RADIOLOGICAL ASPECTS OF THE DEACTIVATION OF HANFORD PRODUCTION REACTORS

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Abstract—Deactivation of three of Hanford's eight large plutonium production reactors at Richland, Washington, brought to light radiological problems which had not been encountered before in the nuclear industry. Large volumes of activation and fission products were generated during the 15 years of operations. Much of this material had been retained in storage and retention basins and some was charged into the ground at designated burial locations. In addition, a small portion of these products had accumulated in open work areas.

The basic procedures used to ensure short-term radiological control of deactivated Hanford production reactors consisted of essentially reducing the radioactive contamination in the open areas to a nominal level and sealing off those locations and systems where decontamination was deemed impractical. Long-term radiological control will be maintained with minimum surveillance during the postdeactivation period by ensuring that traffic in the open areas is kept to a minimum and that sealed-off systems are not disturbed. The proposed paper will describe, with the aid of slides, radiological conditions of the various zones before decontamination work was started and will summarize the techniques used in the decontamination and containment program.

Control programs were also established for numerous underground radiation zones such as the reactor effluent systems and miscellaneous burial grounds. Open retention basins containing up to 300 tons of radiocontaminated silt and sand required implementation of unique containment techniques. The proposed paper, in conjunction with slides, will also describe the techniques used to deactivate these zones.

Approximately 1 year has elapsed since deactivation work was completed on the reactors and their associated facilities. The adequacy of the confinement and decontamination activities is supported by the fact that no contamination spreads have occurred. Within the next 5 years, the major portion of the activation products will be eliminated through natural decay. The remaining activity will largely be attributable to the longer-lived fission products, but these are thought not to be prohibitive in reclaiming much of the land for more purposeful future activities.

I. PLANT DESCRIPTION

The Hanford Plant of the U.S. Atomic Energy Commission is a complex of production, research, development and supporting facilities distributed over a 575 sq miles area of southeastern Washington (Fig. 1). The Plant is under the direction of the USAEC Richland Operations Office (RL). Its mission as a production site has been the production of plutonium weapons parts, and the performance of other atomic energy related activities as required by the Commission. To accomplish these assignments, a physical plant has been constructed at an initial capital cost in excess of $1 billion. The principal process facilities are two fuels fabrication plants; nine large nuclear reactors, three of which are now shut down; two large chemical separations plants; and a final

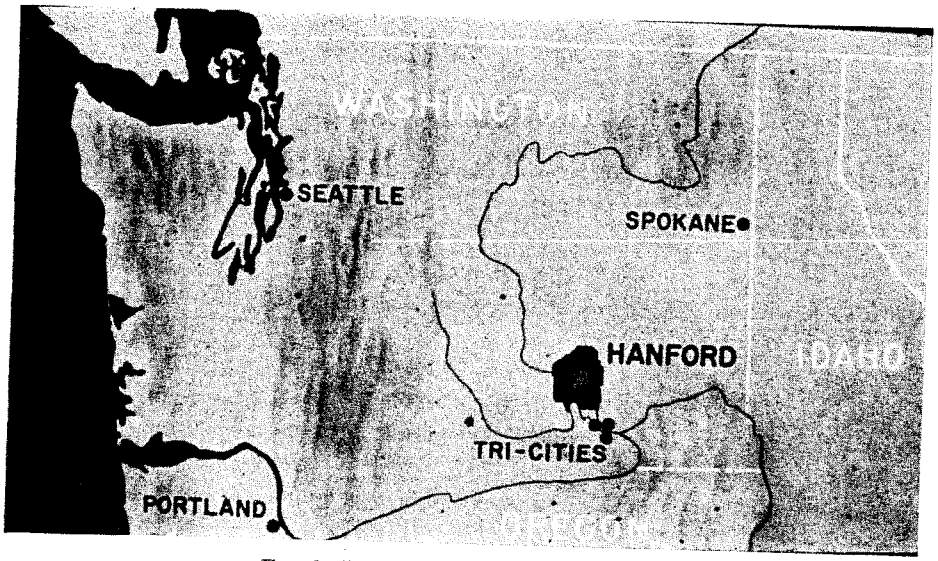

FIG. 1. Location of the Hanford plant.

plutonium processing and fabrication facility. These are supplemented by hundreds of satellite and supporting buildings and facilities.

Until November of 1965, the General Electric Company (G.E.) was responsible for operating the nine production reactors. Since that date, Douglas United Nuclear, Inc., has taken over the "older" reactor operations, and G.E. continues to operate the new dual-purpose reactor. The RL Hanford reservation is also a major research and development center of the Atomic Energy Commission and has an annual Research and Development budget in excess of $30 million. About one-third of this Research and Development effort is in support of Hanford production operations, and the remainder is directed toward a variety of peaceful applications of atomic energy. About three-fourths of this work is conducted within the Laboratories organization and the remainder by research and engineering groups directly attached to production organizations. The nearest city is Richland, Washington (shown in Figs. 2 and 3).

A. *Topography*

The general topography of the Hanford reservation is shown by Fig. 4. The terrain, typical of much of eastern Washington and Oregon, is generally treeless, covered with bunchgrass and sagebrush, and varies from plains to gently rolling hills. A long, high ridge (Rattlesnake Mountain, 3500 ft elevation) bounds the area on the southwest, while the Columbia River is along the north and east boundary. The river shore on the reservation side is gently sloping. The eastern shore from 300 Area north to about 100-H Area consists of high bluffs; river elevation at Richland is about 350 ft.

B. *Geology*

Three major rock formations comprise the geology of reactor sites along the Columbia River. The Columbia River Basalt series forms the bedrock of the region, and current estimates place its thickness at 14,000 to 15,000 ft. The Ringold Formation overlies basalt at a depth of about 500 ft. The late Pleistocene to recent fluviatile and glaciofluviatile sediments overlie the irregularly eroded surface of the Ringold Formation sediments, so that in places they grade into and are almost indistinguishable from the older sediments. Elsewhere, they consist of poorly sorted, but generally coarse-grained sand to pebble and cobble gravel and boulders, largely derived from the basalt plateau to the north.

No damaging earthquake has ever been recorded in the immediate vicinity of the RL

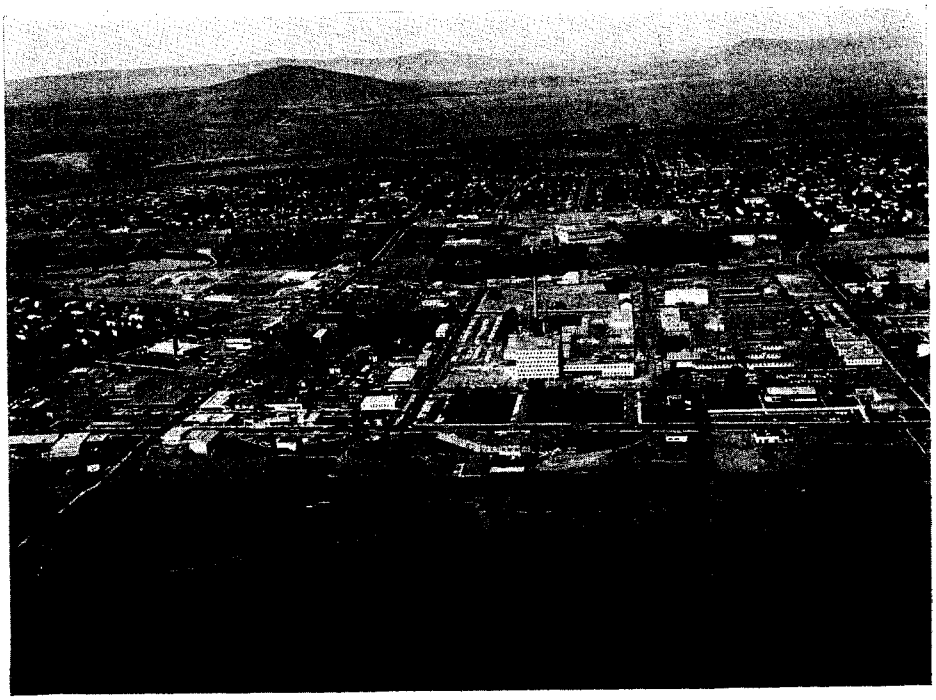

FIG. 2. View of Richland, Washington.

FIG. 3. View of Richland, Washington, and the Columbia River.

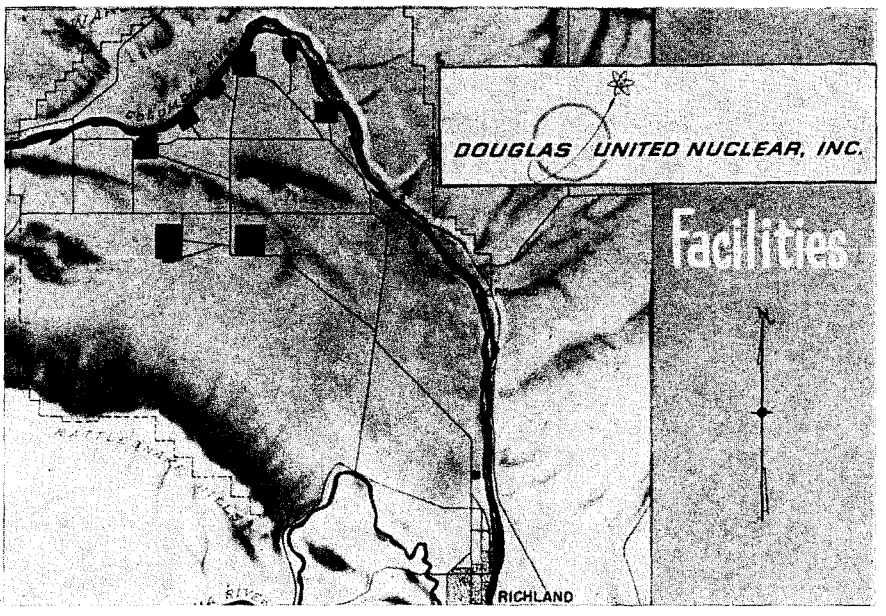

FIG. 4. Douglas United Nuclear, Inc., facilities.

Plant, although the area lies in a region susceptible to earthquake damage from the active seismic zones of western Washington and from the active seismic zone that includes the Walla Walla area. For comparison, the expected probability of earthquake damage at the National Reactor Test Site (NRTS) at Idaho is about the same as RL, but both areas are actually quite low in probability. For building code purposes, the entire area east of the Cascades is in Zone 2 of the Seismic Probability Map. (Pacific Coast Building Officials Conference, Uniform Building Code, 1959 Edition).

C. *Climate*

The Hanford reservation has a semiarid climate of warm summers and mild winters. Daytime temperatures above 90°F are common during July and August. Nights are invariably cool throughout the entire spring and summer. Even in the hottest month (July), the average night-time minimum is 60°F.

Subfreezing temperatures are frequent during the short winter with occasional temperatures below zero. The average minimums for January and February are 24°F and 30°F, respectively. Average highs are 40.5°F in January and 48.8°F in February.

Precipitation is light, averaging about 8 in./year. Most of this falls from November through February. Snowfall usually is confined to January and February and normally comprises about 25% of the annual precipitation. The amount of snow, which may accumulate, is insignificant and generally ranges from a trace to 4 in.

Occasional early-morning fog appears near the river lowlands during the winter months; however, smog is unknown. The climate and physical features necessary for smog formation and continuance are absent and visibility is seldom less than 10 miles. The average annual wind velocity is 7 mph.

D. *Water Supply*

The basic water supply for the Hanford reservation is the Columbia River with average annual flow rates of 394,000 ft^3/sec, 59,000 ft^3/sec minimum, and 127,000 ft^3/sec average. Water from the Columbia River is pumped to the Hanford reactor areas. It is treated and then filtered for use as coolant in the reactors.

E. *Radioactive Waste Disposal*

Conditions at the RL site are particularly favorable for solid, gaseous, and liquid waste disposal, probably more so than at any other major AEC site. Subsurface lateral water flow is very slight, rainfall is low and penetrates to only a shallow depth that is well above the water table. Ion exchange characteristics are good. Thus, if needed, large quantities of low-level liquid and solid wastes can be charged into the ground to decay.

Thermally hot reactor cooling water discharged to the Columbia River contains radionuclides produced mainly by neutron activation of impurities. The impurities originate as corrosion products, chemical additives, and trace elements that are not removed in water treatment processes. Most of these are short-lived radioisotopes which effectively disappear within 24 hr. Nevertheless, reactor effluents are ordinarily retained for short periods in large open basins to allow:

The short-lived activation products to decay.
Particulate radioactive materials to settle.
Cooling time for effluent prior to discharge into the river.

Even though additional direct discharge of once-through reactor coolant to the Columbia River from new facilities is not allowed, activity and contamination levels found in the river are much below the imposed AEC limits.

Small amounts of contaminated reactor ventilation air can be safely discharged to the atmosphere through tall stacks; however, to guard against significant contamination of the environs outside the reservation boundaries, fog-spray equipment, backed by high efficiency filters, has been installed in reactor production facilities. RL reactors are presently confined rather than contained (with the exception of the Plutonium Recycle Test Reactor, which is located near a residential area).

Contaminated solid wastes from the manufacturing and laboratory facilities are buried in permanently marked trenches above the level of the regional ground water. The low rainfall in the area results in moisture penetrating the soil to a depth of only a few feet; hence, leaching of radioactive materials from the solids is negligible.

All radioactive waste streams, gaseous and liquid, are sampled and, in many instances, continuously monitored prior to discharge to assure that established RL-AEC waste disposal limits are not exceeded.

II. REACTOR DESCRIPTION

A. *General*

The deactivated Hanford reactors are graphite moderated, light-water cooled, and fueled with uranium metal. Each of the deactivated reactors consists of a near cubical stack of graphite (the core) which approximates 30 ft on an edge. Each core is traversed from front to rear by about 2000 channels containing aluminum process tubes. These tubes hold fuel elements and provide passage for the "once through" cooling water entering at the front face and leaving at the rear face. The control rods, consisting of neutron absorbing material, enter the reactor from one side and are positioned remotely by controlled motor drives. The "scram" systems (safety rods, etc.) for emergency shutdown are operated from the top of the reactor. The reactor core is surrounded by a graphite "reflector", to conserve neutrons, and by a heavy neutron and radiation absorbing shield. Figure 5 shows a cut-away view of a typical Hanford reactor.

B. *Water Flow*

Water that passes through the reactors is pumped from the Columbia River, into water treatment basins for flocculation and pH treatment, through anthracite filters, and into large storage tanks. The treated water is then pumped into large risers on both sides of the reactor's front face. Horizontal cross connections between the risers (crossheaders) carry the water to jumpers from the crossheaders and thus into the aluminum tubes. The jumpers are called "pigtails"; descriptive of their particular shape. The water flows through the tube, out the rear and into a similar plumbing system on the rear, through downcomers, and out through a discharge line into large retention basins. The retention basins provide both decay time for short-lived radionuclides and time for cooling of the water by way of evaporation prior to discharges back into the river. Figure 6 shows the water flow through a typical reactor area.

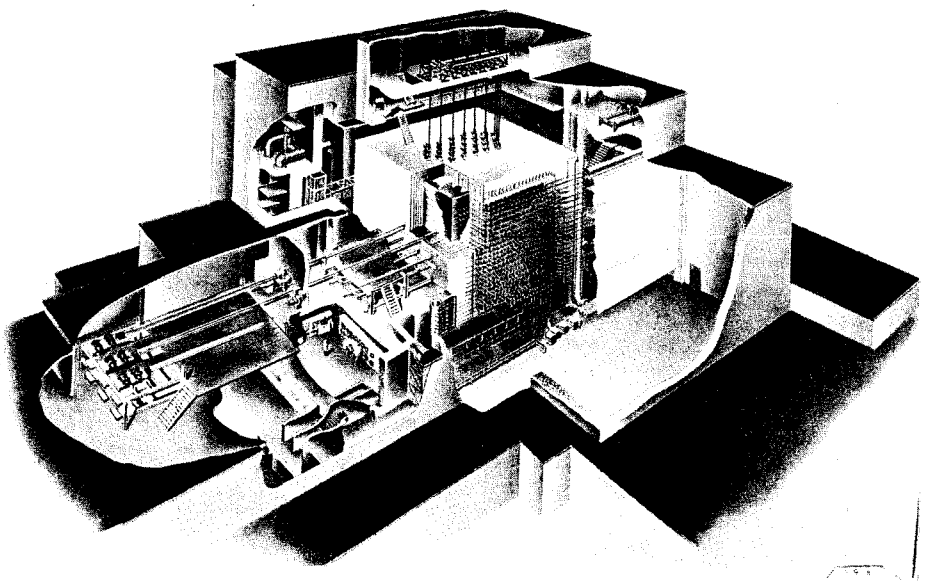

FIG. 5. Cut-away of a typical Hanford reactor.

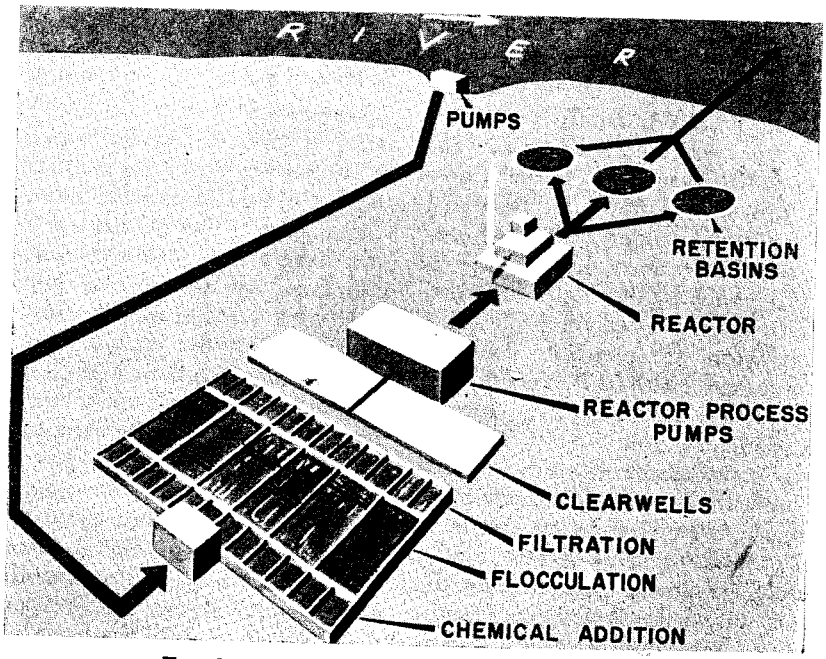

FIG. 6. Water flow through a typical reactor.

C. *Fuel Handling*

Fuel elements (uranium) are transported from the 300 Area Production Fuels plant in special semitrailer trucks. Pallets of "elements" are transferred from the trucks to the reactor metal storage room. During refueling of the reactor, the metal fuel elements are moved from the shipping pallets to charge boxes. The boxes are loaded with fuel, "dummies" (perforated aluminium spacers), and mixers in the appropriate order. The fuel elements are also visually inspected during the charge-makeup operation, and made-up charges are placed on "Tea Carts" for subsequent transfer via the metal elevator to a work platform and the charging machines. The contents of the charge box are unloaded onto the front face charging machine in proper sequence so the fuel will be located, as previously planned, in the process tube. A strict piece count of all fuel is maintained.

After rear-face discharge of irradiated fuel elements, the spent fuel is sorted, picked up, counted, weighed, and sorted in buckets under several feet of water in a large basin. After a specified cooling period, fuel is shipped in special railroad cars to the Chemical Processing plants for separation work.

Irradiated dummies and mixers are also collected in buckets in the water-filled basin, and many are decontaminated for future use. Some of the dummies (those next to the fuel elements) have radiation intensities too high for immediate decontamination, and are charged into large ground pits for radioactive decay.

III. REACTOR DEACTIVATION

A. *Administration*

A deactivation "unit" was specially formed as shown in Fig. 7. This unit was established to coordinate activities for deactivation of DR, H and F Reactors. The guides established by this group were written into a manual covering DR Reactor and later modified for use in deactivating H Reactor and finally F Reactor. The manual contains specific items to be performed during deactivation activities.

Although each deactivation procedure includes appropriate references and suggestions relative to safety, the deactivation unit has no direct safety responsibility. Such responsibility continued under the direction of the area manager who redelegates safety considerations to the various managers of Maintenance, Processing and Power. The supervisors reporting to these managers are considered to be the "mainstays" in the organization, for they assume the direct contact responsibilities with the operating personnel in their respective areas.

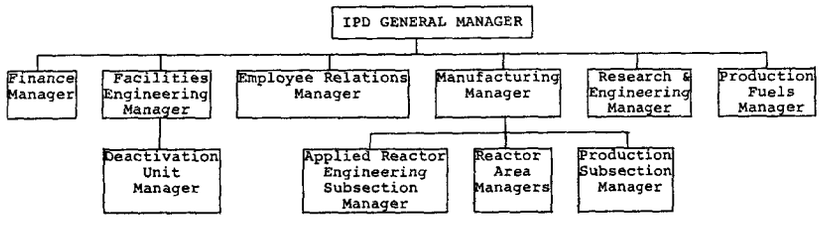

FIG. 7. Organization chart—Personnel Affecting Reactor and Radiation Safety Plus Deactivation Personnel.

The only special procedures required in the operation prior to shutdown of the reactors are those used in physics experiments designed to measure certain nuclear safety parameters. To assure accurate results and safe conditions, a scheduling chart was set up prior to beginning the tests. This chart is shown in Fig. 8. The date is shown along the top with the test listed in the columns staggered to the right indicating the amount of time each test would take. Some of the tests include:

Local control strength
Vertical safety rod calibration
Spline worth
Discharge to minimum critical slab
Cold reactivity—exposure dependence
Supercell

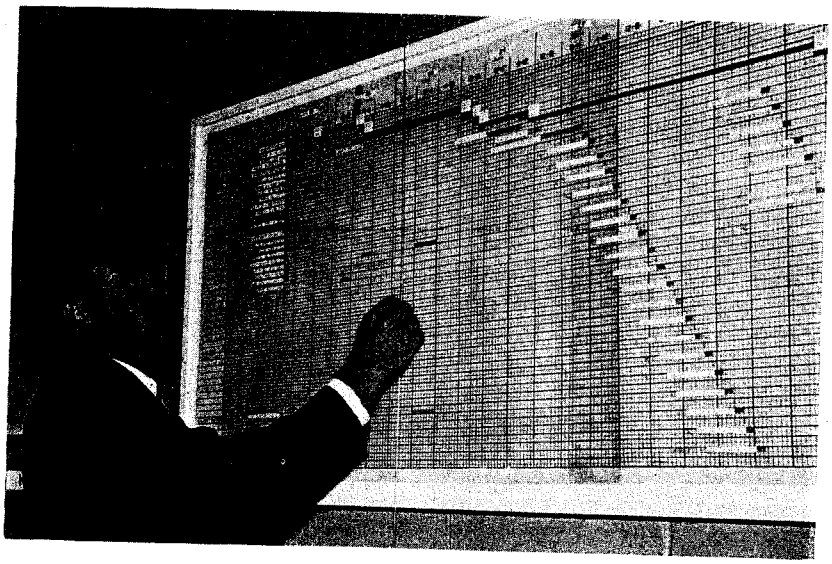

FIG. 8. Scheduling chart.

FIG. 9. Physics test equipment.

Since some of the data obtained have not been fully analyzed, and since much of the material is classified, the results will not be discussed (see Fig. 9 for physics test equipment).

B. *Standard Procedures*

Standard procedures were used to shut the reactors down and to discharge the fuel elements.

C. *Deactivation Procedures*

Procedures were written for:

Decontamination activities
Physical safeguards (e.g. locks, tag)
Posting radiation areas
Transfer of waste to burial grounds and "ultimate posting"
Periodic surveillance after deactivation

These procedures were reviewed by appropriate General Electric Company and AEC personnel for adequacy both in coverage and "safeness".

IV. REACTOR LAYAWAY

General

The deactivation unit mentioned earlier was formed for the specific purpose of closing the reactors known as DR, H and F. DR was shut down in December 1964 and put on a standby status. Since the deactivation of H and F were similar to DR, the deactivation plans for DR were issued in the form of a manual. The manual contained specific items and tasks that were to be performed as part of the deactivation program. All tasks outlined in the deactivation manual were planned and scheduled with safety in mind, whether it was nuclear, industrial or radiological. A special column was included on each instruction sheet pointing out any safety-connected items that should be considered in the performance of work.

Decontamination of the reactors began as soon as the fuel had been discharged. Storage basins, retention basins, and associated effluent piping were given necessary treatment after the irradiated fuel had been shipped. Decontamination, in general, was based on conventional cleanliness and good house-keeping practices prevalent to the nuclear industry. Included were vacuum cleaning, hose-down, wipe-up and disposal of contaminated items. Chemical decontamination was used in specific locations where it had proven to be effective in the past in the removal of rust and encrusted water salts. Materials with a high radiation dose rate were left in locations where there was adequate shielding. These areas were then posted with radiation identification markers and barricaded as required. Equipment and locations not having economic justification for complete decontamination were either isolated, or the contamination was fixed to prevent an inadvertent spread. They were then properly marked, fenced, or barricaded and posted with information on the nature and level of contamination. Contaminated items valued at less than $5000 were either buried or used in the operating reactor areas. Expendable contaminated materials and equipment were removed and either utilized or buried, if this was less costly than decontaminating the items. Interior contaminated surfaces of piping systems and equipment not contributing to radiation dose in general required no treatment other than sealing to contain the contamination. Posting of appropriate warning signs was then initiated to maintain the integrity of the system; the effluent water piping is one example. All parts of the facility, equipment and grounds received a complete radiation survey, and the radiological status was documented and made a part of the layaway information package.

1. *Cleaning Methods.* Low-level loose contamination in such locations as corridors and main traffic areas was removed by water washing, sponging, and mopping. High level loose contamination in other corridor areas that could be contained and removed with a minimum probability of spreading was collected with vacuum cleaning equipment. This was followed by water washing. Contamination that was fixed or had penetrated into porous surfaces required the use of additional cleansing agents in the water, such as detergents and commercial chemical cleaning agents. In stubborn cases, detergent was applied with steam cleaning equipment.

Commercial chemical cleaning agents were used on reactor hardware where past experience indicated no detrimental effects. These agents

were used freely on iron and concrete surfaces where rust, scale, and water salts trapped and concentrated contamination. With this technique, the contamination carriers were, in effect, put into the solution and washed away. Extra caution and additional controls were exercised in the application of these chemical cleansing agents so that they did not inadvertently contact materials and equipment that could be damaged. Some mechanical equipment and almost all the electrical equipment and instrumentation could not be cleaned with water or chemical agents. Therefore, vacuum cleaning and careful wiping with suitable solvents, rags, and swabs were used on this type of equipment. In general, where equipment was not subject to damage and floor drains were present, water washing, sponging and mopping were used prior to the application of chemicals. In other locations, vacuum cleaning was used exclusively. Vacuum cleaners were equipped with traps to collect contaminated dust and dirt and were designed for the easy removal and disposal of the collected dirt.

2. *Shielding and Fixing Methods.* Conventional shield materials were used as required. Radioactive materials not readily removed by normal cleaning methods were fixed in place with either paint or a sprayable plastic. Even high-level contamination was fixed without using concrete or asphalt coatings. Where economically justified, lead brick and lead sheet of appropriate thickness were selected for gamma shielding. However, significant quantities of lead brick were not needed after reactor shutdown. Some locations, which involved large areas and where subsequent removal was a consideration, were shielded with earth fill.

3. *Radiological Criteria.* The Hanford Radiation Control Standards and Procedures (HW-45674) were used where applicable and were consulted as a guide for problems peculiar to the task of reactor plant layaway. The sections in the standard on radioactive waste disposal, shipment of radioactive materials, release from radiation zone status, and radiation markers, plus other sections, were directly applied in the Plant deactivation program.

The following radioactive contamination activity and radiation dose-rate levels were used as a guide in decontamination and cleaning of the plants and appurtenances.

(*a*) *Nonradiation zones.* Working surfaces, doors, tables, work benches, and control panels were to be decontaminated to less than 100 counts per minute (cpm)* as determined by the standard smear technique and to less than 1 mR/hr.

(*b*) *Radiation zones requiring posting.* In general, porous floor surfaces and equipment surfaces were to have less than 3000 cpm of smearable contamination and a dose rate less than 3 mR/hr measured at 1 ft from the surface. The common traffic areas within controlled radiation zones were to be cleaned to less than 1000 cpm by smears. The external surfaces of the reactor, except the rear face, were to be decontaminated to less than 3000 cpm of smearable contamination and less than 3 mR/hr measured at 6 in. from the surface. The rear face and rear discharge area of the reactor were to be cleaned to approximately 10 mR/hr measured at 1 ft from the surface.

(*c*) *Significant contamination zones.* Barricades, warning signs, and/or fixation of contamination were used as safeguards for equipment, material, or locations where:

Significant contamination spread could occur, or

Dose rates exceeded 10 mR/hr.

Included in this classification, for example, were the reactor interior, downcomer and effluent system interior, gas dryer beds, and irradiated metal storage basin.

When a reasonable amount of time and effort had been expended in cleaning any location or piece of equipment without attaining the above goals, the work was to be stopped and the condition reevaluated. An alternate treatment was to be used such as fixing the contamination, shielding, and disposal, accompanied with appropriate posting of warning signs and barricades. All loose contamination was to be removed even though the activity level was below the recommended levels.

4. *Application.* A systematic program was developed and followed during the decontamination of radiation zones within the deactivated

* A standard GM was used for measurements in cpm.

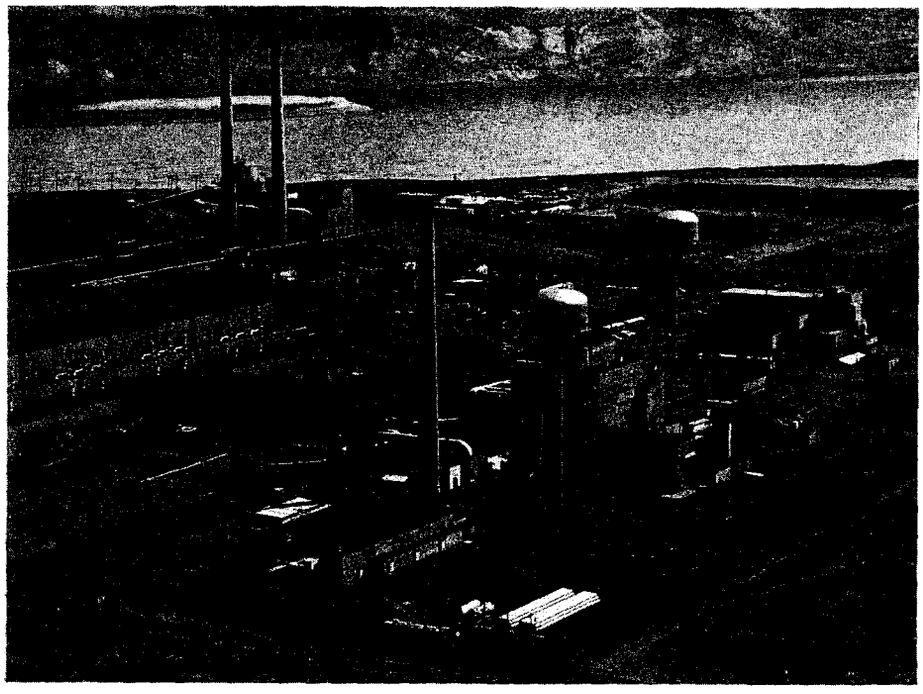

FIG. 10. Aerial view of a typical reactor area.

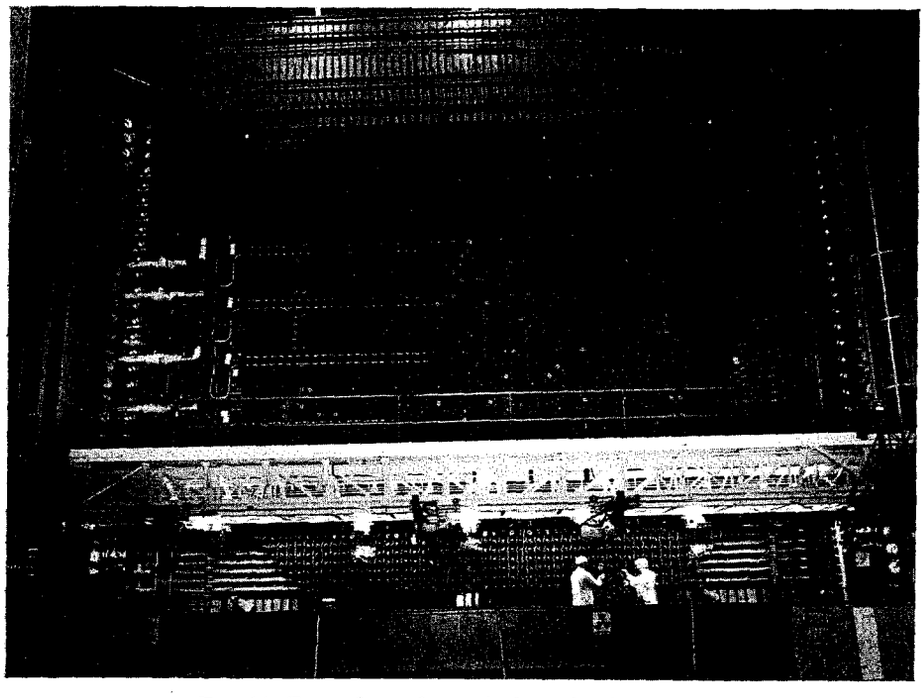

FIG. 11. Front face of a typical production reactor.

reactor facilities. An aerial view of F-Area buildings is shown in Fig. 10. Initial efforts consisted of removing equipment, tools and materials that were not intended for storage in the reactor buildings. This was followed by the implementation of a general "housekeeping" effort and an eventual survey of each radiation zone. In many cases, the radiation surveys indicated that no additional decontamination effort was required to satisfy the postdeactivation radiological control measures mentioned earlier. Figure 11 shows the front face of one of the Hanford reactors and is typical of the type of area that had to be decontaminated. The reactor building contained numerous radiation zones, some of which contained smearable contamination as high as 50,000 cpm. The general flow of decontamination work was from top to bottom and from the right side to the left.

The radioactive contamination in the open areas was, however, readily reduced to a nominal level of less than 3000 cpm. There were several locations where a spread of contamination could occur or which involved dose rates above 10 mR/hr; these locations were either sprayed with a sealant or barricaded and posted with tags describing their status. In each case, the amount of effort expended on decontamination of a specific location was based to some extent on previous decontamination experience.

Approximately 70 locations were surveyed for contamination in each reactor. An average of 43 were previously established radiation zones. Some 25 zones required decontamination with detergent solutions or chemicals to satisfy the decontamination criteria as discussed above.

(*a*) *Reactor pile and discharge basin.* The reactor was sealed; Fig. 12 shows a schematic of a typical reactor pile and the associated discharge basin. Reactor tubing and hardware were also sealed. The discharge and storage area shown in Figs. 13 and 14 did pose special problems. The reactor discharge basin contained a considerable inventory of radionuclides deposited during discharge activities. These radionuclides originated in three ways:

Loss of fission products from irradiated, ruptured metal fuel elements

Neutron activated stable elements (from cooling water) that had collected on fuel elements, dummies, mixers, and tube walls

Activated elements in structural materials in the reactor pile

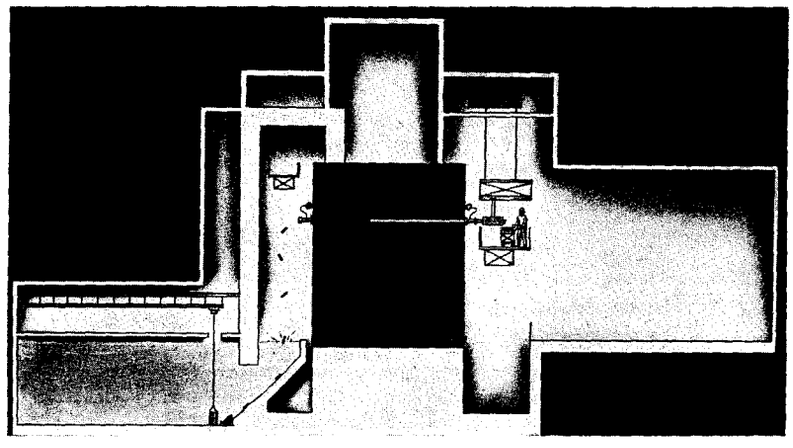

FIG. 12. Schematic of a typical reactor.

The quantity of materials deposited in the basin precluded economical removal. Therefore, each reactor storage basin was left in a partially water-filled condition.

All loose contamination was secured and irradiated material was removed or shielded to reduce radiation levels below 3 mR/hr at 1 ft. Equipment and foreign objects that could be

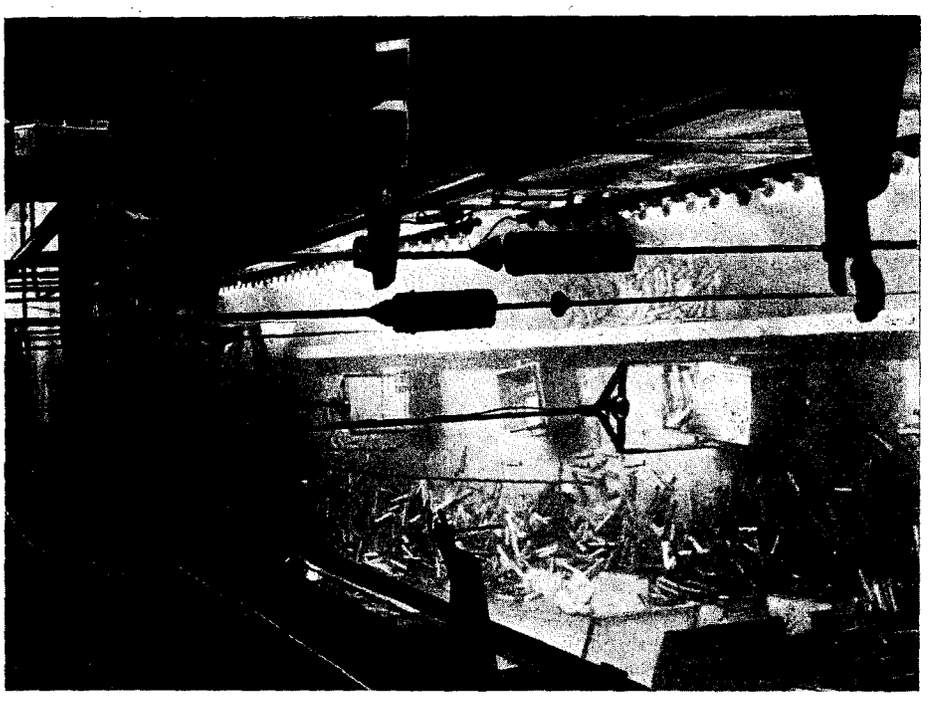

FIG. 13. Reactor discharge area.

FIG. 14. Reactor storage area.

readily picked up were removed from the basin. The water level was gradually lowered and the basin walls were hosed down and scrubbed with commercial detergents and chemical cleansing agents. The radioactive sludge on the bottom of the basin was left in place. The basin was then posted and barricaded as required by existing radiation protection standards.

A radiological analysis was made at one of the deactivated reactors. The basin water level was lowered from 17 ft 7 in. to 4 ft. Dose-rate measurements taken at the top of the basin did not exceed 7 mR/hr and no smearable contamination was detected on the basin walls. The analysis demonstrated that radiation dose rates and contamination could be controlled by keeping an appropriate level of water in the basins. An alternate method for radiological control would be to dump a nominal amount of earth or cinder into the basins. To date, it has proven to be less expensive, however, to keep water in the basins instead of filling them with earth or cinder.

(*b*) *Ventilation system.* The reactor ventilation supply system did not require decontamination. A borderline exception was the internal portions of the DR and F Reactor rear face supply ducts that required stabilization of loose contamination. All dry and wet filters were left in place.

Except for the 105-H rear face exhaust duct, the ventilation exhaust ducts did not require decontamination. Access covers were left in place to prevent contamination spread, and radiation warning signs were then posted at appropriate locations.

On completion of decontamination work on a given reactor, a ventilation test was then conducted. All supply and exhaust fans were shut off for a continuous period of 16 hr. In effect, this left the reactor building ventilation system in a deactivated status. In conjunction with the test, all outside doors were closed, and the exhaust ducts to the reactor building stack were left in the open position. At the conclusion of the test, a complete radioactive contamination survey was made in the building to determine if any radioactive contamination had migrated from the various radiation zones to "clean" areas; the results were negative.

(*c*) *Water plant piping and equipment.* As can

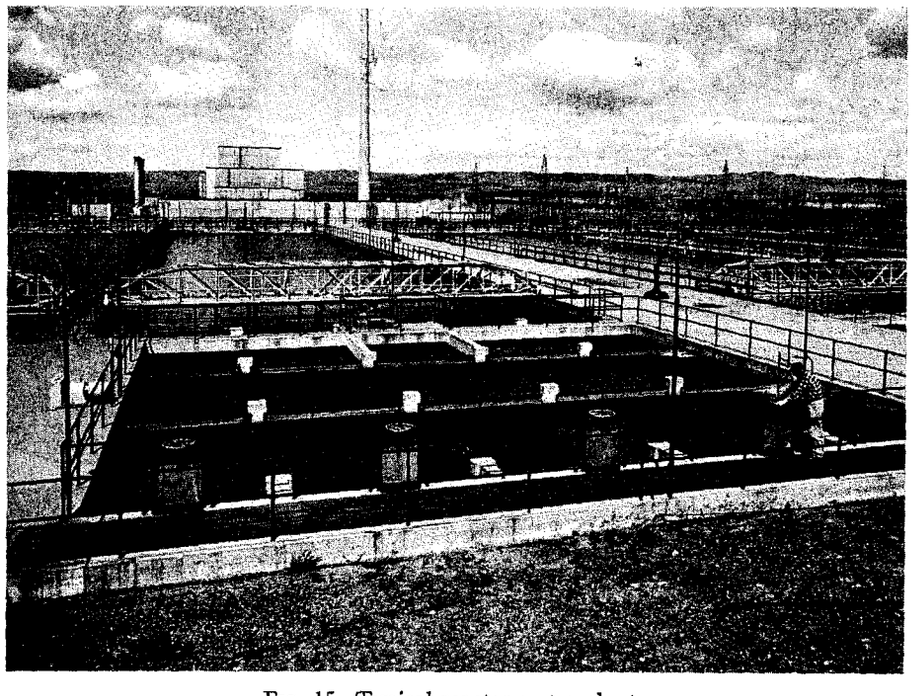

FIG. 15. Typical reactor water plant.

be seen in Fig. 15, the three water plants supporting the reactors were large and complex. Since all three deactivated reactors were immediately down river from other operating reactors, "low-level" activity, from neutron activation of stable elements in the cooling water used for the upstream reactors, had plated out on the equipment used in the water plants. The 183 settling basins (Fig. 16) were cleaned of loose foreign material and hosed down. The rest of each water plant was hosed down and left in a standby condition. After a short period of time, contamination levels were low enough for transfer of the equipment to other water plants.

Because the coolant effluent systems are still contaminated with very low levels of radioactivity, control measures are necessary. The

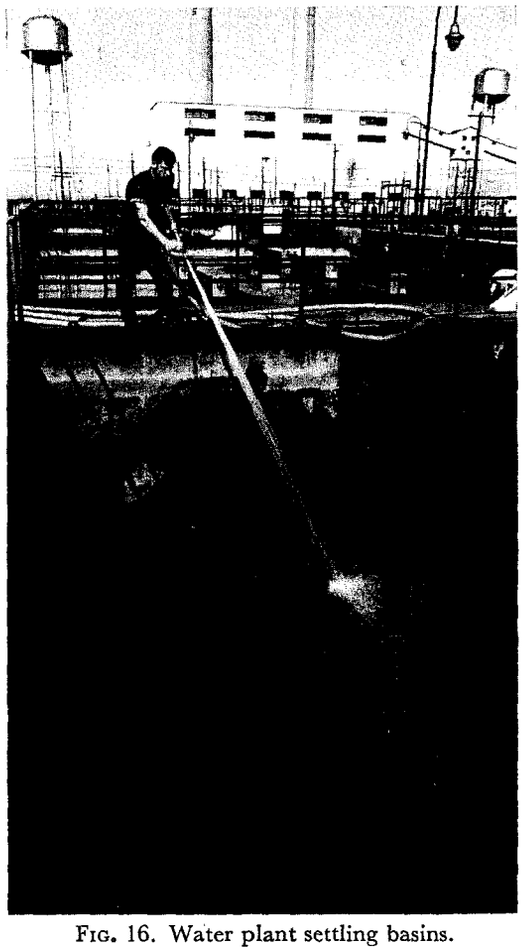

FIG. 16. Water plant settling basins.

radionuclide of greatest concern is ^{65}Zn with a 245-day half-life. The control procedures established for the water plants will preclude the spread of contamination, and will prevent personnel contact for a period of 5 years. After the 5-year period, no further control will be necessary because the activity will decay to an insignificant level.

(*d*) *Reactor retention basins.* Perhaps the reactor retention basins presented the biggest radiological problems. Original plans called for complete removal of baffle plates and the separating center wall (see Figs. 17, 18, 19 and 20). A demolishing crane was used to knock down the baffle plates (baffle plates insure water mixing) to the floor of the basin. Jackhammer operators tried to weaken the center concrete partition, so that the demolishing crane could knock it over to the floor of the basin, too. Jackhammer operators were required to wear full protective apparel and respiratory protection.

All wrecking attempts proved ineffective because of the reinforcement steel within the center wall. Originally, the activity in the bottom of the basin was to be stabilized with 4 ft of earth fill, which would slope upwards and cover the sides, subsequently creating a large earthen "bowl".

The amount of dirt necessary to fill the retention basin soon proved to be costly. To eliminate the additional cubic ft of dirt fill required for sloping the sides, an asphalt spray was used to fix contamination on the center, side, and end walls. The resultant savings in manpower and equipment were significant. The end result was probably more effective using asphalt, since high winds could move sloped earth shoulders and cause a spread of "low-level" contamination.

Prior to deactivation of the retention basins, representative samples were taken to ascertain levels of contamination in the 500 tons (total F and H Reactor basins) of sludge on the basin floor. These representative samples revealed accumulations of:

$\sim$ 800 Ci of ^{152}Eu ($\sim$ 13-year half-life).
$\sim$ 400 Ci of ^{65}Zn ($\sim$ 245-day half-life).
$\sim$ 40 Ci of ^{60}Co ($\sim$ 5-year half-life).
$\sim$ 30 Ci of total β emitters (e.g. ^{147}Pm, $^{89\text{-}90}Sr$, ^{99}Te).

Since these radionuclides were uniformly mixed in the 500 tons of sand and silt, dose rates from

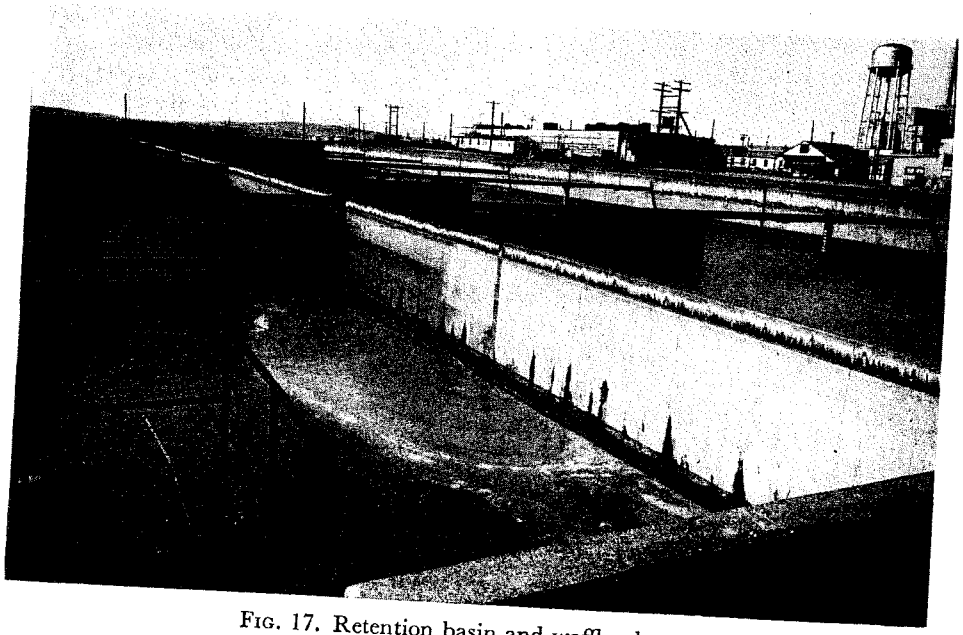

FIG. 17. Retention basin and waffle plater.

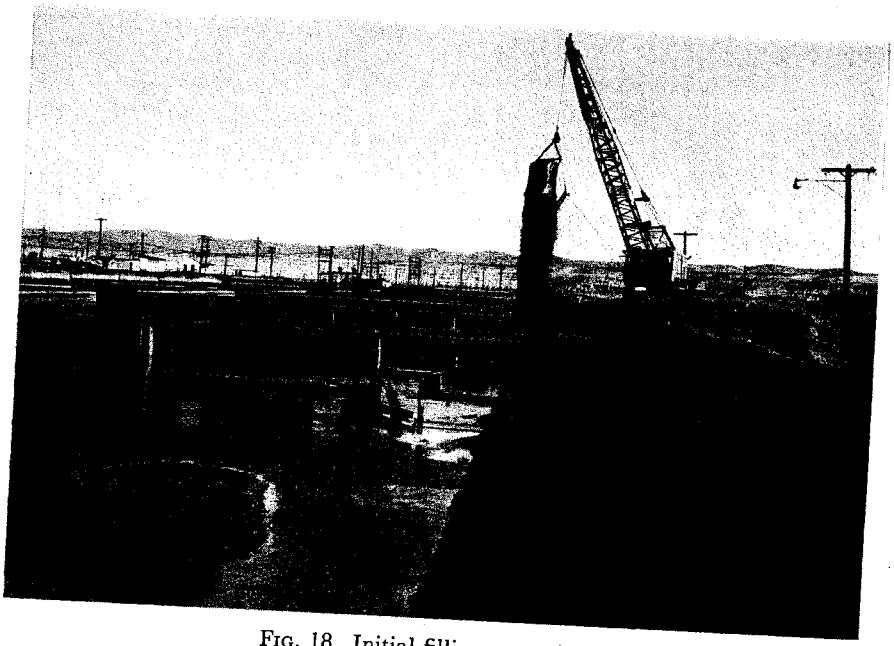

FIG. 18. Initial filling operation.

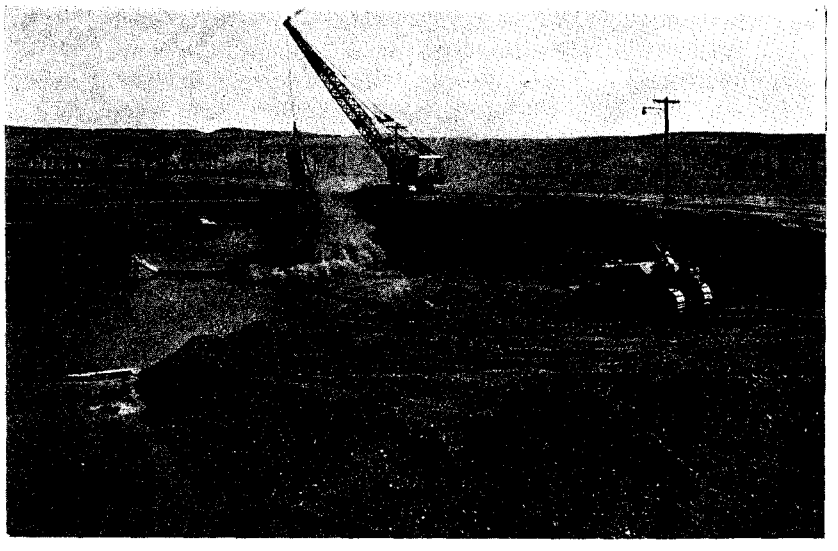

FIG. 19. View of basin center cavity.

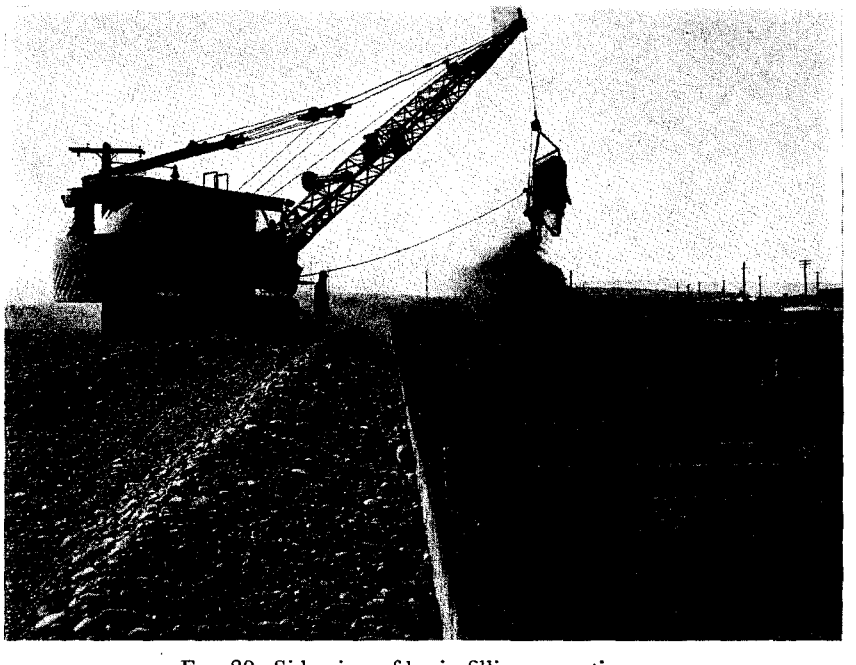

FIG. 20. Side view of basin filling operation.

the wet sludge were nominal. Modest safeguards and controls would be required if use for the land was mandatory within the next 5 years.

FIG. 21. Low-level burial site.

Estimates show that in 10 years, dose rates will be low enough to reclaim the area encompassed by the basin walls with little exposure to workers. After 50 years, radionuclides will not be significant even though ^{152}Eu will theoretically have a calculable value.

Radiation symbols were posed after deactivation activities were complete.

(*e*) *External radiation zones.* There were several locations in each reactor area that contained underground radioactive materials. Only two of the deactivated reactor areas will be discussed, since one plant is located in a dual area with an operating reactor.

At one of the reactor areas there are 13 underground radiation zones; the other area has 16. Five of these locations, encompassing a perimeter of 6000 ft, have been permanently terminated as burial sites. Figure 21 shows a typical "low-level" burial site. The permanently posted burial grounds contain two general types of radioactive waste: neutron activated reactor components and surface contaminated material and equipment. The activated components consist almost entirely of steel and aluminum. Figure 22 shows the boron-steel balls used for emergency reactor control being removed from a deactivated reactor. The boron-steel balls are typical of the type of activated material placed in the permanent burial grounds. The

FIG. 22. Boron steel balls being removed from a reactor facility.

most significant radionuclide contained in this type of material is ^{60}Co which has a half-life of 5 years. Other types of neutron activated materials placed in the burial grounds are aluminum tubes, reactor hardware, and thermocouple wires. Bundles of process tubing have dose rates as high as 5 R/hr at 6 ft. The surface contaminates are primarily corrosion and activation products from the reactor cooling water. The most significant long half-life radioisotope for this type of material is ^{65}Zn which has a half-life of 245 days.

All abandoned burial trenches and pits were backfilled to normal grade, which provided at least 4 ft of cover and limited the radiation intensity level to less then 1 mR/hr.

Table 1. Typical Decay Rates

Zone	March 5, 1965		March 21, 1966	
	Direct	Smears	Direct	Smears
Winch	3 mR/hr	1000 cpm	1 mR/hr	500 cpm
Top of unit	3 mR/hr	1000 cpm	1 mR/hr	500 cpm
Ball collection	300 mR/hr	1000 cpm	3 mR/hr	500 cpm
X-2 level	3 mR/hr	1000 cpm	1 mR/hr	100 cpm
X-1 level	3 mR/hr	1000 cpm	1 mR/hr	100 cpm
Vacuum system	50 mR/hr	1000 cpm	40 mR/hr	500 cpm
Rear face	40–70 mR/hr		20 mR/hr	
Charge face	4–6 mR/hr		3 mR/hr	

The burial grounds were then posted in accord with existing RL-AEC standards; the concrete posts conform to the standard established by the state of Washington for highway marking.

Some of the other underground radiation zones were liquid waste disposal sites not requiring permanent markers. Concrete posts were not installed in these areas, since it was predicted that radiological control measures will not be necessary for any use of the land 5 years after reactor deactivation.

(*f*) *Personnel exposure.* Whole-body radiation exposure received by workers during deactivation work was considerably less than that received during normal maintenance and discharge work. To be specific, an exposure accountability program showed that:

DR Reactor craftsmen received 12 R of whole-body exposure; 2 R to monitors, 7 R to operators, 2 R to maintenance craftsmen and 1 R to others.

H Reactor craftsmen received 11 R of whole-body exposure; 1 R to monitors, 5 R to operators, 1 R to maintenance craftsmen and 4 R to others.

F Reactor craftsmen received 14 R of whole-body exposure; 3 R to monitors, 7 R to operators, 2 R to maintenance craftsmen and 2 R to others.

The 37 R received by workers during the deactivation activities for the three reactors represents approximately one-fifth of the total exposure required to operate a Hanford production reactor for 1 year.

V. CONCLUSION

Approximately 1 year has elapsed since deactivation work was completed on the reactors and their associated facilities. During this period, routine monitoring and control programs have continued in force. Some of the deactivation procedures have been casually mentioned in the body of this paper.

The total surveillance program, however, has been much more sophisticated than these notations would imply. For example, complete

annual survey programs have been completed for each of the reactor buildings. Typical data on decay rates for specific locations within a reactor building are given in Table 1.

To assure continued control throughout the year, surveys on frequently travelled locations were made. Experience to date has adequately shown that the radiological criteria adhered to during the deactivation of the three reactors were sufficiently restrictive. The periodic radiation and contamination surveillance program (as described above) for the reactors has proven to be adequate. The decay rates for the remaining radioactive materials apparently have decayed with a half-life considerably below the predicted value of 5 years.

Deactivation experience gained to date at Hanford has demonstrated that:

Economical deactivation of large single pass reactor production facilities can be accomplished safely and effectively.

Relatively large quantities of activated elements decay rapidly and will not limit future renovation activities.

Considerable thought and preplanning is required to achieve continued radiological control.

Remaining activity in Hanford facilities will be largely attributable to the longer-lived fission products, but these will not be prohibitive in reclaiming much of the land for more purposeful future activities.

DISCUSSION

J. POMAROLA (*France*):

J'ai apprecié la très remarquable concordance des films et des dosimètres de poche. M. Craig peut-il nous donner des précisions sur les films et les dosimètres?

D. K. CRAIG:

The film badges were the standard AERE film badges as used by the U.K. Radiological Protection Service and the pocket dosimeters were Stephen self-reading quartz fibre dosimeters.

D. C. LAWRENCE (*U.S.A.*):

What was the total amount of Pu^{239} involved and what percent was released?

D. K. CRAIG:

The source contained 160 g of plutonium, i.e. 10 Ci. We estimate that about 30% of this was released into the primary and pool water systems. The ruptured source is still, at this stage, in double containment at the bottom of the pool. An attempt will be made to measure the amount of Pu released by extracting and measuring the amount of Pu left as soon as our hot cell facilities are completed.

O. L. CORDES (*U.S.A.*):

What was the estimated cause of source failure?

D. K. CRAIG:

Quite frankly, stupidity. No one had, prior to the incident, calculated the heat transfer from and heat generation of the source. Subsequent calculations showed that, at a reactor power of 6–7 MW, the cooling of the source was inadequate in the core location chosen. Hazard evaluations of the reactor had omitted to consider possible hazards arising from the source.

L. DE FRANCESCHI (*Italy*):

Due domande per il Dr. Craig:

1. Nel reattore Safari non si usa allontanare la sorgente di neutroni dal core non appena raggiunta la criticità?

2. Che cosa significavano, nelle figure che sono state mostrate, i "massimi livelli di attività" raggiunti?

D. K. CRAIG:

1. The reactor was at the time of the incident still under the control of the nuclear sub-contractor. It had been suggested to him prior to the start of the acceptance test that the Pu-Be source be removed. The Operations Manager declined to do so as he thought the source would be all right.

2. The "maximum activity levels" prior to the incident indicated in Figs. 2 and 3 referred to the maximum readings that had been obtained with the reactor at a power of 6–7 MW and all ventilation systems operating normally.

J. POMAROLA (*France*):

Je désire demander une précision à M. Fitoussi. Il nous a parlé d'une contamination par les produits de fission. Mais dans le cas d'une rupture de gaine survenant sur une telle cellule, n'y a-t-il pas eu aussi une contamination par le Pu^{239}?

L. FITOUSSI:

La question de M. Pomarola est importante. En effet dans le cas d'éléments de combustible présentant des taux de combustion élevés, la concentration des isotopes du plutonium peut être élevée. Dans le cas de la cellule qui a donné lieu à l'incident décrit dans ce rapport, le taux de combustion a été évalué à 3650 MWj/t, ce qui correspond pour cette cellule à une concentration de 1 mg de plutonium par gramme d'uranium. En supposant un taux d'émission de l'ordre de 1% (comme pour les produits de fission solides) on calcule un risque potentiel de l'ordre de 10% relativement à celui de l'iode-131. Toutefois, comme il est dit dans le rapport, nous n'avons pas pu mettre en évidence a posteriori la présence du plutonium dans les prélèvements atmosphériques et de surface.

B. W. EMMERSON (*U.K.*):

1. At what fuel temperature was I^{131} still being released from the fuel element?

2. Was the gaseous effluent released via an I^{131} extraction filter?

L. FITOUSSI:

1. Pour répondre à la première question je dois donner une précision complémentaire concernant la

pile EL3 qui présente une puissance spécifique de l'ordre de 40 MW/t. La puissance dégagée par les produits de fission est donc importante et nécessite un refroidissement efficace car 12 heures après le défournement la température de l'uranium peut dépasser 600°C.

2. Le circuit d'extraction d'air de la pile EL3 comporte un dispositif de filtres de secours comprenant entre autres un piège à iode à charbons actifs. Ce dispositif n'est mis en service qu'en cas d'accident important car il nécessite l'arrêt de la pile.

Or pendant ces opérations, la pile était en fonctionnement et l'activité rejetée ne présentait pas de risque important. C'est pourquoi le dispositif de secours n'a pas été mis en service.

E. W. Jackson (*U.K.*):

In the results of downwind concentration of I^{131} given by Gammill and Bunch for several release experiments, and claimed to be capable of being used to predict the amount in curies emitted by the reactor, there is no mention whatever in the tables shown of the deposition of material from the clouds in transit. I cannot see what it is possible to calculate from the results on this basis.

D. F. Bunch:

Although not indicated in the presentation, depletion of the cloud by deposition was considered. For the stated meteorological conditions, depletion of airborne activity by deposition was found to be insignificant in these tests.

B. W. Emmerson (*U.K.*):

1. How was contamination, as collected on surface smears, examined for isotopic and energy distribution?

2. What degree of protective clothing was required whilst decontaminating large surfaces, as exampled in Fig. 9?

L. Wallis:

1. We have no data bearing on this question.

2. Airborne contamination was not a problem. Therefore, no protective clothing was worn.