-E Health and Safety Manual (ANL 1984) underwent several revisions; the ANL ESH Manual replaced it in the early 1990s. The current version of the ESH Manual is an electronic compendium of sections that undergo frequent update (ANL 2005). The ESH Manual provides considerably more guidance than its predecessor documents about the requirements for personnel monitoring, internal and external dosimetry, and personal protective equipment. In particular, the ESH Manual specifies that all badged workers (i.e., those who have the potential to receive 100 mrem annual effective dose equivalent; 5 rem annual dose equivalent to an organ, tissue, or extremity other than lens of the eye; or 1.5 rem dose equivalent to the lens of the eye) must wear dosimeters in radiation areas and should

wear them while on the site. In addition, the ESH Manual addresses the selection procedures and frequencies for bioassay, but implementation is described more concisely in Standard Operating Procedures ESH-HPP-504 (Marchetti and Holtzman 1994) and ESH-HPP-506 (Marchetti, Holtzman, and Keane 1997).

2.5.2 Access Control

ANL-E went through many changes over the years from a laboratory where predominantly classified activities took place to a relatively open campus where outside researchers from industry, academia, and other national laboratories can gain access to the sophisticated scientific and engineering research facilities on the site. In 1949, 84% of the work at ANL-E was classified. Access to facilities was strictly controlled in the early years by physical barriers. A 10-ft barbed-wire fence surrounded the laboratory in 1951 (Holl 1997). However, in 1953, President Eisenhower's Atoms for Peace initiative promoted extensive declassification of reactor technology, which in turn led to a decline in the need for and practicality of security clearances and fences (Holl 1997).

In 1956, the Radiation Safety Guide (Novak 1956) formally established laboratory regulations and procedures for working with radioactive materials. Although physical means of barring access to active areas (those areas in which radioactive materials were located in such amounts that they constitute a potential personnel hazard) were not directly described, the Guide indicated that occupants of active areas were responsible for clearly defining and marking such areas. Further, certain regions of the laboratory were specifically identified and marked as areas where radiation hazards normally existed. A Work Entry Clearance Form was required for certain areas, and Radiation Safety approval was sometimes required, which suggests that entry to some radiation or classified areas was controlled.

With the introduction of the ANL-E Health and Safety Manual in the early 1970s, a "radiation area" was clearly defined (ANL 1984, Ch. V-3, p. 3) and requirements were specified for clearly identifying radiation areas. Ropes and/or barriers were required for areas with external exposure rates of more than 100 mR/hr.

The ESH Manual (ANL 2005) clearly specifies, in greater detail than provided by the preceding documents, the requirements for access into controlled and radiological areas. It is likely that many of these requirements were in place before publication of the first ESH Manual in the early 1990s because this document represents the present state of the gradually evolving access control procedures at ANL-E. According to the current ESH Manual, access to radiation areas requires completion of Radiation Worker I training for unescorted access and wearing of an assigned dosimeter. Access to a high radiation or contamination area requires completion of Radiation Worker II training at a minimum, wearing of a dosimeter and supplemental dosimeter, and a signed Radiological Work Permit. Physical access controls are required for high radiation areas with a dose rate greater than one rem/hr. Access to very high radiation areas is prohibited, and physical controls are required. Exit controls are required for certain areas to limit the potential for contamination spread. In addition, the ESH Manual contains detailed requirements for posting of controlled areas and for use of radiation safety interlock systems.

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GLOSSARY

accelerator
Device for imparting kinetic energy to charged particles.

boiling-water reactor
Nuclear reactor in which the water coolant boils as it absorbs the heat of the nuclear reaction.

breeder reactor
Nuclear reactor in which the operation produces a net increase in fissionable reactor fuel.

control rod
Device constructed of material to absorb neutrons manipulated within a nuclear reactor to slow or increase the nuclear reaction.

criticality
Event where a nuclear chain reaction is sustained (controlled or not).

curie (Ci)
A special unit of radioactivity equal to 3.7×10^{10} disintegrations per second; 1 disintegration per second is 1 becquerel.

cyclotron
Accelerator capable of large beam currents where the beam is injected in the center of a circular magnet. A fixed radio frequency applied to two D-shaped electrodes accelerates the beam as it passes from one to the other as the potential alternates. The radius of the beam increases as the energy increases.

decontamination and decommissioning (D&D)
Removal of radioactive and other potentially hazardous materials from a facility and removal of the facility from service, usually including dismantling or demolishing of the facility.

dose
Specific amount of energy from ionizing radiation or a toxic substance absorbed per unit of mass.

Dynamitron
Direct current accelerator manufactured by Radiation Dynamics. The terminal is charged with a multistage rectifier system excited by radio frequencies.

enriched uranium
Uranium enhanced from its natural state to contain a higher percentage of the isotope ^{235}U.

exposure
Measure of X- or gamma radiation capable of ionizing air (usually in units of roentgens).

fission
Nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

fission product
Nuclides that results from fission.

hot cell
Specialized shielded laboratory in which radioactive materials can 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 radiation.

ionizing radiation
Radiation with sufficient energy to separate electrons from neutral atoms or molecules.

linear accelerator
Straight single-pass accelerator where radio frequencies accelerate the beam over the length of the accelerator.

neutron (n)
Basic atomic particle that is electrically neutral with nearly the same mass as a hydrogen atom.

neutron, fast
Neutrons with energy equal to or greater than 10 kilo electron volts.

radiation
Energy transferred through air or some other media in the form of particles or waves (see ionizing radiation); includes light and radio waves.

radioactivity
Spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

radioactive waste
Radioactive materials for which there is no use.

radionuclide
Radioactive species of an atom characterized by the number of protons and neutrons in its nucleus (the mass number).

rem
Unit of dose equivalent equal to the product of the energy absorbed in units of rad and a quality factor.

Sievert (Sv)
International System unit for dose equivalent; 1 Sv is equal to 100 rem.

synchrotron
Roughly circular accelerator in which the particles travel in synchronized bunches at fixed radius.

tandem Van de Graaff accelerator
Accelerator in which charge exchange (negative to positive) occurs in the terminal on either a thin foil or in a gas stripper tube.

tritium

Radioactive isotope of hydrogen having one proton and two neutrons. 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.

Undulator

A device made with permanent magnets used in synchrotron light sources which moves beam particles quickly back and forth so that synchrotron radiation from the N (N ~60 to 100) bends constructively interfere so that beam brightness is increased by about a factor of N^2. The energy of the peak brightness beams can be adjusted by changing the magnet spacing.

Van de Graaff accelerator

Direct current high-voltage accelerator in which a terminal in a pressurized tank accelerates the beam. The voltage is generated by charge carried on an insulating belt.

water-moderated reactor

Reactor that uses water to slow the speed of neutrons from fissioning atoms to increase the number of neutrons that cause fission.

X-ray

(1) Ionizing electromagnetic radiation of external nuclear origin with energies generally less than 250 kilo electron volts (includes synchrotron radiation, which is ionizing). (2) A radiograph.

zero power

Operating a reactor to maintain a chain reaction at an extremely low power level producing very little heat. Zero power reactors are used as sensitive laboratory tools to pretest experimental loadings of test reactors and for other analytical purposes. Also called low power.