Proceedings of the Secon

United Nations International Conference on the Peaceful Uses of Atomic Energy

Held in Geneva

1 September - 13 September 1958

Volume 18

Waste Treatment and Environmental Aspects of Atomic Energy

UNITED NATIONS

Geneva

1958

TABLE OF CONTENTS

Volume 18

Session D-19: Environmental Aspects of the Large Scale Use of Atomic Energy

TABLE OF CONTENTS

Session C-21

THE TREATMENT OF RADIOACTIVE WASTES, PART I

LIST OF PAPERS

The Role of Waste Management in the Development of the Nuclear Energy Industry

By Joseph A. Lieberman*

Much has been written in speculation regarding the impact, or lack thereof, of radioactive wastes on the development of nuclear technology. On the one hand views have been expressed to the effect that this aspect of the industry is of negligible consequence. On the other hand it has been said that safe and adequate waste management is the major obstacle confronting the orderly economic growth of application of the benefits of nuclear fission to medicine, agriculture and industry.

Unfortunately, outside of a relatively restricted scientific and technical treatment of the subject by a relatively small group of specialists, there is considerable lack of information and resulting confusion. It is this situation which led the Subcommittee on Waste Disposal and Dispersal of the US National Academy of Sciences–National Research Council Committee on Biologic Effects of Atomic Radiation to initiate the preparation of a summary-information document on the subject. A draft of this report is now being edited.

Outside of the specialist group, radioactive wastes are generally considered as an uncategorized entity. Usually no distinction is made regarding the nature, quantity and origin of the waste materials or the environment in which they must be considered. The word "radioactive" has been so strongly impressed in our minds that it has become the all-inclusive descriptive term to the point where important characteristics of wastes such as concentration of radioactive material, total quantity of radioactivity, isotopic composition and chemical and physical nature are often overlooked. Yet these are the characteristics which are the keys to waste management.

The purpose of this paper is to discuss the technical and administrative aspects of waste management in the light of our present experience and knowledge and to focus on the possible effects on the development of the nuclear industry. This approach should give an insight into how this facet of nuclear technology might relate to other considerations such as the selection of sites for nuclear installations, the establishment of operating criteria for such installations and the administration of these criteria to assure protection of the public health and safety.

* Sanitary Engineer, US Atomic Energy Commission.

In any discussion of waste management it must be recognized that the primary management objective is the protection of man and his environment. Economic utilization of the "wastes" is obviously highly desirable, but nevertheless secondary in comparison.

To delineate the discussion further it may be stated that three major basic components are involved, as follows:

1. The maximum quantity of specific isotopes allowable in man or his various organs. This includes immediately the concept of maximum allowable concentrations of various isotopes in air and water, the ecological implications of biologic concentration of radioactivity by various organisms in our food chain and other highly important, complex and, in some instances, unknown biological considerations. From an engineering standpoint, a quantitative standard of permissible concentration of radioactivity in air and water is necessary.

2. The specific nature of the radioactive waste under consideration This is a highly variable component. In order for it to be considered properly, it must be approached in specific quantitative terms. It should be completely understood, for example, that there is little basis for comparison of waste-management techniques or problems associated with the liquid wastes emanating from a normally operating water-cooled reactor, and those associated with the aqueous reprocessing of enriched-uranium–aluminum alloy fuels.

3. The physical, chemical and biological characteristics of the environment in which the waste is to be handled. Included here, again in specific quantitative terms, is knowledge of or data on the atmosphere, the hydrosphere and the lithosphere relating to dilution or concentration of radioactivity in the environment.

Essentially, then, proper waste management consists in so identifying and quantitatively describing items 2 and 3, and their combined behavior, so as to assure conformance with the standards established in item 1. Here a very important, but sometimes unrecognized, distinction is made between standards and performance or operating criteria necessary to achieve these standards. For the most part, the standards are the result of the best available biological and medical knowledge and are of universal application. One should, however, recognize the limitations of these standards due to lack of complete knowledge and, further, that such standards must be subject to modification as more and better knowledge is gained. On the other hand, because of the variability of the wastes and the environment, these components must be evaluated on an individual-case basis. The quantitative results of such an evaluation generally will not be universally applicable.

DISPERSAL OF LOW-LEVEL WASTES

The two general attitudes toward waste management have been noted previously and need not be discussed in any detail here. They are characterized by the phrases "concentrate and contain" and "dilute and disperse". The "dilute and disperse" approach is applicable to wastes with generally low concentrations of radioactive materials and to environments with adequate dilution capacity. The term "dispersal" is used here to describe the discharge of wastes to the environment in a manner that permits little or no direct control by man over the fate of the wastes following their discharge. The discharge of gaseous wastes to the atmosphere and of liquid wastes to surface waters or to the ocean are examples of dispersal. Experience to date has shown that specific environments may be utilized to obtain, in effect, a sufficient decontamination factor with certain types of waste so that the standards of maximum allowable concentration in the air we breathe, the water we drink, or the food we eat, can be met. It is general practice to apply, for the general public, reduction factors of 10 to 100 to standards published by the International Commission on Radiological Protection and the US National Committee on Radiation Protection and Measurement and other agencies in other countries.

In establishing performance criteria for waste-dispersal operations from nuclear installations, two cardinal principles are therefore invoked.

1. The minimum practicable amount of radioactivity should be dispersed into the environment. "Practicable amounts" are determined by quantitative assessment of specific environments to assure protection of the public health and safety.

2. Continuing periodic checking is mandatory to verify that performance criteria are being followed and accepted standards are being met. Performance criteria must be modified as changing requirements dictate.

If these principles are to be applied in a reasonable realistic way, designers and operators of nuclear facilities must have early knowledge of the quantity and characteristics of wastes to be managed and, further, must take this into proper consideration when selecting the site for the installation and in the design and construction of the plant. Routine plant operation and various degrees and kinds of malfunction, which may result in large noncontinuing volumes of wastes, must receive equal attention. Adequate detention-tank capacity to permit holdup of such waste surges and treatment at efficient rates are generally essential. Mechanical transport of large volumes of liquid wastes to dispersal points remote from the installation has been avoided in the United States. Burial grounds for solid wastes have to date been centralized to the maximum extent possible in relatively large non-populated government-owned reservations.

In summarizing the situation with respect to dispersal operations in the United States, our experience so far has demonstrated that safe adequate systems for such operations can be established and necessary treatment or process components can be engineered, provided sufficient basic information and data are made available. In the future, as dispersal operations tend to expand and overlap and standards tend, perhaps, to become more stringent, it is probable that in-plant performance criteria will receive greater emphasis, leading to increased treatment facilities and operational costs.

DISPOSAL OF HIGH-LEVEL WASTES

As distinguished from waste treatment, little actual work has yet been done on large-scale ultimate-disposal systems. The term "ultimate disposal" is used here to describe the return of wastes to the environment in a manner that (*a*) permits continuing long-term control by man over the wastes, and (*b*) assures that the wastes will be contained essentially at the point of discharge so that man and his environment are not adversely affected. The time element involved is hundreds of years. Safe dispersal of large quantities of radioactivity in the environment is not now feasible and appears quite remote for the future. The result of this situation is our development of an extensive tank-storage program (capital cost estimated to date at about $\$65 \times 10^6$). It is fairly certain that interim tank storage will continue to be an integral part of any ultimate-disposal scheme.

With regard to treatment of highly radioactive liquid wastes (primarily from reprocessing of irradiated fuels) for ultimate disposal, considerable investigation has been carried out on the fixation of radioactive material in inert solid media. The objective is to so convert the wastes into a solid non-leachable material that they may be permanently stored in specific environments with negligible long-term hazard.

Two general schemes for accomplishing this objective have been under study at a number of laboratories in the United States. One involves the conversion of the highly radioactive liquid wastes to a solid-oxide form by heating in some kind of liquid–solid contactor. Work done at the Brookhaven National Laboratory with a rotary-ball-kiln unit and at the Idaho Chemical Processing Plant and Argonne National Laboratory with a fluidized-bed unit are examples of this approach. The other general scheme involves incorporating the radioactive material either physically or chemically in clays, glasses or synthetic-crystal minerals such as synthetic feldspars or micas. These two general schemes can be complementary in some respects in that the solid oxide may be used as a starting material in a separate fixation system. Alternatively, the oxide product may be passed through a leaching step, to remove the soluble radioactivity, followed by the fixation of the leach solution in an inert solid.

Enough work has been done in the laboratory to indicate the technical feasibility of a variety of such systems. Engineering development is farthest advanced at the Idaho Chemical Processing Plant with the solid-oxide scheme utilizing the fluidized bed. There the detailed engineering design (by the Fluor Corporation) of a 60-gal/hr-prototype development unit is being completed. At the Brookhaven National Laboratory preliminary engineering study of a rotary-kiln plant and a clay-fixation unit has been done. Generally, in all of these systems, practical solutions to a number of important associated problems have yet to be demonstrated on an engineering scale. These problems include control of ruthenium and other radioactive aerosols, volatilization of specific fission products, and corrosion.

The feasibility of direct disposal of high-level wastes into selected geologic formations will be demonstrated only after extensive laboratory and field experiments, which are just now being initiated. Engineering and economic analyses are in their early stages, but sufficient work has been done to justify pursuit of such approaches at least on a limited scale. Of the geologic formations proposed for this purpose in the United States, which include salt structures, deep synclinal basins, impermeable shales and certain deep porous formations, disposal into prepared cavities in salt appears to be most advanced in programming.

At the present time it appears that an optimum solution to the problem of ultimate disposal of highly radioactive liquid wastes would include the conversion of the waste to a solid inert form and the long-term (essentially permanent) storage of these solids in a specially selected geologic formation such as a salt bed. Obviously, as the degree of inertness of the solid material is increased, the requirements for the geologic formation become less restrictive.

Ocean disposal of high-level wastes has been given some consideration. Quite often confusion has resulted from an inadequate categorization of the quantity or nature of radioactive wastes involved. For high-level fission-product wastes emanating from chemical reprocessing (i.e., tens or hundreds of curies of radioactivity per gal), it appears conclusive that ocean disposal will not be feasible for many years to come, if at all. Required specific knowledge of oceanic behavior is so inadequate, and attendant engineering problems appear so complex, compared with other possible solutions, that industry and government will perhaps be forced to systems inherently easier to directly control. Again it is emphasized that this conclusion applies to the highly radioactive wastes resulting from chemical reprocessing of irradiated fuels and not to smaller quantities of low- and intermediate-level wastes in the solid, packaged and liquid states.

Economic utilization of fission products would have an important bearing on the high-level-waste problem, but at this writing the word "bearing" cannot be equated to "solution". Economic return from the waste streams is obviously something to be sought but it must be remembered that, from the standpoint of protection of public health and safety, the necessity of safe disposal systems will remain. In fact, the problems of waste management may even be increased because of widespread use and dispersion of highly radioactive materials. In this connection it is also important to make the technical distinction between recovery of specific fission products for useful purposes and the essentially complete removal of these fission products as a waste-disposal technic. Systems to accomplish the latter remain to be developed.

The selection of sites for installations which generate high-level wastes is of utmost importance, particularly with respect to ultimate long-term disposal. Many variables enter into this consideration. Availability of suitable disposal sites, the relative hazard and economics of transport of irradiated fuels and wastes, the types of fuel processed and the types of processing involved all play an important part. It is probable, however, that installations generating high-level wastes will be relatively few in number. This emphasizes the need for exceedingly careful analysis of site selection for such installations. It must be emphasized again that a single solution for all situations is neither required nor feasible. The industry undoubtedly will be required to give increased attention to an integrated evaluation of over-all systems of fuel reprocessing, waste storage, waste treatment and ultimate disposal. It is also quite likely that reactor-core design will have to be included in such integrated evaluations.

Up to the present no one has had any actual operating experience in the long-term ultimate disposal of highly radioactive wastes. Consequently there does not exist a firm operating basis for assessing the economics of this phase of the technology in the development of the industry. Generally, the po tion of unit power cost attributable to waste disposal is obtained by subtraction. One adds the percentage of the unit power costs due to reactor costs, reactor operations, fuel, fuel reprocessing, etc., and then subtracts these costs from the total unit power cost he hopes to achieve. The remainder is then indicated as the cost allowable for waste management. Such economic analyses are not impressive but are probably all that can be done at this stage of development. On the basis of the best information and judgments available, it does not appear that the costs of waste disposal will constitute a serious impact on the over-all economics of the nuclear energy industry. For example, allocating 1% of a total unit power cost of 8 mills/kwh to waste management and using conservative parameters such as reactor burn-up of 5000 Mwd per ton of fuel, processing-waste volume of 600 gal per ton and reactor thermal efficiency of 25%, one can compute an allowable unit cost for ultimate disposal of highly radioactive reprocessing wastes of the order of $4 per gal. It is believed that systems previously noted can be successfully established and operated within these costs. This achievement has yet to be demonstrated. In addition, these costs represent an added incentive for the industry to design nuclear reactors having fuels with longer useful life and to develop chemical processes evolving smaller volumes of waste per unit of fuel processed.

One of the most important questions in waste management in the development of the nuclear industry is that of continuing long-term responsibility for radioactive wastes following actual disposal. Industry can and must assume increased responsibility for the physical operations involved in waste management. The performance criteria for these operations must be established cooperatively by industry and government. In meeting the long-term responsibility for protection of man and his environment, government must play the dominant part, with all of the international as well as national implications.

Indeed, the industry–government relationship in this area may well be one of the major pillars to support the rational development of a nuclear industry that will be integrated fully and safely into our peacetime social and economic structure.

The Storage of High-Level Radioactive Wastes; Design and Operating Experience in the United States

By O. H. Pilkey,* A. M. Platt† and C. A. Rohrmann†

ORIGIN OF WASTES

In the course of operating nuclear reactors for power generation or for the production of fissionable material, the reactivity of the fuel decreases because of burn-up of the fissionable material and by build-up of interfering concentrations of fission products, some of which have a high capacity for absorbing neutrons. Those isotopes which are formed by fission and which have a high neutron-capture cross-section are called poisons. Because of burn-up of the fuel and concurrent "growing in" of the poisons, the fuel must be replaced before all of its fissionable material content has been consumed. To assure economical operation of nuclear reactors, the spent fuel must be processed chemically to recover the remaining fissionable and fertile materials by methods which separate them from the extraneous and objectionable fission products. The purified fissionable and fertile materials obtained by this separations process can then be reconverted to fuel for re-use in reactors. The achievement of economical atomic power depends on the realization of low costs in all stages of the fuel cycle of which the separations process is a part.

In the separations processes the fission products, along with the many conventional chemical agents necessary for the operation of the process, emerge as wastes. Although, ideally, a separations process should produce a single waste stream, such is not the case in practice. Effluents such as steam condensates, cooling water, condensed vapors evolved from boiling radioactive process solutions and streams in contact with waste gases may, on analysis, have sufficient radioactive contamination to require storage or further processing for clean-up and eventual disposal. In view of the great biological hazard associated with the intense radioactivity of a portion of the fission products, these wastes, as determined by the nature and concentration of these fission products, must be securely stored indefinitely. Such storage is the eventual destination of the hazardous waste derived from the fuel cycle of all nuclear reactors. The facilities provided in the United States for the permanent storage of such materials and some of the accumulated operating experience with these are the subject of this paper.

NATURE OF THE WASTES

High-level wastes may be described and characterized generally as being either acid or alkaline, concentrated aqueous salt solutions, hazardous to all living organisms because of intense radioactivity, and capable of spontaneous and prolonged boiling because of absorption of their own radiant energy. These waste streams contain the major portion of radioactive fission products and therefore require storage facilities which will provide secure containment for an indefinite period. The hazardous nature of these fission products, although existing in concentrations which in ordinary industrial-chemical operations are regarded as fantastically small, requires most extreme precautions in their handling and disposition. For example, toxic materials[1] such as chlorine, cyanide, arsenic, lead and mercury are tolerated in common industrial effluents in concentrations amounting to a few parts per ten million (10^7). However, the figures for maximum permissible concentrations (MPC) for certain radioactive fission products,[2] if expressed on the same basis, are smaller by a factor of one hundred million (10^8) and would be expressed on a weight basis as parts per 10^{15} parts of effluent. With such requirements the disposal of a number of effluents in the nuclear-processing industry by the usual industrial methods is completely intolerable. At present, earth-covered metal and concrete tanks provide an economical and reliable method for the storage of high-level radioactive wastes. The utmost in corrosion resistance of the container material is required. Since these containers are buried underground, they must be built with adequate strength to resist high external earth pressure and also, in certain cases, to resist the pressure of the ground water. In addition, the property of the wastes to heat themselves and boil irregularly results in pressure changes and thermal variations which require special design and structural considerations.

Essentially all wastes being generated on a large

* Construction Engineering Operation, Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

† Hanford Laboratories Operation, Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

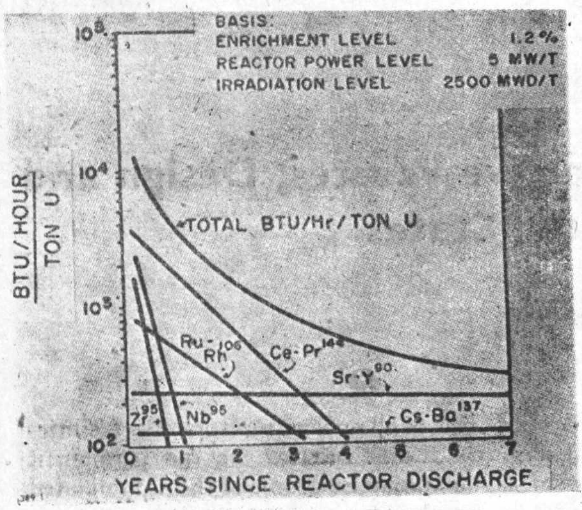

Figure 1. Heat generation in slightly enriched uranium

Table 1

	Molarity Redox	Purex
$Na_2U_2O_7$	Trace	Trace
$NaNO_3$	4.5	4.5
Na_2SO_4	0.05	0.2
Na_2CrO_4	0.3	—
$NaAlO_2$	1.3	Trace
NaOH	1.2	0.2
$Fe(OH)_3$	Trace	0.2
Approximate heat-generation rate, watts/liter	0.5	8.0
Specific gravity	1.37	1.15

scale today are derived from solvent-extraction-type processes for uranium and plutonium decontamination and recovery. The combined wastes from the series of extraction cycles comprise the high-level wastes of interest here. The wastes which are stored in ordinary steel must be maintained alkaline. Wastes are also stored in the acid condition in stainless-steel vessels. In certain operations, the added costs of such stainless-steel storage can be justified. However, in the very large-scale operations involving the storage of many millions of gallons of waste, concentrated alkaline compositions are retained exclusively in ordinary steel. It has been reported that at the Hanford site alone there are about 50,000,000 gal of waste stored in such facilities.

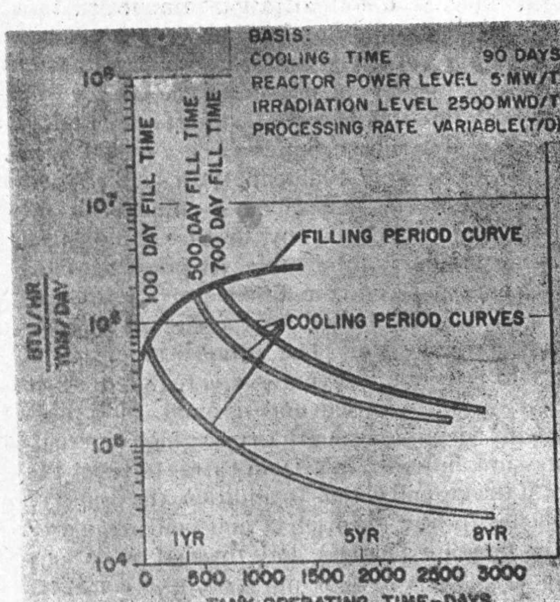

Figure 2. Heat generation in a waste-storage tank

Composition of Wastes

The approximate composition of typical high-level alkaline wastes in major components, as delivered to storage, is shown in Table 1.

THE HEAT-GENERATING PHENOMENON

When the plutonium or uranium fuel atoms undergo fission, the fragments comprise stable and radioactive isotopes of a number of elements. The radioactive isotopes vary widely in their half-lives. Fortunately, many have half-lives so short that by the time the separations process is applied they have been transformed into stable elements. Those with half-lives sufficiently long remain in the wastes from the separations processes. Their beta and gamma radiation, which is continuously released, is absorbed in the total stored volume and produces heat. This form of heat generation in a fluid is a unique industrial phenomenon, particularly when it is noted that such heat generation is taking place throughout each increment of the whole volume. Furthermore, such heat generation is not controllable by any known method. The fact that the heat-generation rate decreases as the radioactive isotopes decompose to stable elements is not a significant factor in design because the highest initial rates must be provided for.

The decay of the fission products associated with the stored wastes produces heat at a rate determined by the extent and intensity of the irradiation of fuel in the nuclear reactor and by the length of time the fission products have "cooled" since reactor discharge. Typical heat-generation rates resulting from fission-product decay are shown in Fig. 1 for a fuel initially containing 1.2% U^{235} and irradiated at 5 Mw/ton for 500 days. It will be noted that the overall rate of heat evolution steadily declines, although the rate of decrease slows with time.

The accumulated heat generation associated with a waste-storage tank will be somewhat different from the simple case just depicted. The general trends may be illustrated by Fig. 2. During the time that the wastes from a separations plant are added to a given tank the rate of heat generation in that tank increases, depending on the rate of uranium processing and its irradiation and cooling history. The peak heat generation attained is a function of the same variables.

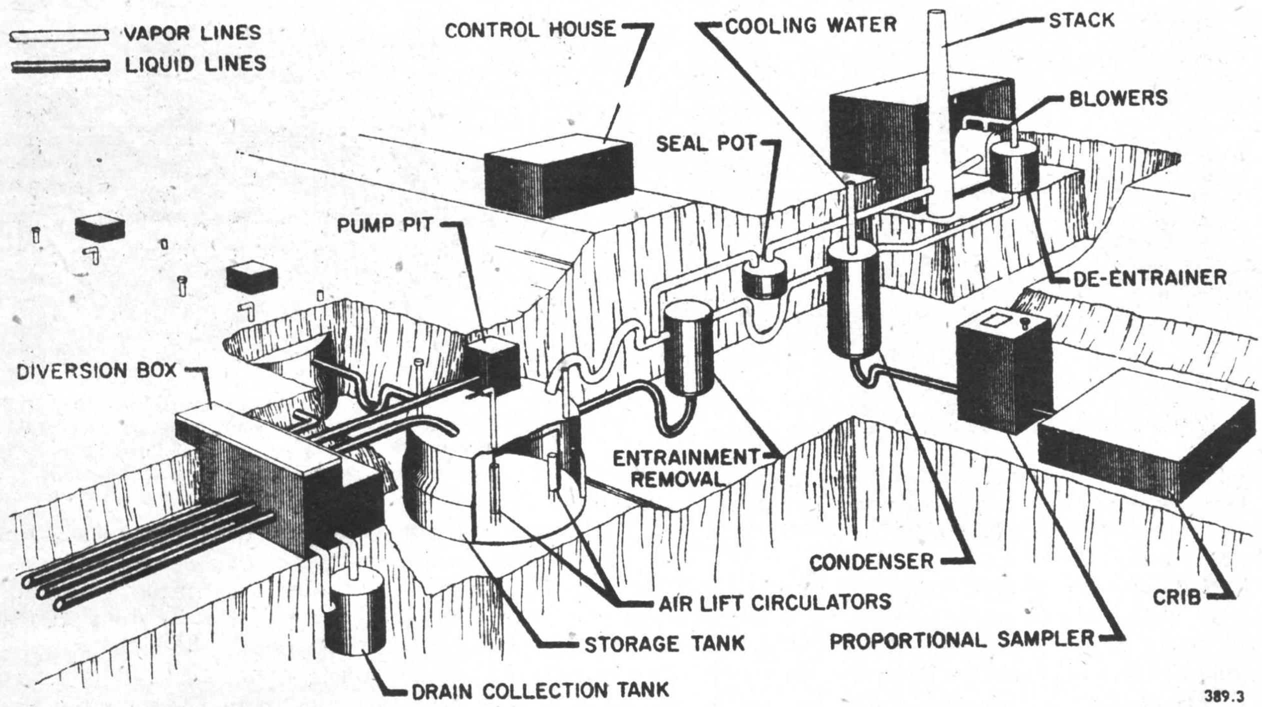

Figure 3. Schematic, typical high-level waste-storage facility

When the addition of fission products to the tank ceases, the heat-generation rate is at a maximum and continues to decrease as the fission products decay. During the first year of storage, the rate of heat generation is governed by the decay of fission products with a short half-life (e.g., 60 days or less). During this period the heat-generation rate decreases rapidly. Within a few years the rate of heat generation falls to a small fraction of the peak rate; further decreases are gradual and are controlled by the longer-lived fission products. In concentrated wastes the heat generated is sufficient to cause the wastes to boil for long periods of time due to the decay of the long-lived fission products (cesium and strontium). For example, operating conditions are possible which would create a waste that would boil for 100 years. To some extent such boiling is utilized to reduce the volumes stored, by letting the wastes concentrate themselves.

DESCRIPTION OF HANFORD HIGH-LEVEL WASTE-STORAGE FACILITIES

High-level wastes from fuel-processing operations at the Hanford plant are stored in steel-lined reinforced-concrete tanks equipped with external condensers for removal of the heat produced by radioactive decay. A sketch of a typical high-level storage system is shown in Fig. 3.

Wastes from the separations plants are routed to the storage-tank group, or farm, by means of an underground system of stainless-steel piping contained in a reinforced-concrete trough or encasement. A zig-zag or "dog-leg" layout provides for free expansion and contraction caused by thermal changes. A photograph of the construction of a portion of the encased waste pipe lines is shown in Fig. 4.

At each tank farm the waste-delivery lines terminate in a diversion box from which the wastes can be directed to the individual tanks. The diversion box is equipped with switching pipes or jumpers by which the routing of a waste stream can be changed or diverted from one tank to any other. The diversion box is constructed of thick concrete for radiation shielding and is connected to a collection tank in which any leakage in the box or attached encasements can accumulate. Such accumulation can also be delivered to the storage tanks. As tanks become filled, routings are changed by mechanically repositioning the jumper connections by remote-handling methods. A photograph of such an operation is shown in Fig. 5. Opera-

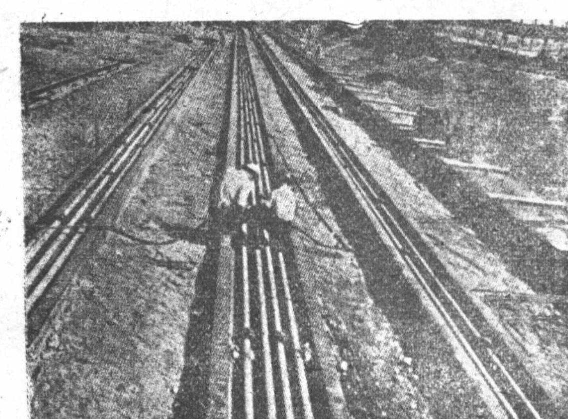

Figure 4. Construction of waste lines and encasements

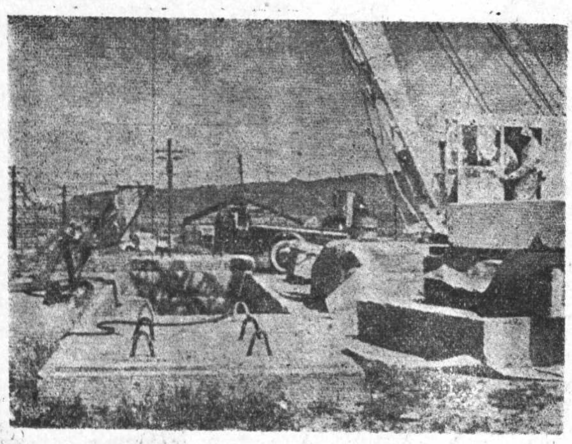

Figure 5. Workmen changing routing of waste in a diversion box. The large mirror over the opening permits observation without direct exposure to radiation

tors are able to see their work only by the use of the large mirror placed over the box. Such methods are necessary to avoid exposure to the radiation coming from the waste lines in the diversion box.

This operating technique, which is used in most large-scale facilities for processing radioactive materials in the United States, depends on construction of the diversion-box nozzles and fabrication of the jumpers to extremely close tolerances. Figure 6 is a photograph of a typical jumper. An electrically operated impact wrench, which hangs from a crane, drives the single nut on each connector head to connect and disconnect the jumper. The remotely operated impact wrench is the only tool required to conduct the operation of diverting the delivery of waste from one tank to another. Experimental installations of standard industrial-type valves, which were operated with long handles extending through the thick concrete shielding, have been made. These test installations have not successfully demonstrated advantages over the jumper method of remote operation.

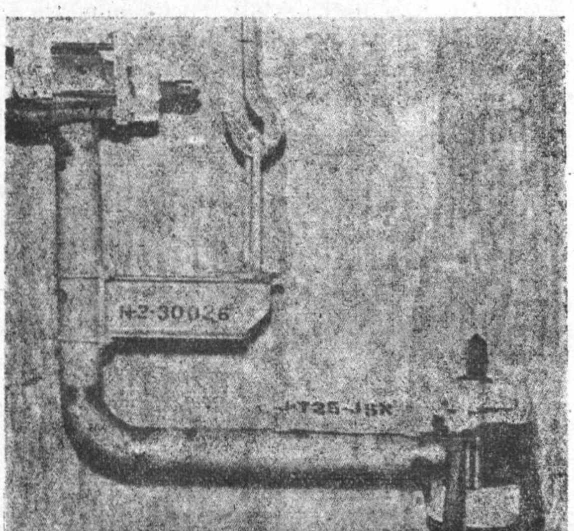

Figure 6. A typical remote jumper

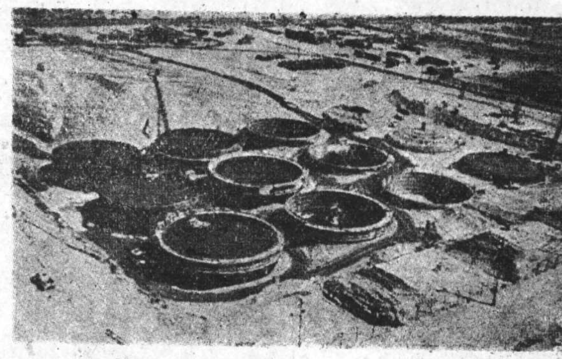

Figure 7. Construction of a waste-storage tank farm showing operations of pouring concrete walls with the inner steel tank filled with water. Backfilling of earth, sandblasting for interior-surface preparation and dome and wall forming

The tanks are usually constructed in groups of multiple units, each with a capacity from 500,000 to 1,000,000 gal, with an internal diameter of approximately 75 ft, and a height from 20 to 40 ft. A view of a tank farm during construction is shown in Fig. 7. The steel liner covers the bottom and sides of the reinforced-concrete tank. The tank fill lines enter near the top of the steel liner. Overflow lines may or may not be provided, depending upon whether or not it is desired to allow the liquids to cascade from one tank to another.

A number of nozzles enter the tank through the dome to provide means for temperature, pressure, liquid-level and radiation measurement, and for sampling and installation of auxiliary equipment for liquid transfer or agitation. Figure 8 shows the cross-section of a typical Hanford waste-storage tank. Other equipment, shown in Fig. 3, is installed to control the problems associated with the removal of the heat generated by radioactive decay of the fission products being stored. A seal pot is provided for protection against excessive pressure changes in the waste-storage tank system. The vapors from the

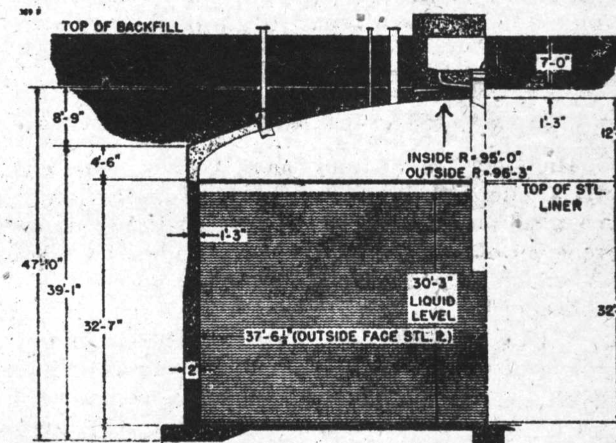

Figure 8. Cross section of typical Hanford waste-storage tank

storage tanks pass through a device for removal of entrained liquids and are then condensed. Uncondensed and noncondensable vapors pass through a filter and fan to a stack for atmospheric dispersal. Liquid effluents from the filter and condenser proceed to a ground-disposal basin or are returned to the storage tanks. Wells are drilled in the storage area to allow the earth to be monitored for evidence of tank leakage and performance of other neighboring waste-disposal facilities.

The capital investment and operating cost associated with an underground waste tank-storage facility are greatly affected by the size of the facility and by the nature of the surroundings. However, facilities with several tanks having a 500,000 to 1,000,000 gal capacity can be constructed in dry easily-excavated earth for an overall cost of about 25 to 30 cents per gal. With elaborate vapor-handling systems and thicker steel for increased corrosion resistance for self-boiling wastes, the costs are about 40 cents per gal.

INSTRUMENTATION AND CONTROL OF THE HANFORD WASTE-STORAGE SYSTEM

The problems associated with operating a boiling high-level radioactive-waste storage facility include monitoring the material in each of the tanks to note liquid levels, sludge levels, and temperatures, assuring adequate heat removal, and eliminating or minimizing the surge-boiling characteristics of such wastes. Thus, each waste-storage tank is provided with the following accessories for measurement and control:

(*a*) A pressure indicator and alarm.

(*b*) A weight-factor indicator and alarm (for liquid level).

(*c*) A specific gravity indicator.

(*d*) A conductivity-type level indicator (to check liquid levels).

(*e*) A T-type hand-operated probe (to determine sludge levels).

(*f*) Thermal elements (for temperature measurement).

(*g*) Air-lift circulator differential-pressure recorder.

(*h*) Air-lift circulator air-supply-flow indicators.

(*i*) Alarm system for the two compressors supplying motive air to the circulators.

In addition, each group of tanks has liquid-level and alarm instrumentation to monitor the loop seals shown in Fig. 3. The liquid and sludge stored in the tanks are sampled on a non-routine basis by lowering suitable devices through the access manholes and/or spare risers on each tank.

OPERATING EXPERIENCE WITH HANFORD WASTES

A property of the heating phenomenon, which is especially unusual in the large volumes, is the characteristic of irregular rate of heat release. Wastes may be releasing heat (boiling) at a moderate rate and then periodically burst into a violent surging boil. At such periods the heat-release rate may be more than twenty times the normal uniform rate. Under these conditions pressurization of the tanks occurs. Such events are thought to be caused by the release of heat stored under uniform conditions of hydrostatic head throughout the large volume, rather than by super-heating phenomena. Although heat may be released from a tank by uniform boiling at rates of as much as a few million BTU per hr, this is indeed a slow rate of heat evolution from the liquid surface in a tank which may be 75 ft in diameter. Turbulence would not be expected under such conditions which may release heat uniformly at rates even as high as 1000 BTU/hr/ft^2. Bubble formation may not even be attained. With the whole volume at equilibrium it can be seen that much heat could be retained without boiling, particularly in the deep part of the tank volume where the temperature would be a few degrees above the atmospheric boiling temperature. Something is assumed to upset the equilibrium and initiate the peculiar surging boil. Alkaline wastes contain precipitates which effectively carry fission products. Such precipitates settle and produce a layer of much higher heat-generation capacity at the bottom of the tanks. It may be assumed that the equilibrium is upset by bubble formation in high-temperature areas, probably in the sludge layer. On escaping, this bubble expands and draws into its upward path liquid which bursts into a boil as its vapor pressure exceeds the hydrostatic head of its immediate environment. Thus, a surge of boiling is propagated and continues until a large fraction of the stored heat is liberated. However, even during the course of this event, the surge boiling increases and decreases in intensity in a fairly regular manner. Cyclic pressurization has thus been observed. This is believed to be the self-damping effect on boiling caused by back pressure in restrictions in the vapor-release facilities. It is concluded that the maximum pressure attainable under surge boiling cannot exceed the maximum hydrostatic head of the liquid in the tank. This limit is used as a basis for the design of new facilities. It is also the basis for storage-tank operation, in that facilities are provided which assure that such pressures will not be exceeded. The maximum pressure observed during surge boiling has been about 2 lb/in^2, which is substantially below the maximum hydrostatic head.

With the development of the solvent-extraction processes with their minimum waste volumes, as distinguished from the original precipitation method, the heat-generation phenomenon reached levels which required the provision of elaborate cooling facilities for all tanks containing high-level wastes. During the operation of the obsolete precipitation process for plutonium production, self-heating of the wastes was expected. Simple finned-tube air-cooled condensers were adequate for condensing the water vapor from the small amount of vent gases. These wastes, which were of large volume since no effort was made to concentrate them for minimum storage costs, did not

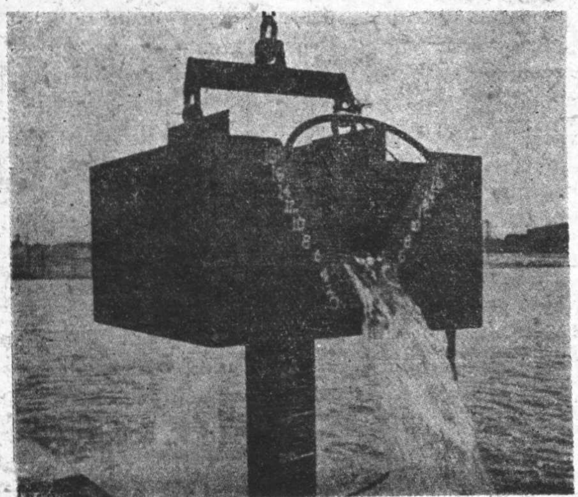

Figure 9. Demonstration test of air-lift circulator operating with a lift of 3 ft 2 in. with a flow of 326 gpm and using about 25 ft³ of motive air per min

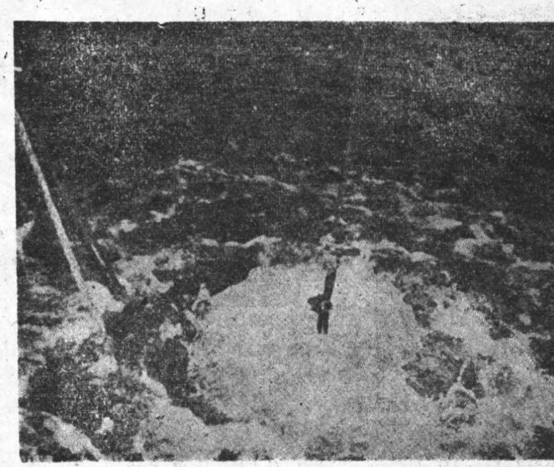

Figure 10. Demonstration test of air-lift circulator in fresh water operating submerged and producing a flow of about 1300 gpm with about 20 ft³ of motive air per min

attain boiling temperatures. Solvent-extraction process wastes, however, because of intensive efforts to minimize salt content and to reduce volume, rapidly attain boiling conditions and are expected to continue to boil for many years (Fig. 12).

In order to eliminate cyclic uncontrolled boiling, the concept of an air-lift agitator or circulator for the liquid was examined, demonstrated in large-scale facilities and subsequently installed in all high-level waste-storage tanks. Figures 9 and 10 show demonstrations of circulators being tested in cold fresh water.[3] Although such equipment is simple and highly satisfactory for eliminating uncontrolled surge boiling, extensive auxiliary facilities must be provided to assure prolonged uninterrupted operation. For example, in highly concentrated wastes the air flow to the circulators is impeded and eventually interrupted by solid formation and crystallization at the air inlet. Airflow to each circulator is therefore continuously charted. As the rate falls, alarms are actuated. Water is then manually routed to the air line to dissolve the interfering material and restore the flow of air. Figure 11 illustrates the application of the air-lift

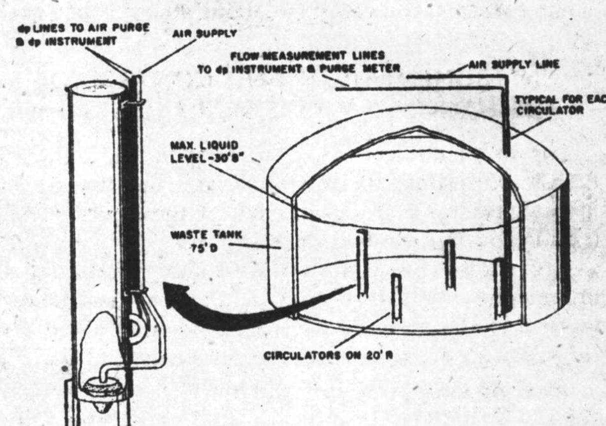

Figure 11. Application of waste-tank circulators

Figure 12. Waste-storage area in winter. This photograph, which was made during a period of unusually cold weather, shows the absence of snow over some of the buried tanks and gives visible evidence of the heat generated by radioactive decay in the stored wastes