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HISTORICAL RADIONUCLIDE RELEASES FROM CURRENT DOE OAK RIDGE OPERATIONS OFFICE FACILITIES

MAY 1988

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OAK RIDGE, TENNESSEE 37831

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HISTORICAL RADIONUCLIDE RELEASES FROM CURRENT DOE OAK RIDGE OPERATIONS OFFICE FACILITIES

SUMMARY

This report contains a summary of the history of radionuclide releases from Department of Energy Oak Ridge Operations facilities and the calculated radiation doses to the public due to those releases. Included in the report are estimates of the quantity of radioactive material contained in the airborne and waterborne effluents and in solid wastes at the Oak Ridge National Laboratory, Y-12 Plant, and the Oak Ridge Gaseous Diffusion Plant in Oak Ridge, Tennessee, the Paducah Gaseous Diffusion Plant in Paducah, Kentucky, the Portsmouth Gaseous Diffusion Plant in Portsmouth, Ohio, the Feed Materials Production Center in Fernald, Ohio, and the RMI Company in Ashtabula, Ohio.

For uranium releases, this report updates information contained in the Report on Historic Uranium Releases for Current DOE Oak Ridge Operations Facilities, issued June 24, 1985.

Section 3 of the report contains tables which show the total quantity of radioactive material from each facility. Appendix A provides a more detailed year-by-year summary for each radionuclide from each facility.

Several factors cause uncertainty over the accuracy of the quantities reported. The historical records do not contain complete information on actual measurements of material released. However, the available information allows an estimate of these emissions to be made, based on what is known about the operating history of the installation. For much of the historical data presented in this report, emissions had to be estimated, although in latter years of operation, these measurement data are available for many of the radionuclides. Specific quantities of radioactive material shown in the report should be considered as the most reasonable estimate based on the information available. These numbers are not meant to be interpreted as precise measurements.

The calculated dose to the population within a 50 mile radius of each facility, based on the total quantities of radioactivity shown in the report, is shown in the table below. Along with this estimate of dose due to the effluents from the facilities is the radiation dose that the same population received from background radiation over the same period. (For more information, refer to Section 4 of the report.)

Included in the table is an estimate of the possible health effects from the radiation dose as compared to the number of health effects estimated from background radiation doses. For the purposes of this report, the health effect being considered is the number of cancer fatalities and genetic effects in the population. These calculations do not include estimates of population dose and health effects for the Feed Material Production Center. Data are still being collected and evaluated to allow comparable calculation for that facility.

Based on the evidence in this report, the following conclusions can be made:

- the calculated population radiation doses due to the estimated amounts of material released from these facilities are only a small fraction of the radiation doses due to background radiation

- the estimated number of health effects which could be attributed to these releases are small compared to the natural incidence of the health effects

SUMMARY OF CALCULATED DOSES AND HEALTH EFFECTS

FACILITY	CALCULATED DUE TO EFFLUENTS Dose [a] (person-rem)	CALCULATED DUE TO EFFLUENTS Health Effects [b]	CALCULATED DUE TO BACKGROUND RADIATION Dose [c] (person-rem)	CALCULATED DUE TO BACKGROUND RADIATION Health Effects [d]
Oak Ridge National Laboratory	3,928	0.6	9,530,400	1,572
Y-12 Plant	11,543	2	11,132,700	1,837
Oak Ridge Gaseous Diffusion Plant	1,237	0.2	10,295,100	1,699
Paducah Gaseous Diffusion Plant	1,003	0.2	4,767,000	787
Portsmouth Gaseous Diffusion Plant	298	<0.1	5,760,000	950
Feed Materials Production Center	-[e]	-[e]	12,571,200	2,074
RMI Company	347	<0.1	12,000,000	1,980

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a Effective dose equivalent to the population within a 50 mile radius of each facility over the operating history of the facility calculated from the amount of radioactive material released

b Estimated number of fatal cancers and genetic effects which may have occurred in the population within a 50 mile radius of each facility over the operating history of the facility as a result of the radiation dose shown

c Dose to the population within a 50 mile radius of each facility due to background radiation levels

d Estimated number of fatal cancers and genetic effects which may have occurred in the population within a 50 mile radius of each facility over the operating history of the facility as a result of background radiation levels shown

e Comparable calculations for FMPC are still being evaluated and have not yet been finalized

HISTORICAL RADIONUCLIDE RELEASES FROM CURRENT DOE, OAK RIDGE OPERATIONS OFFICE FACILITIES

1.0 INTRODUCTION

This report discusses the history of radionuclide releases from DOE/ORO facilities, including the resultant calculated radiation dose to the public from those releases. It was prepared for the purpose of providing information of use and interest to the public. More detailed reports, from which most of the data presented in this report were drawn, have been prepared for each facility.

For uranium, this report updates information contained in the "Report on Historic Uranium Releases from Current DOE Oak Ridge Operations Facilities" issued June 24, 1985.

Since the 1940s, large amounts of radioactive material, including uranium processed in production facilities, have been central to the program functions supporting the Department of Energy, Oak Ridge Operations (DOE/ORO) overall mission. The principal program functions are:

1. Enrichment of uranium for nuclear power plant fuel.

2. Production of nuclear weapons components for National Defense programs.

3. Processing of uranium feed materials and production of uranium fuel cores for plutonium production reactors.

4. Broad scope research and development.

Seven different plant facilities support these programs. Enrichment of uranium fuel has involved three gaseous diffusion plants located near Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. The enrichment facility in Oak Ridge was taken out of operation in 1985. The Y-12 plant in Oak Ridge is a metallurgical and machining facility producing nuclear weapons components. The Feed Materials Production Center at Fernald, Ohio, and the RMI Extrusion Plant in Ashtabula, Ohio, each perform different steps in the processing of uranium feed materials. The broad scope research and development facility, Oak Ridge National Laboratory in Oak Ridge, has handled a wider variety of radioactive materials than have the other facilities.

Each of these program operations have generated radioactive wastes and have released radioactive material to the environment. The amount of material released and waste generated varies among the facilities, depending on the operations at the facility.

2.0 SOURCES AND MODES OF RADIONUCLIDE RELEASES

2.1 Oak Ridge National Laboratory (ORNL)

ORNL, an energy research and development facility, has been in operation since 1943. Currently operated for DOE by Martin Marietta Energy Systems, Inc., ORNL research focuses on technology development in energy related areas of:

- o nuclear fission and fusion
- o biology and the environment
- o conservation and renewable energy
- o physical sciences

Radioactive material is used in most areas of research and development at ORNL. As a consequence of this material use, releases of radioactivity, varying from tritium (hydrogen-3) to transuranics (neptunium, plutonium, etc.), have occurred from many different activities.

2.1.1 History of Airborne Releases from ORNL

Before 1950, releases of radioactivity to the atmosphere from ORNL were from stacks serving individual facilities. The two most significant of these were the RaLa (radioactive lanthanum) facility and the Graphite Reactor. The RaLa facility, which processed nuclear reactor fuel slugs in the production of radioactive lanthanum, had no treatment system for gaseous discharges until 1949, and was operated until 1956. Consequently, unknown quantities of noble gases, particulates, and radioiodine, particularly iodine-131, were released from the facility. The Graphite Reactor also operated without a filtration system for airborne releases from 1944 until 1948.

In 1950, a centralized off-gas and ventilation system was installed with particulate filters and an electrostatic precipitator to remove airborne particles from the releases. In 1961, scrubber systems were added to remove radioiodines.

Routine airborne discharge data records date back to 1961 for iodine-131 discharges. An upgrade of the sampling system in 1970 resulted in the reporting of noble gas discharges. Tritium and alpha-emitting particulates which were not specifically identified have been reported since 1972.

2.1.2 History of Liquid Releases from ORNL

From 1943 to 1949, liquid wastes were treated by being held in tanks and settling basins for radioactive decay and for

settling of particulate material before discharge to White Oak Lake. The lake provided further settling and additional time for radioactive decay prior to release into the Clinch River.

From 1949 to 1954, an evaporator was used to concentrate the most radioactively contaminated liquid waste before storage in concrete tanks. Beginning in 1951, much of the liquid waste was placed into pits and trenches for disposal. These pits and trenches were designed to retain the radionuclides until the radioactivity could decay to low levels. The evaporator was taken out of service in 1954 and all of the liquid radioactive waste went to pits and trenches until 1963. During the late 1950s and early 1960s ruthenium-106 was the primary radionuclide released from trenches into White Oak Creek because of its poor absorption in soil. Beginning in 1964, hydrofracture technology was used for waste disposal. With this technique, wastes were injected into shale at a depth of about 1,000 feet, along with a cement grout to isolate the waste from contact with the biological environment.

A process waste water treatment plant was installed in 1957, to demonstrate recovery of fission products from liquid wastes. The process waste water was only slightly radioactive compared to the low level waste just described. A replacement facility began operation in 1976.

Currently, the most significant radionuclides released from ORNL to the water pathway are leakage from waste disposal areas of strontium-90 and cesium-137. These are significant because of their radiotoxicity, their mobility in the environment, and the quantities released. Other radionuclides of significance are tritium and transuranics. The current (through 1986) releases of all radionuclides are divided roughly by source as follows:

- Seventy to eighty percent of the radioactive material released leaches from waste disposal areas to White Oak Creek or Melton Branch with subsequent drainage into White Oak Lake and eventually into the Clinch River. However, in 1985, problems with the liquid waste system in the main ORNL complex resulted in a significant portion of the Sr-90 coming from sources other than waste disposal areas.

- Approximately ten percent from operating facilities such as research reactors, laboratories, and processing plants. Some of these liquid wastes are discharged to temporary hold-up basins for testing and treatment before release to White Oak Creek. Improvements in treatment of process water have reduced the amount discharged from these sources.

- Approximately ten percent from contaminated surfaces and soils in the vicinity of operating facilities. These areas are contaminated from previous spills and leaking underground pipes and tanks. Release occurs through storm water runoff or cross contamination between liquid waste and drain system pipes.

2.1.3 History of Solid Waste Disposal at ORNL

Until commercial radioactive solid waste facilities became available, it was necessary for ORNL to accept waste from non-government sources. Later, non-ORNL wastes were limited to selected materials which other DOE facilities, such as sites not having disposal capabilities, were unable to handle. In recent years, acceptance of wastes from others has been sharply cut back in recognition of concerns over the technical adequacy of ORNL's disposal facilities.

Radioactive contaminated solid wastes have been placed in shallow land burial facilities. Although records of waste volume were maintained, more detailed estimates of the radioactivity content of these wastes were not recorded until 1977. Much of the data prior to that time are only rough estimates. Data available through these newer records is not precise, however, due to difficulty in determining the content of all solid waste being generated.

Uranium disposal data are based on accountability records and are therefore considered somewhat more accurate than for other radionuclides. Since the records do not distinguish between uranium contained in material which was buried and that placed in retrievable storage, the data include both.

2.2 Y-12 Plant

Built in 1943, the Y-12 plant currently functions to:

- Produce nuclear weapons components.
- Provide fabrication assistance to DOE weapon design laboratories.
- Process source and special nuclear material.
- Support ORNL facilities on the Y-12 site, and
- Support other government agencies in machining or assembly of various items

The radionuclide releases from Y-12 result from uranium metal machining and chemical processing operations and plant waste management practices. As a part of the operations, enriched

uranium is processed into uranium metal. Most of the releases are uranium, although some technetium-99 and trace transuranics associated with enriched uranium solutions are also contained in liquid effluents and solid wastes.

2.2.1 History of Airborne Emissions from Y-12

The major source of airborne radiological emissions from the Y-12 Plant has historically been, and continues to be, emissions of small uranium particles from metal machining and chemical processing operations. The primary means of controlling these emissions is the use of High Efficiency Particulate Air (HEPA) filters, baghouses, and exhaust gas scrubbers. The 13.9 curies of uranium activity emissions from the Y-12 Plant from 1944 to 1987 result principally from major enriched uranium sources. Uranium emission information after 1954 was obtained from Y-12 Plant accountability records, the DOE Effluent Information System Radioactivity Summary Report, and the Solid Waste Information Management System. Prior to 1954, analytical and sampling techniques at the Y-12 Plant were not able to detect airborne sources of uranium, but enough data was uncovered in health physics reports and other sources to make some of the emissions estimates in this report possible. Since data is not available for the time period of 1948 to 1953, no reliable emissions estimates can be made.

Uranium emissions from the Y-12 Plant were highest from 1959 through 1970. This can generally be attributed to increases in production during that time. The construction of new baghouses and other equipment at the Y-12 Plant beginning in 1969 has improved control of uranium particles and lowered overall plant emissions. From 1984 to 1987, several major enriched uranium emissions control systems at the Y-12 Plant were upgraded to further reduce emissions (as part of the Production Capabilities Restoration Project). Additional reductions in emissions are now being realized at the Y-12 Plant as the Air and Water Pollution Control Project completes the installation of additional emission controls. Although significant improvements have been made and are still being made to uranium emission control at the Y-12 Plant, work is continuing to identify and implement additional areas for improvement.

The need for improved emissions monitoring capability from the large number of process exhaust ventilation stacks that serve Y-12 uranium handling operations was identified in 1985. New emissions sampling/monitoring equipment was installed and began operating in early 1987 on 85 process exhaust stacks in the Y-12 Plant. The new emissions monitoring system will allow the Y-12 Plant to continue to monitor progress being made in reducing emissions and ensure that

the release of uranium particles is being maintained As Low As Reasonably Achievable (ALARA).

In addition, there are several hundred room exhaust fans within the Y-12 Plant with some potential to release small quantities of uranium into the atmosphere. While the majority of these systems are not fitted with emission controls, an extensive health physics monitoring program within the plant is used to ensure that uranium concentrations in process buildings are maintained ALARA.

2.2.2 History of Liquid Effluents from Y-12

Liquid effluent releases of radioactivity from the Y-12 Plant have generally been uranium from the same sources which resulted in airborne emissions. In addition, sources of contamination such as outside storage facilities have allowed for the runoff of precipitation containing uranium. Liquid wastes containing economically recoverable uranium have historically been recycled in Y-12 Plant production operations. Liquid wastes that did not contain recoverable uranium were discarded. Until recent years, treatment facilities were not generally available and the waste was discharged into the storm sewer system and into East Fork Poplar Creek (EFPC). Beginning in 1951 and until 1984, some liquid wastes were discharged into the S-3 ponds located in the western end of the Y-12 Plant site. Leakage from the S-3 pond area contributed to uranium releases into Bear Creek, as did precipitation runoff from the Bear Creek Burial Grounds (BCBG). Both EFPC and Bear Creek flow into Poplar Creek and ultimately into the Clinch River near ORGDP.

In March 1984, when ORGDP received a permit to process Y-12 Plant waste, the discharge of wastes into the S-3 ponds was discontinued. The material contained in the ponds has recently been treated to remove contaminants and discharged under the Y-12 National Pollutant Discharge Elimination System (NPDES) permit. Remedial action activity of the S-3 ponds is now underway, to eliminate them as a source of uranium release in the future.

In addition to liquid releases of uranium from the Y-12 Plant site, some thorium process solutions from ORNL research programs and Y-12 Production operations have been discharged to the storm sewer and ultimately to EFPC. The discharged ORNL solution included thorium oxide slurries from corrosion testing experiments and from the cleanup operations in ORNL Reactor Engineering. Liquid releases of both thorium and uranium from the Y-12 Plant site have been reduced in recent years as process modifications have been completed and new wastewater treatment plants were constructed and began operation.

In addition to the solid wastes, the Bear Creek Burial Ground wastes included uranium-contaminated liquid wastes such as oils, solvents, and mop water. Disposal of liquid waste to the burial ground was terminated in 1982, with only solid uranium and uranium contaminated wastes buried since that time.

2.2.3 History of Contaminated Solid Waste Disposal at Y-12

Radioactive solid wastes generated include uranium and uranium contaminated materials. Uranium wastes include depleted uranium metal and oxide in the form of chips, turnings, powders, scrap, and process residues with uranium contamination, resulting from the milling and machining processes. These process residues consist of such uranium-contaminated materials as gloves, floor sweepings, filters, and demolition debris.

Most of the solid wastes have been buried in the Bear Creek Burial Grounds, with some deposited in burial areas within the plant perimeter fence and on Chestnut Ridge. Because most of the uranium waste buried is depleted uranium metal chips and since this metal ignites spontaneously, the chips have been placed in dumpsters that contain water to prevent spontaneous burning. The dumpsters containing both uranium and water are weighed, for waste disposal records, prior to burial. Because the weight of uranium shown in disposal records is actually the total weight of the depleted uranium and the water together, the solid waste report numbers are biased high due to the water weight. This positive bias resulted in an error in the quantities reported in the 1985 uranium release report of approximately 1,500,000 kg of depleted uranium from 1947 to 1984, resulting from the weight of water. (Refer to Table 9 of Appendix A.) A uranium chip oxidation facility is expected to be put into routine service in 1988 to replace this method. Oxidized uranium chips will be stored in concrete vaults, eliminating burial in unlined shallow trenches for a major portion of the Y-12 Plant uranium waste. In addition, since the oxidized chips can no longer burn, water will be eliminated from the storage process.

2.3 Gaseous Diffusion Plants

The three gaseous diffusion plants process uranium hexafluoride in order to increase the uranium-235 content. The Oak Ridge facility began operation in 1945 and was placed in a "ready standby" status in the summer of 1985. The plant was placed in "permanent shutdown" status in December 1987. The plant near Paducah, Kentucky, has been in operation since 1952, and the Portsmouth, Ohio, facility since 1955.

The gaseous diffusion process releases are primarily uranium from the enrichment operations. There have also been some releases of uranium daughters (radioactive isotopes resulting from the decay of uranium), transuranics, and some fission products, such as technetium, xenon, and krypton, from some of these facilities.

2.3.1 History of Airborne Releases from Gaseous Diffusion Plants

Oak Ridge GDP

The primary radionuclides which have been released in the past from the ORGDP include krypton-85, technetium-99, and uranium.

The krypton-85 was released during a five-year period (1976 through 1980) as a result of performing the research and development activities at ORGDP for ORNL.

The primary sources of airborne releases of technetium-99 and uranium have been through the gaseous diffusion process vents, the feed plants, and accidental releases. Prior to 1964, ORGDP was involved in the enrichment of uranium to high concentrations of uranium-235 for weapons production. After 1964, only low concentration enrichment was performed for use in commercial power generating facilities.

The feed plant where uranium from spent fuel was fluorinated to uranium hexafluoride (UF_6) from 1950 to 1968, was the primary source of technetium-99, neptunium-237, and plutonium-239 at ORGDP. Radioactive air emissions from the purge cascade vent operations were decreased by the installation of solid-chemical traps and a liquid potassium hydroxide scrubber in 1977.

Since August 1985, the uranium enrichment operations at ORGDP have been discontinued, thus eliminating the emissions of uranium from the process. Presently, the sources of airborne uranium emissions are from the laboratories and the K-1420 Decontamination Facility. Two new sources that will begin operation in the near future are the K-1435 TSCA Incinerator and the K-1420-C Floor Pan/ Cylinder Cleaning Facility.

Portsmouth GDP

Most of the routine airborne radionuclide emissions from the Portsmouth GDP are released from the Top and Side Purge Cascades in the X-326 Process Building. The Purge Cascades operate continuously to separate UF_6 from light gases (mostly air) that have entered the cascade. Essentially all the technetium and most of the uranium activity released by the facility escapes from these vents. Virtually all the remaining routine uranium emissions are released from the Cold

Recovery and Wet Air Evacuation Areas in the X-330 and X-333 Process Buildings. These areas are used to remove and recover UF_6 from portions of the cascade that require maintenance or repair (Cold Recovery) and to evacuate air from portions that are returning to service.

Much of the year-to-year variability in Portsmouth air emissions and over half of the total historical uranium emissions are due to unplanned or accidental releases of uranium. The largest single unplanned release occurred in March 1978, when a cylinder of liquid UF_6 fell from its carrier while being removed from a sampling stand. The cylinder cracked open and an estimated 4,820 kilograms (2.6 Ci) of uranium escaped to the atmosphere. Other recent unplanned releases of uranium included cylinder valve failures in October 1978 (560 kg, 0.13 Ci) and July 1979 (460 kg, 0.10 Ci), a process malfunction in December 1983 (50 kg, 0.69 Ci), and a slow leak in December 1985 and January 1986 (49 kg, 0.03 Ci). In addition, unplanned releases ranging from 44 grams to 817 kg of uranium accounted for over 80 percent of the atmospheric uranium emissions prior to 1980.

Technetium, an impurity in recycled uranium, first appeared in gaseous emissions in 1976. Between that time and 1984, technetium emissions were estimated from samples collected from simple side taps, that is, from sample collection valves on the side of the process stream. Data collected since 1984 has revealed that technetium travels through the cascade in a complicated, two-phase flow that could, under some conditions, seriously overestimate results from side tap samples. This may be the cause of the reported high technetium emissions in 1982, when vent sampling indicated technetium emissions of 11.1 Ci. Environmental monitoring results obtained during that year indicate that emissions were in the range of 0.5 to 1 Ci. Sample collection since 1984 has been designed to eliminate this problem.

Paducah GDP

During the first years of the Paducah GDP operation, there were several atmospheric releases of UF_6 resulting from accidents related to feeding UF_6 to the diffusion plant and related to filling UF_6 containers from manufacturing facilities or the diffusion plant. By the end of 1962, operating skill and equipment had advanced to the point that the quantity of uranium lost in accidental releases was negligible. Historically, the largest portion of routine uranium discharges has resulted from operation of the C-410 feed plant and the C-340 metals plant. The feed plant converted uranium trioxide (UO_3) to uranium hexafluoride (UF_6), and the metals plant independently converted UF_6 to uranium tetrafluoride (UF_4). Both of these facilities were shut down in May 1977.

Currently, quantities of uranium released to the atmosphere are small operating losses associated with the enrichment cascade and UF_4 processing operations.

The Paducah feed plant was designed and sized to process both natural uranium and uranium from reactor tails returned from the plutonium production reactors for enrichment. This reactor return material contained trace quantities of technetium-99, neptunium-237, thorium-230, and plutonium-239. Small quantities of these radionuclides were discharged to the atmosphere from the enrichment cascade with technetium-99 being the most notable in terms of curies emitted.

2.3.2 History of Liquid Effluents from Gaseous Diffusion Plants

Oak Ridge GDP

The primary radioactive liquid effluent source at the Oak Ridge GDP has been from the uranium recovery processes utilized in the K-1420 Decontamination Facility. During the decontamination processes, residual concentrations of uranium, technetium-99, neptunium-237, and plutonium-239 were released through liquid effluents. The liquid wastes discharged from the recovery operations were passed through a settling pond where insoluble uranium compounds settled out. Soluble compounds were discharged to Poplar Creek which flows to the Clinch River.

At the present time, the primary sources of uranium discharged into the liquid effluent are from the radioactive waste treatment facility. It is used for treating waste solutions containing low concentrations of uranium. The chemical effluents from these facilities are monitored and permitted under the NPDES program.

Portsmouth GDP

The bulk of waterborne radionuclides at the Portsmouth GDP are attributable to decontamination and cleaning of equipment. Historically, solutions with medium to high concentrations of radionuclides were processed through Uranium Recovery (liquid-to-liquid extraction of uranium) followed by precipitation of heavy metals by pH adjustment and, later, technetium removal by ion exchange. Solutions with low concentrations and the treated solutions from Uranium Recovery were discharged to the X-701B Holding Pond, where lime was added to precipitate remaining heavy metals. Supernatant from the X-701B Holding Pond is discharged to Little Beaver Creek. Currently, all decontamination and cleaning solutions are being processed through Uranium Recovery regardless of concentration. The effluent has been rerouted to the X-6619 Sewage Treatment Plant, which in turn discharges directly to

the Scioto River. Other sources of waterborne radionuclides are the plant laundry, which also discharges to X-6619, and slightly contaminated stormwater runoff.

Waterborne radionuclide releases are almost directly related to the level of decontamination and cleaning activity, which peaked from 1976 to 1980 during improvement and upgrading of cascades. Not only did uranium and uranium daughter releases increase during this period, but the first significant releases of technetium occurred.

The only unplanned release to significantly affect waterborne discharges was a release from a UF_6 liquid cylinder in March 1978. Some of the liquid UF_6 reached the storm sewers and an estimated 680 kg of uranium (0.4 Ci) escaped via the West Drainage Ditch to the Scioto River before the ditch could be sealed off.

Paducah GDP

Uranium and other radionuclides discharged to surface streams at the Paducah GDP resulted primarily from chemical processing, chemical cleaning, or uranium recovery activities. During the period 1956 to 1969, a significant portion of waste material from the Paducah feed plant was dissolved for uranium recovery and resulted in the discharges of radionuclides to the drainage ditches. Beginning in 1970, this and other material from the fluorination system was put in storage for future processing.

Another source of uranium and other radionuclides entering plant drainage was the result of washing UF_6 cylinders. Periodically, UF_6 cylinders are washed to remove deposits so that they can be inspected and pressure tested. Some of the solutions went through a wet chemical uranium recovery process which resulted in discharges to water. Recently, these solutions have gone through a precipitation process with most of the radioactivity being collected with the solids. Filtrates go to the plant drainage system.

Major cascade improvement programs during the periods 1958 to 1962 and 1974 to 1981 resulted in large quantities of equipment being removed from the cascade and decontaminated. Decontamination activities generated larger quantities of liquid waste. Decontamination solutions were processed through either the uranium recovery system or the precipitation system. Measurable quantities of uranium and other radionuclides have been discharged in final rinse solutions discarded to the drainage system.

The release estimates for the Paducah GDP contain estimated quantities of plutonium, a radionuclide not usually found in

uranium enrichment. These effluents arise from reprocessing uranium from nuclear reactor fuel elements, which was discontinued in 1971. While the other gaseous diffusion plants also processed this type of material and may have had comparable levels of plutonium in their effluents, only the Paducah facility made records which allow the quantity of plutonium to be calculated.

2.3.3 History of Contaminated Solid Waste Disposal at the Gaseous Diffusion Plants

Oak Ridge GDP

Solid waste burial operations at the Oak Ridge GDP, except for thorium-232, were a direct result of uranium enrichment activities, The quantities and variations in the types of solid waste generated were generally related to types of activities and production levels. Floor sweepings, rags, and waste paper from general cleanup operations in the process buildings contained trace quantities of uranium and other radionuclides. Wastewater treatment sludges, airborne effluent treatment residuals; such as filter and trapping media, scrubber solids, and contaminated scrap metals were disposed of onsite.

During the operating history of the Oak Ridge GDP facility, processes have been reconditioned and/or replaced, generating large amounts of scrap metal for decontamination and subsequent storage. The radioactively contaminated scrap metal is presently being stored, and is being evaluated to determine the appropriate disposal method.

Materials that were at one time disposed of by shallow-land burial are currently being collected and stored as low-level waste at the Oak Ridge GDP facility. Thorium-232 was involved with certain Y-12 production programs and was present at the Oak Ridge GDP as solid wastes.

Portsmouth GDP

Solid radioactive waste at the Portsmouth GDP consists of contaminated scrap and equipment that could not be adequately decontaminated and solid residues from decontamination and cleaning activities. Historically, this waste has been accumulated in containers and buried in the X-749 Low Level Waste Burial Ground. A program of minimizing radioactive waste generation and burials since late 1985 resulted in no burials occurring in 1986 and 1987.

In addition to solid scrap and residues, significant amounts of uranium contaminated lubricating oil must also be disposed

of. Historically, this was done by natural biodegradation in the X-231A and X-231B Oil Biodegradation Plots, which operated through 1977 and 1983, respectively. Since 1983, uranium contaminated oils have been stored pending the startup of the TSCA Incinerator at the Oak Ridge GDP.

Finally, the past treatment of water discharges at the X-701B Holding Pond has generated a radionuclide contaminated lime sludge, which is currently stored in the holding pond and two associated containment ponds. Treated decontamination and cleaning solutions are no longer routed to X-701B and Portsmouth is in the process of obtaining a permit for a water treatment system to replace X-701B altogether. Once this system starts up, the three ponds will be cleaned out and the sludge treated for disposal.

Uranium disposal data for these facilities is based on accountability records, and is reasonably reliable. However, there is no reliable record of technetium disposal. Soil and groundwater monitoring to date have shown slight to no migration of radionuclides from these facilities.

Paducah GDP

The major activities contributing to the generation of low-level radioactive waste at the Paducah GDP are decontamination activities and the operation of the C-340 metals plant. The operation of the metals plant greatly affected the quantity of uranium buried. The process of converting UF_4 to uranium metal produced large quantities of slag containing small quantities of UF_4 and granules of uranium metal. In addition, the C-340 uranium metal cleaning and machining operations produced a steady stream of uranium sawdust, oxide, and shavings to burial grounds. The other major contributor to buried radionuclides is the precipitate from the lime precipitation system. Drummed filter cake resulted from the treatment of nonrecoverable decontamination and cylinder wash solutions.

The two primary burial areas at the Paducah plant are the C-404 low-level waste burial ground and the C-749 uranium burial ground. Most of the radionuclide contaminated waste generated through mid-1986 was buried in these two areas. Low-level radioactive waste is not presently being buried at the Paducah facility.

2.4 Feed Materials Production Center (FMPC)

The FMPC, which is located at Fernald, Ohio, processes uranium feed materials into uranium metal forms for use in national defense

programs. It has been in operation since 1951. Since the operations are concerned with conversion, refinement, purification and casting of uranium, the releases from this facility have been primarily uranium.

2.4.1 Airborne Effluents from FMPC

Emission control devices are used at each major release point in the process to reduce plant emissions. Bag-type dust collectors are used to capture or remove radioactive dusts generated by the manufacturing process. However, collector failures have resulted in releases of uranium to the atmosphere. Improvements in the filtration system, including installation of more efficient filters, were begun in 1986. Recent improvements to storage silos have also reduced the volume of radon emissions.

2.4.2 Liquid Effluents from FMPC

Liquid effluent releases consist of clarified treated wastewater from the uranium production buildings, water from the storm sewer system, and sewage plant effluent. Wastewater is treated to reduce uranium concentration before being released to nearby waterways.

2.4.3 Contaminated Solid Waste Disposal at FMPC

When feasible, the uranium contaminated waste generated at FMPC is treated to remove uranium for recycling back into the plant process. If this is not feasible, the waste is packaged and stored in drums for eventual offsite disposal, although onsite disposal was practiced in the past. The practice of placing radioactive solid waste into storage silos and pits has been discontinued.

2.5 RMI Extrusion Plant

The RMI facility is a privately owned plant in Ashtabula, Ohio, which started operation in 1962. Uranium metal is extruded at this facility into tubes and billets for use as nuclear reactor fuel at the DOE Savannah River and Richland, Washington, sites.

2.5.1 Airborne Releases from RMI

Airborne uranium release may occur from seven plant operation release points (the seventh release point came into existence in 1987), but historically, two operations serve as the primary release points. These are an abrasive saw and pyrophoric scrap incinerator. These release points have recently been equipped with more efficient emission control devices.

2.5.2 Liquid Effluents from RMI

Water used to quench hot uranium extrusions and to clean plant equipment are the major sources of liquid effluents from the facility. Wastewater is treated for uranium removal prior to discharge into waterways.

2.5.3 Contaminated Solid Waste Disposal at RMI

Radioactively contaminated solid waste has not been disposed of at the RMI plant.

3.0 RADIONUCLIDE RELEASE DATA

3.1 Historic Data

Estimated total quantities of radionuclides which have been released from each DOE/ORO facility are shown in Tables 3.1.1 through 3.1.7. The tables present only the total amounts for each isotope. For a more detailed yearly release estimate for each facility, refer to the tables in Appendix A to this report.

In tables 3.1.1 through 3.1.7 and the tables in Appendix A, the quantities of radionuclides released are given in terms of their radioactivity, which is expressed in curies. A curie is a measurement of the amount of radioactivity present. The mass associated with a curie varies among different radioisotopes and is related to the half-life of the material. For example, only 0.0004 ounces of cesium-137 will yield one curie, but 6,600 pounds of uranium-238 are required to yield one curie. In this report uranium releases are also given in terms of mass, expressed in kilograms, since the mass of uranium per curie is significantly higher than for other radionuclides.

The summary tables do contain some differences among the facilities due to the manner in which data were collected. For example, only the Portsmouth GDP table lists releases of uranium daughters. While uranium daughters were released from other gaseous diffusion plants, the data are not available to allow an estimate of those quantities. Similarly, small releases of plutonium-239 could have occurred from gaseous diffusion reprocessing at facilities other than the Paducah GDP. However, the estimated quantities of plutunium-239 are not available for those other facilities because the different recordkeeping methods did not provide the information required to estimate those quantities.

ORNL

In Table 3.1.1, the summary for ORNL shows a variety of fission products. The largest quantities shown on the table are for the airborne release of xenon-133, and for burial or disposal of the fission products cesium-137 and strontium-90.

Since xenon-133 is a nonreactive gas which decays rapidly, the quantity released from ORNL does not significantly contribute to individual or population doses.

Of the total quantities listed in Table 3.1.1, 59 percent of the Cs-137 and 78 percent of the Sr-90 were placed in the hydrofracture facilities operated at ORNL from 1964 to 1979 and from 1982 to 1984. Of the remaining amount, 39 percent of the Cs-137 and 17 percent of the Sr-90 were disposed in pits and trenches from 1951 to 1976. The remaining small percentages were contained in solid wastes.

Table 3.1.1

Summary of Radionuclides Released to Air and Water or Buried at ORNL from 1944 through 1987

ORNL	AIR (Curies)	WATER (Curies)	BURIAL [a] (Curies)
H-3	224,071 [b]	166,300	98,000
Co-60	-	325.06	8,961
Kr-85	215,629 [b]	-	-
Sr-89	-	11.3	-
Sr-90	-	1,197.8	880,557
Nb-95	-	286.9	-
Zr-95	-	376.6	-
Ru-103	-	-	13
Ru-106	-	6,931.6	16,104
I-131	403.5 [b]	175.3	-
Xe-133	1,041,100	-	-
Cs-134	-	-	636
Cs-137	-	693	1,174,709
Ce-144	-	341.9	-
Th-232	-	-	4.9
Pu-238	-	-	1.4
Pu-239	-	-	173.9
Cm-243/244	-	-	6,568
Uranium	-	-	159.6 (23,930 kg)
Unidentified alpha	0.000045 [b]	-	3,860
Unidentified beta	-	2,694	1,152,686
Total rare earth	-	1,295 [c]	2,784
Transuranics	-	5.2	3,100 [d]
Mixed fission products	-	-	14,570

[a] Burial includes material placed in pits and trenches from 1951 to 1976, and material put into hydrofracture facilities during 1964 to 1979 and 1982 to 1984.

[b] Quantities shown for airborne releases of H-3, Kr-85, I-131, and unidentified alpha are from 1961 to 1987.

[c] Excluding cerium

[d] Excluding plutonium-239

Y-12

Table 3.1.2 presents the summary for the Y-12 Plant. As could be expected from the plant operating history, the most significant releases have been uranium.

The table lists several materials other than uranium and thorium. These radionuclides were associated with reactor product uranium solutions received from other DOE sites since 1953. The recovery process for this product solution resulted in some of these radionuclides remaining in the material which was returned to the other sites. The waste from the process went to the S-3 ponds, although recorded as a burial. Since measurements were made for contamination control purposes, the exact quantities of material that went to the ponds are unknown. Reporting thresholds were established for these materials for accountability and security purposes. Releases to the ponds were always below these reporting thresholds.

Table 3.1.2

Summary of Radionuclides Released to Air and Water or Buried at Y-12 Plant from 1944 through 1987

Y-12	AIR (Curies)	WATER (Curies)	BURIAL [a] (Curies)
Uranium	13.87 (6296 kg)	116.58 (182,374 kg)	7,097 (17,290,523 kg)
Thorium	-	0.680	18.59
Np-237		-	- [b]
Tc-99			56.60 [c]
Cs-137	-	-	-
Co-57/60	-	-	-
Nb-95	-	-	-
Pu-238/239	-	-	-
Ru-106	-	-	-
Zr-95	-	-	-

[a] Prior to 1972, liquid wastes containing uranium that were transferred to the S-3 ponds were recorded as burials.

[b] Radionuclides other than uranium and thorium were contained in liquid waste streams discharged to S-3 ponds. Then annual quantities for each were below the accountabilty reporting threshold for security purposes, so no record of exact quantities exist. The individual fission products and transuranics have been qualitatively identified in this waste stream. The security accountability reporting threshold for each is shown on Table 10 in Appendix A.

[c] 600 g received from ORGDP and disposed at Y-12 burial grounds.

ORGDP

Table 3.1.3 provides a summary of radionuclide releases from ORGDP. The most significant radionuclides are uranium and technetium. A small amount of krypton-85 was also released to the atmosphere due to an experiment conducted at ORGDP for ORNL. These releases occurred from 1976 to 1980. Kr-85 is a nonreactive gas which, in this small quantity, does not contribute significantly to radiation doses.

Table 3.1.3

Summary of Radionuclides Released to Air and Water or Buried at ORGDP from 1945 through 1987

ORGDP	AIR (Curies)	WATER (Curies)	BURIAL (Curies)
Uranium	15.64 (10,519 kg)	14.77 (16,700 kg)	24.35 (32,821 kg)
Tc-99	10.0	91.3	-
Kr-85	106.5	-	-
Np-237	-	0.0073	-
Th-232	-	-	7.7 [a]

a Burial records indicate presence of thorium, however, quantities were not recorded. This maximum number is estimated from information in the burial records.

Paducah

Table 3.1.4 shows the summary of releases for the Paducah Gaseous Diffusion Plant. This table contains entries for plutonium-239, a transuranic element not generally encountered in uranium enrichment. The radionuclide is present due to the processing of uranium which had been recovered from reactor fuel elements. Liquid releases of plutonium stopped in 1971 with discontinuation of reprocessing. The table also contains entries for technetium-99, a fission product which also came to the site in recovered uranium.

Table 3.1.4

Summary of Radionuclides Released to Air and Water or Buried at Paducah Gaseous Diffusion Plant from 1952 through 1987

Paducah GDP	AIR (Curies)	WATER (Curies)	BURIAL (Curies)
Uranium	33.26 (59,450 kg)	15.11 (28,050 kg)	1,327 (3,320 kg)
Tc-99	66.25	3,179	463
Np-237	-	2.07	1.89
Pu-239	-	12.28	2.51
Th-230	<0.1 [d]	<7 [d]	<6 [a]

[a] Discharge data for each year is unavailable. Th-230 is not included in Tables 14-16, Appendix A.

Portsmouth

Table 3.1.5 shows the summary of releases from the Portsmouth Gaseous Diffusion Plant. This table contains entries for uranium, technetium-99, and uranium daughters. As mentioned earlier, while several facilities actually release uranium daughters, only the Portsmouth facility has compiled emission data on these comparatively minor radionuclides.

Table 3.1.5

Summary of Radionuclides Released to Air and Water or Buried at Portsmouth Gaseous Diffusion Plant from 1955 through 1987

Portsmouth GDP	AIR (Curies)	WATER (Curies)	BURIAL (Curies)
Uranium	8.01 (10,510 kg)	14.1 (7,824 kg)	3.46 (5,140 kg)
Uranium daughters	0.692	30.3	-
Tc-99	18.0	212.8	-

RMI

Table 3.1.6 summarizes the material released from the RMI Extrusion Plant. The facility has had no onsite burial of uranium. Radionuclides other than uranium, which exist as trace contaminants in recycled material have been released from RMI, as discussed in annual environmental monitoring reports. However, historical data is available only for uranium.

Table 3.1.6

Summary of Radionuclides Released to Air and Water or Buried at RMI Company from 1944 through 1987

RMI	AIR (Curies)	WATER (Curies)	BURIAL (Curies)
Uranium	0.57 (886 kg)	2 (3,271 kg)	0

FMPC

The summary for FMPC is shown on Table 3.1.7. The column headed "BURIAL" on this table actually shows the amounts of waste material placed in the pits and silos. Several fission products are also shown on the table, as a result of fuel recycle activities. As expected, the largest quantities shown in the table are for uranium.

3.2 Uncertainties in Tabulated Historical Data

The values presented in each table should be interpreted as reasonable estimates of the amounts of material released or buried. From early years of operation, records are not available to document the exact quantities involved. Sampling or monitoring for specific isotopes or of several release points was not begun until relatively recent years. Because of these assumptions and estimations, the specific data presented in the table should not be interpreted to be exact or precise values. In the areas of uncertainty, conservative assumptions were made to provide estimated quantities. Some of the uncertainties involved for each facility are discussed below.

3.2.1 Uncertainties in ORNL data

- Many of the specific radionuclides were not monitored in early years of operation.

Table 3.1.7

Summary of Radionuclides Released to Air and Water or Buried at FMPC from 1951 through 1987

FMPC	AIR (Curies)	WATER (Curies)	BURIAL [a] (Curies)
Uranium	89.3 (135,387 kg)	49.96 (76,201 kg)	3,540 (5,357,782 kg)
Thorium	0.51	0.05	8.68
Sr-90	-	0.12	-
Tc-99	-	120.4	-
Ru-106	-	0.069	-
Cs-137	-	0.68	-
Ra-226	0.107	6.16	1,804
Ra-228	0.00012	3.43	-
Np-237	-	0.0021	-
Pu-238	-	0.00018	-
Pu-239/240	-	0.0018	-

[a] Denotes wastes in storage, including material in pits and silos

- Radionuclide specific information on the composition of wastes placed into trenches and pits are only estimates based on knowledge of processes involved in generating wastes, the quantities typically generated by the process, and the measurement of gross radioactivity.

- Solid waste quantities were estimated from records of volume of waste disposal, not from records of quantities of radionuclides involved.

- Tritium discharge data prior to 1972 could only be estimated from the ratios of waste produced to production levels in more recent years.

- The uranium burial records include both the amount of uranium buried as well as the amount placed in retrievable storage.

- Verification of solid waste quantities was done, in part, by interviewing individuals who had worked in the program in ORNL earlier years, to supplement gaps in documentation.

3.2.2 Uncertainties in Y-12 data

- The uranium quantities buried on site were derived from the weight of dumpsters, containing uranium and water in which the uranium was placed prior to disposal.

- A linear deterioration of filter systems on the airborne uranium emission points was assumed. This means the amount of deterioration in the system was assumed to have occurred gradually over the years since installation. Because the deterioration more than likely occurred at an uneven rate (very little during earlier years, when systems were new, most of the deterioration occurring within the recent past), estimates of earlier releases would be reported somewhat higher than the actual release concentration that occurred.

- Uranium discharge data from 1944 to 1954 were not as complete as in later years, but enough data was available to make discharge estimates for those years.

- Measurements of transuranics and fission products were made for contamination control purposes only. Estimates of amounts going into the S-3 ponds were based on those measurements rather than the waste stream.

3.2.3 Uncertainties in Oak Ridge Gaseous Diffusion Plant Data

- Uranium releases for all but recent years were based on accountability records.

- Data for other radionuclides are intermittent at best. For example, no specific information on burials exists prior to 1958. Technetium-99 releases were not included in reports prior to 1974.

3.2.4 Uncertainties in Paducah Gaseous Diffusion Plant Data

- Specific sampling data are available only after 1958. Earlier values are estimates, based on production levels.

- Early sampling data were reported as gross alpha and gross beta values only. Qualitative analyses were not available. Specific radionuclide concentrations in effluents were extrapolated from the available, more recent data.

3.2.5 Uncertainties in Portsmouth Gaseous Diffusion Plant Data

- Specific radionuclide analysis of air samples has been performed routinely only since 1975. Earlier reported data are extrapolated from more recent isotopic compositions.

- In analysis of liquid samples, any beta-gamma analysis that is less than a predeterminated value is assumed to be all uranium daughter products. Specific radionuclide analyses are performed to verify isotopic composition only on samples exceeding that value.

4.0 RADIATION DOSES TO THE PUBLIC FROM RELEASES

4.1 Calculation of Population Doses

Neither mass nor radioactivity can be easily related to the effect of radiation, also known as radiation dose equivalent (often referred to as "dose"). A rem is a measure of the amount of radiation dose and its relative efficiency at producing a health effect. Individual doses are usually discussed in terms of millirem - 1/1000th of a rem.

Radiation dose is generally reported in one of three ways:

- Organ dose - The radiation dose to a specific organ of the body. Many radionuclides tend to concentrate in one or more organs, remaining there until the body excretes them, or their radioactivity decays away, or a combination of both. (The dose calculated in this report is actually the committed dose equivalent. It is the dose received over the 50-year period following exposure. Some radionuclides, e.g., Sr-90, remain in the body for long time periods. The calculation used in this report includes this extended period of exposure.)

- Effective dose - a weighted average of all the individual organ doses. This value indicates the effect on the body as a whole, from organ doses and whole body dose.

- Whole body dose - the radiation dose received when the entire body is irradiated uniformly. This quantity arises from an external exposure to radiation (i.e., radioactive material is outside the body, irradiating the whole body uniformly) or from internal deposition of radionuclides that do not concentrate in a specific organ, such as isotopes of carbon or hydrogen which are uniformly distributed through the body.

The maximum radiation dose that an individual may have received from releases of radioactive material can be estimated using a model in which the quantity of material released over a specific time interval is used to estimate the radiation dose to an individual, accounting for such things as the dispersion of the material from the release point, the amount of air breathed, the amount of water or food consumed, mechanism of uptake of the material into the body, and other factors. This technique entails the use of computer programs to perform a series of calculations and estimates based on certain assumptions.

Individual radiation doses are usually calculated in this manner on an annual or more frequent basis, since the estimate applies only to one specific location. The calculation of radiation doses for individuals for longer time periods require information not readily available, such as long-term meterological data and the individuals' location during the time.

A way of calculating long-term radiation effects is through use of the population, or collective dose, which is calculated by multiplying the average individual dose in an area by the population of that area. This value is an estimate of the radiation dose received by the general public. For most purposes, population doses are calculated for the area within a 50 mile (80 km) radius of each facility.

Table 4.1.1 presents the calculated population dose, in person-rem, for the 50 mile radius of each facility. These population doses are calculated for airborne releases and from liquid releases. As a comparison, the table also shows the cumulative population dose to the same population resulting from natural and enhanced sources of radiation. The average resident of this country receives a radiation dose of approximately 300 millirem per year from these natural and manmade sources, including naturally-occurring radioactivity in rocks, soil, food, air and water, and fallout from above-ground nuclear weapons tests conducted in the 1950s and 1960s. Table 4.1.3 lists a few natural and manmade sources of radiation exposure.

Table 4.1.2 shows the calculated maximum individual radiation doses resulting from discharges of radionuclides from each facility in 1987.

Another pathway for possible exposure of humans is by eating fish from waters receiving the liquid effluents. An estimate of the total population dose from this pathway for the three Oak Ridge, Tennessee facilities is shown in Table 4.1.4. The significance of these calculated doses is explained in Section 4.3.

In order to obtain this estimate, it was assumed that:

- The exposed population consisted of the downstream population from Oak Ridge to Chattanooga (303,000 persons).
- Fish concentrate the radionuclides (primarily cesium and strontium) in their bodies by a factor of 2,000 times the water concentration.
- Ten percent of the population consumes 7.3 kg. (16 lb.) of sport fish per year with one percent of the sport fish ground into patties which include bone.
- Fifty percent of the commercial catch is consumed by humans with ten percent being made into patties which include bone.

TABLE 4.1.1.

COMPARISON OF TOTAL POPULATION EFFECTIVE DOSE RESULTING FROM OPERATION OF DOE/ORO FACILITIES VS. NATURAL BACKGROUND RADIATION

	ORGDP	Paducah GDP	Portsmouth GDP	Y-12	FMPC	RMI	ORNL
Reporting Period from: to:	1946-1987 (41 yrs.)	1952-1987 (35 yrs.)	1955-1987 (32 yrs.)	1944-1987 (43 yrs.)	1951-1987 (36 yrs.)	1962-1987 (25 yrs.)	1949-1987 (38 yrs.)
Population within 50-mile radius (1980)	837,000	454,000	600,000	863,000	1,164,000	1,600,000	836,000
Effective dose to total population within 50-mile radius accumulated over reporting period (person-rems.)							
Liquid effluents	7		4	60			3,003
Airborne releases	1,230	1,003	294	11,483	[a]	347	900
Total	1,237	1,003[b]	298	11,543		347[b]	3,928
Natural background within 50-mile radius accumulated over reporting period (person-rems.)	10,295,100	4,767,000	5,760,000	11,132,700	12,571,200	12,000,000	9,530,400

[a] Comparable calculations for FMPC are still being evaluated and have not yet been finalized.

[b] Airborne release pathway only; waterborne pathway is a minor additional contributor to public radiation exposure.

TABLE 4.1.2.

DOSES TO MAXIMALLY EXPOSED PERSONS
FROM 1987 RELEASES FROM DOE/ORO FACILITIES

	ORGDP (1987)	Paducah GDP (1987)	Portsmouth GDP (1987)	Y-12 (1987)	FMPC (1987)	RMI (1987)	ORNL (1987)	Natural Background (U.S. Average)
Effective Dose Equivalent millirems/year[a]	<1	<1	<1	2.1	1.2	<1	<1	300[b]
Maximum Organ Dose, millirems/year[a]	<1	<1	<1	17.0	8.9	<1	<1	--

a Airborne release pathway only; except for ORNL waterborne pathway is a minor additional contributor to public radiation exposure at the other sites.

b From National Council on Radiation Protection and Measurements Report Number 93, "Ionizing Radiation Exposure of the Population of the United States" (1987).

TABLE 4.1.3.

NATURAL AND ENHANCED SOURCES OF RADIATION [a]

Natural	Effective Dose [b] (millirems/year)	Enhanced	Effective Dose [c] (millirems/year)
Cosmic radiation		Natural gas cooking range	0.4
Sea Level	27	Gas and Aerosol (Smoke) Detectors	0.008
Denver, Colorado	50	Building Materials	7
Soil and rocks		Jet Plane Travel	1
Atlantic and Gulf Coastal Plains	16	Airport Inspection Systems	0.002
Eastern Slope of Rocky Mountains	63		
Inhaled (radon)	200		

[a] Data from National Council on Radiation Protection and Measurements Report No. 93, "Ionizing Radiation Exposure of the Population of the United States" (1987).
[b] Average individual exposure to a member of the population of the U.S.
[c] Average individual exposure to the exposed population (i.e., those exposed to the specific sources)

Table 4.1.4.

Estimated Population Dose from Consumption of Fish in Clinch and Tennessee Rivers from Oak Ridge to Chattanooga, Tennessee through 1987

Facility	Reporting Period	Estimated Effective Dose (Person-rem) from: Sport Fishing	Commercial Fishing
ORNL	38 years	652.3	147.4
Y-12	43 years	1.5	0.3
ORGDP	41 years	0.2	0.04
Total		654.0	147.7

Since statistical data were available only for commerical fishing quantities, several assumptions were needed to estimate the amount of sport fishing done on these rivers. The estimate that ten percent of the population (30,300 persons) consumes 7.3 kg (16 lbs.) of fish per year through sport fishing undoubtedly overestimates the exposed population considerably.

Of the commercial fishing catch of 100,000 kg (2,200,000 lbs.) per year, the predominant use of the fish is in fertilizers and cat food. Assuming that one-half of the total catch is consumed by humans is also a conservative estimate.

Because some of the radionuclides present tend to concentrate in bone, an assumption was made that ten percent of both the sport and commercial fishing catch was ground into fish patties. These patties would contain the bones and the flesh of these fish and serve as the exposure pathway for radionuclides concentrating in bones. The ten percent estimate is a conservative quantity.

4.2 Uncertainties In Calculation of Population Dose

Many factors contribute to the uncertainty of the calculations, making the reported radiation doses estimates and not precise and accurate measurements. Some of the assumptions and uncertainties involved are:

- Uncertainty in actual quantities of material released, as previously discussed.

- Imprecision of models describing dispersion and diffusion of materials into the environment from the point of release. Mathematical models can, at best, only approximate the degree of dispersion and are not exact descriptions of natural processes.

- Variability in the ingestion and inhalation patterns of a population. In order to calculate population doses, certain assumptions must be made in regard to the amount of food, water, and air an average individual would consume during the time interval. There must also be assumptions as to how much of the food is grown locally as opposed to outside the 50-mile radius, and to the drinking water source in estimating how much is drawn from streams affected by plant effluents. The variability of these actual values from the assumed average value contributes to imprecision in dose estimates.

4.3 Significance of Calculated Radiation Doses

One method of understanding the significance of the public radiation doses listed in Table 4.1.1 is by comparing them to the background doses over the same period, also shown on Table 4.1.1. The population dose estimated for each facility is less than 1 percent of the estimated background population dose.

Another means of evaluating the significance of the population radiation dose is by using a statistical risk factor. The risk factor would make an estimate of the potential for a specific health effect to be found in an exposed population, based on the estimated radiation dose to the population. Risk factors have been developed, based on health effects studies of high radiation doses, to estimate the probability of such efforts in a population from lower radiation exposures. For the purposes of discussion in this report, the health effects being considered are fatalities due to cancer.

While these factors are frequently used to calculate the risk to a population, there is a large degree of uncertainty as to the correct model for extrapolating health effects. The degree of risk from low radiation doses is too small to be observed directly. Therefore, calculation of health effects from low doses does not give an accurate estimate of risk.

Risk factors developed by research conducted by United Nations organizations are commonly used to relate radiation dose to the number of health effects that could be expected from that dose. DOE/ORO has used a risk factor of 0.000165 fatal cancers and genetic effects occurring per person-rem of population effective dose equivalent. Table 4.3.1 below summarizes the estimated number of health effects that could have occurred as a result of the levels of radioactivity contained in effluents from each facility. These are the estimated number of fatal cancers and genetic effects which might have been expected in the population within a 50 mile radius of each facility spread over the entire time that the facility has been in operation.

For comparison, Table 4.3.1 also shows the number of health effects that could be expected in the same population over the same period of time based on the background level of radiation. This comparison shows that the estimated number of health effects which could have been expected due to radionuclide releases is small when compared to the estimated number of the same health effects which could have been expected due to natural background radiation. Because the normal incidence of these effects is so large, the possible effects occurring due to radionuclide releases is indistinguishable from the background.

Table 4.3.1.
ESTIMATED HEALTH EFFECTS FROM HISTORICAL RADIONUCLIDE RELEASES FROM DOE ORO FACILITIES THROUGH 1987

Facility	Operating Time (years)	Population Within 50 Miles (1980	Number of Health Effects - Radiation [a]	Number of Health Effects - Background Radiation
ORGDP	41	837,000	0.2	1,699
Paducah GDP	35	454,000	0.2	787
Portsmouth GDP	32	600,000	<0.1	950
Y-12	43	863,000	2	1,837
FMPC	36	1,164,000	- [c]	2,074
RMI	25	1,600,000	<0.1	1,980
ORNL	38	836,000	0.6	1,572

a Number of fatal cancers and genetic effects which could be expected to occur in the population as a result of the radiation dose levels shown in Table 4.1.1.

b Number of fatal cancers and genetic effects which could be expected to occur in the population as a result of the background radiation dose levels shown in Table 4.1.1.

c Comparable calculations for FMPC are still being evaluated and have not yet been finalized.

5.0 COMPLIANCE WITH RADIATION STANDARDS GUIDELINES AND REGULATIONS

Several radiation standards and guidelines have been promulgated by federal agencies for protection of the public and environment. The release data in this report can be compared with the regulatory limits.

The Nuclear Regulatory Commission (NRC) standards are widely used in licensing activities involving the use of radioactivity. They are shown to illustrate their similarity to DOE standards. In addition, state regulations are generally consistent with NRC and Environmental Protection Agency (EPA) standards.

5.1 Radiation Dose Standards

Public radiation dose standards have been issued by DOE, EPA, and NRC and are intended to limit exposures through all pathways (e.g., breathing air, food and water consumption, external radiation). One part of the regulations is the concept of limiting radiation exposure to levels which are "as low as reasonably achievable" (known by the acronym, ALARA).

5.1.1 Federal Radiation Council (FRC)

The FRC was formed in 1959 to provide a federal policy on human radiation exposure, providing, among other things, guidance for federal agencies in the formulation of radiation standards. The guidance issued on May 18, 1960, established the following Radiation Protection Guides for normal peacetime operations:

"(1) For the individual in the population, the basic guide for annual whole body dose is 0.5 rem. This guide applies when the individual whole body doses are not known. As an operational technique, where the individual whole body doses are not known, a suitable sample of the exposed population should be developed whose protection guide for annual whole body dose will be 0.17 rem per capita per year...

"(2) Consideration of population genetics impose a per capita dose limitation for the gonads of 5 rems in 30 years. The operational mechanism described above for the annual individual whole body dose of 0.5 rem is likely in the immediate future to assure that the gonadal exposure guide (5 rem in 30 years) is not exceeded."

The EPA is now assigned the policy-making responsibilities of the FRC. An interagency task force has been formed for the purpose of reevaluating the 1960 guidance.

5.1.2 DOE

DOE has established a maximum effective dose equivalent standard for members of the public:

The effective dose equivalent for any member of the public from all routine DOE operations[1] (natural background and medical exposures excluded) shall not exceed the values given below:

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1. Routine DOE operations means normal planned operations and does not include actual or potential accidental or unplanned releases.

	Effective dose equivalent[2] mrem/year	(mSv/year)
Occasional annual exposures[3]	500	(5)
Prolonged period of exposure[3]	100	(1)

No individual organ shall receive an annual dose equivalent in excess of 5 rem/year (50 mSv/year).

This standard is in the process of being revised. The current draft of the revision would retain the limit of 100 mrem (0.1 rem) as the maximum annual effective dose for any member of the public from the routine, continued operation of DOE facilities, but delete the provisions for occasional annual exposures of 500 mrem.

5.1.3 NRC

The NRC radiation exposure standards for members of the public are contained in the Code of Federal Regulations 10 CFR 20.105. "There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as to anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrated that the proposed limits are not likely to cause any individual to receive a dose of the whole body in any period of one calendar year in excess of 0.5 rem."

5.1.4 EPA

EPA has issued environmental standards (40 CFR 190) for the uranium fuel cycle that are applicable to those portions of uranium enrichment operations that directly support the production of electrical power for public use utilizing nuclear

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2. Effective dose equvalent will be expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parenthesis. As used in this standard, effective dose equvalent includes both the effective dose equivalent from external radiation and the committed effective dose equivalent to individual tissues from ingestion and inhalation during the calendar year.

3. For the purpose of these standards, a prolonged exposure will be one that lasts, or is predicted to last, longer than five years.

energy. These standards came into effect December 1, 1979, but are not directly applicable to DOE facilities.

Operations are to be conducted in such a manner as to provide reasonable assurance that the "annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment and to radiation from these operations."

On February 5, 1985, EPA issued a national emission standard for radionuclides under the Clean Air Act. The regulation (40 CFR 61) establishes the standard as: "Emissions of radionuclides to air from DOE facilities shall not exceed those amounts that cause a dose equivalent of 25 mrem/y to the whole body or 75 mrem/y to the critical organ of any member of the public. Doses due to radon-220, radon-222, and their respective decay products are excluded from these limits."

5.2 DOE/ORO Facility Compliance With Standards

Table 4.1.2 presents 1986 effective and organ doses calculated using releases from each DOE/ORO facility. The recent population doses are well below the applicable standards.

6.0 CONCLUSIONS

The information provided in this report leads to the following conclusions:

- While a considerable amount of data on releases of radionuclides has been collected since the DOE/ORO facilities began operation, it is not possible to provide a complete, accurate accounting of radionuclide releases from these facilities. Reasonable estimates may be made for most instances, based on the available information.

- Using the available information on releases, it is possible to calculate doses to individuals and population within 50 miles of each facility.

- These dose estimates could be high or low. The lack of complete data on releases could result in low estimates of dose; whereas the calculational assumptions generally lead to higher than expected doses.

- Estimated historical doses are much lower than the doses received from natural and man-enhanced radioactivity.

APPENDIX A

Yearly Summaries of Estimated Radionuclide Releases from DOE/ORO Facilities

Table 1

Oak Ridge National Laboratory (ORNL)
Estimated Atmospheric Releases of Radionuclides
(Curies)

Year	I-131	H-3	Kr-85	Xe-133	Unidentified Alpha
1961[a]	42.00	b	b	b	b
1962	121.20[c]	b	b	b	b
1963	54.00	b	b	b	b
1964	84.50	b	b	b	b
1965	18.40	b	b	b	b
1966	15.79	b	b	b	b
1967	22.30	b	b	b	b
1968	10.38	b	b	b	b
1969	16.38	b	b	b	b
1970	1.43[d]	b	15,000	75,000	b
1971	3.46	b	15,000	71,000	b
1972	1.70	1,800	15,400	64,900	4.0×10^{-6}
1973	2.18	9,100	14,000	68,600	4.0×10^{-6}
1974	1.97	555	20,000	99,200	4.0×10^{-6}
1975	2.10	534	17,700	87,500	4.0×10^{-6}
1976	1.25	6,019	11,500	54,000	4.0×10^{-6}
1977	1.37	2,524	8,606	42,030	4.0×10^{-6}
1978	1.70	2,500	12,000	59,000	4.0×10^{-6}
1979	0.30	5,109	10,500	51,190	4.8×10^{-6}
1980	0.22	14,800	8,800	42,800	4.9×10^{-6}
1981	0.50	11,300	6,700	32,400	7.8×10^{-8}
1982	0.13	19,000	11,700	57,100	2.7×10^{-6}
1983	0.05	22,200	11,900	57,700	4.3×10^{-6}
1984	0.10	33,400[e]	14,900	72,700	9.6×10^{-8}
1985	0.09	20,180	6,623	32,280	6.0×10^{-7}
1986	<0.035	31,000	10,600	51,000	0
1987	0.02	44,050	4,700	22,700	0
Total[f]	403.52	224,071	215,629	1,041,100	4.5×10^{-5}

[a] Estimates of releases prior to 1961 unavailable due to lack of data.

[b] No data.

[c] First estimate based on in-stack sampling information.

[d] First estimate reflecting the effects of an upgraded charcoal filter system.

[e] First tritium release estimate developed from monitoring data rather than from a calculation based on radionuclide inventory.

[f] All digits carried through to avoid rounding errors. Only first two digits are significant.

Table 2

ORNL

Estimated Discharges of Radionuclides from White Oak Creek to the Clinch River
(Curies)

Year	Gross Beta	^{137}Cs	^{106}Ru	^{89}Sr	^{90}Sr	TRE(-Ce)[a]	^{144}Ce	^{95}Zr	^{95}Nb	^{131}I	^{60}Co	^{3}H	TRU[e]
1944[b]	600												
1945[b]	500												
1946[b]	900												
1947[b]	200												
1948[b]	494												
1949		77	110		150	77	18	180	22	77		NA[c]	0.04[d]
1950		19	23		38	30	NA	15	42	19			0.04
1951		20	18		29	11	NA	5	2	18			0.08
1952		10	15		72	26	23	19	18	20			0.03
1953		6	26		130	110	7	8	4	2			0.08
1954		22	11		140	160	24	14	9	4	NA		0.07
1955		63	31		93	150	85	5	6	7	7		0.25
1956		170	29		100	140	59	12	15	4	46		0.28
1957		89	60		83	110	13	23	7	1	5		0.15
1958		55	42	NA	150	240	30	6	6	8	9		0.08
1959		76	520	0.3	60	94	48	27	30	1	77		0.68
1960		31	1,900	1.9	28	48	27	38	45	5	72		0.19
1961		15	2,000	2.0	22	24	4	20	70	4	31		0.07
1962		6	1,400	1.7	9	11	1	2	8	0.4	14		0.06
1963		4	430	1.0	8	9	2	0.3	0.7	0.4	14		0.17
1964		6	190	0.8	7	13	0.3	0.2	0.1	0.3	15	1,900	0.08
1965		2	69	0.6	3	6	0.1	0.3	0.3	0.2	12	1,200	0.50
1966		2	29	0.9	3	5	0.1	0.7	0.7	0.2	7	3,100	0.16
1967		3	17	0.7	5	9	0.2	0.5	0.5	0.9	3	13,300	1.03
1968		1	5	0.6	3	4	0.03	0.3	0.3	0.3	1	9,700	0.04
1969		1	2	0.3	3	5	0.02	0.2	0.2	0.5	1	12,200	0.20
1970		2	1	0.3	4	5	0.06	0.02	0.02	0.3	1	9,500	0.40
1971		1	0.5	0.2	3	3	0.05	0.01	0.01	0.2	1	8,900	0.05
1972		2	0.5	NA	6	5	0.03	0.01	0.01	0.3	1	10,600	0.07
1973		2	0.7		7	NA	0.02	0.05	0.05	0.5	1	15,000	0.08
1974		1	0.2		6		0.02	0.02	0.02	0.2	0.6	8,600	0.02
1975		0.6	0.3		7		NA	NA	NA	0.3	0.5	11,000	0.02
1976		0.2	0.2		5					0.03	0.9	7,400	0.01
1977		0.2	0.2		3					0.03	0.4	6,200	0.03
1978		0.3	0.2		2					0.04	0.4	6,300	0.03
1979		0.2	0.1		2.4					0.04	0.4	7,700	0.03
1980		0.6	0		1.5					0.04	0.4	4,600	0.04
1981		0.2	0.1		1.5					0.04	0.7	2,900	0.04
1982		1.5	0.2		2.7					0.06	1.0	5,400	0.03
1983		1.2	0.2		2.1					0.004	0.3	5,600	0.05
1984		0.6	0.2		2.6					0.05	0.2	6,400	0.03
1985		0.4	0.007		3.0						0.6	3,700	0.008
1986		1.0	0		1.8						0.54	2,600	0.024
1987		0.6	0								0.12	2,500	0.006
Totals	2,694	693.6	6,931.6	11.3	1,196.6	1,295	341.93	376.61	286.91	175.33	325.06	166,300	5.248

[a]Total rare earths minus cerium.

[b]Individual radionuclide data not available.

[c]"NA" means no analysis performed

[d]Estimated from measurements made during last quarter of 1949.

[e]Transuranics

[f]All digits carried through to avoid rounding errors. Only first two are significant.

Table 3

ORNL

Estimated Quantities of Radionuclides in Solid Waste
(Curies)

Year	TRU-U[a]	Cs-137	H-3	Others[b]	Pu-239	Sr-90	Th-232	Total Uranium	Total[c] Uranium (kg)
1958[d]								0.43	0.045 [e]
1959									
1960									
1961								0.37	8.25
1962								0.32	14.49
1963								0.17	226.9
1964								3.95	57.82
1965								0.18	64.15
1966								0.54	65.31
1967								17.2	57.23
1968								0.86	13.63
1969								3.89	54.40
1970								9.66	12,886
1971								7.09	186.8
1972								0.70	102.0
1973								2.82	47.0
1974								12.02	755.6
1975								13.45	1,596.3
1976 [f]	2.5×10^{3}	1.7×10^{4}	9.0×10^{4}	1.1×10^{4}	1.0×10^{2}	4.5×10^{4}	4.2×10^{-1}	21.76	91.86
1977	7.7	1.2×10^{2}	1.7×10^{1}	3.3×10^{3}	1.0×10^{-2}	1.8×10^{1}	8.0×10^{-3}		
1978	1.0×10^{-01}	2.3×10^{2}	1.0×10^{3}	2.3×10^{2}	4.0×10^{-3}	2.1×10^{2}	1.0	38.97	1,935.5
1979	1.6	3.5×10^{2}	5.8×10^{2}	3.9×10^{3}	3.0×10^{-1}	1.1×10^{2}	3.0×10^{-2}		
1980	6.9	1.4×10^{3}	7.3×10^{1}	5.4×10^{4}	3.0×10^{-2}	2.4×10^{3}	5.0×10^{-1}		
1981	5.5	2.1×10^{2}	2.5×10^{1}	1.1×10^{5}	6.0×10^{-2}	1.2×10^{2}	3.0×10^{-4}	5.81	912.9
1982	1.0×10^{-01}	6.9×10^{2}	2.7×10^{3}	3.4×10^{3}	2.0×10^{-3}	5.1×10^{1}	2.0×10^{-2}	0.083	11.63
1983	2.5×10^{-01}	9.4×10^{2}	2.3×10^{3}	1.8×10^{3}	1.0×10^{-1}	1.7×10^{1}	5.0×10^{-1}	0.13	170.1
1984	4.1×10^{-01}	1.2×10^{3}	3.1×10^{2}	9.0×10^{3}	9.0×10^{-3}	1.6×10^{1}	5.0×10^{-2}	0.88	266.6
1985	5.0×10^{-01}	1.4×10^{1}	5.1×10^{2}	1.0×10^{4}	2.0×10^{-2}	4.0×10^{-1}	6.0×10^{-4}	9.98	385.9
1986	0	5.0×10^{3}	3.6×10^{-1}	8.5×10^{3}	0	9.0×10^{1}	1.0	2.94	18.84
1987	6.3×10^{2}	2.7×10^{4}	4.7×10^{1}	5.3×10^{5}	3.0×10^{1}	1.1×10^{3}	1.3	5.50	4,000
TOTAL	3.1×10^{3}	5.5×10^{4}	9.8×10^{4}	6.8×10^{5}	1.3×10^{2}	5.0×10^{4}	4.9	159.6	23,929

[a]Transuranics other than ^{239}Pu.

[b]Others consist of all beta gamma not specifically listed (includes total rare earths).

[c]The ratio between curies and mass (kg) varies from year to year due to variations in isotopic composition.

[d]Estimates of quantities prior to 1958 not possible due to unavailability of data.

[e]All digits carried through to avoid rounding errors. Only first two are significant.

[f]The 1976 data for radionuclides other than uranium are estimates of the total burials from 1943 through 1976.

[g]Quantities are for the years 1977 through 1980. Detail by year is not available.

Table 3 (Continued)

ORNL

[a]Transuranics other than ^{239}Pu.

[b]Others consist of all beta gamma not specifically listed (includes total rare earths).

[c]The ratio between curies and mass (kg) varies from year to year due to variations in isotopic composition.

[d]Estimates of quantities prior to 1958 not possible due to unavailability of data.

[e]All digits carried through to avoid rounding errors. Only first two are significant.

[f]The 1976 data for radionuclides other than uranium are estimates of the total burials from 1943 through 1976.

[g]Quantities are for the years 1977 through 1980. Detail by year is not available.

Table 4

ORNL

Estimated Quantities of Radionuclides in Liquid in Pits and Trenches
(Curies)

Year	Sr-90	UID Beta[a]	Pu-239	Cs-137	Co-60	TRE[b]	Ru-106	Ru-103
1953	c	390						
1952		953	0.0					
1953		77,165	0.2					
1954		7,224	1.0					
1955		21,390	1.6					
1956		34,990	2.6					
1957		41,920	2.9					
1958		52,790	3.1					
1959		280,000	3.5					
1960		25,026	3.1					
1961	2,913		3.4	26,675	24	1,024	1,638	13
1962	2,963		4.0	35,586	284	2,030	2,680	
1963[d]	10,121		3.9	100,360	1,587		3,207	
1964	22,764	37	4.5	147,970	329		433	
1965	93,107	20	4.1	119,975	2,110		495	
1966	8,345	61	0.8	16,386	229		51	
1967	16	42						
1968	9	32						
1969	6	19						
1970	6	17						
1971	6	12						
1972	15	20						
1973	11	13						
1974	4	8						
1975	3	3						
1976	2	2						
TOTAL[e]	146,916	472,686	38.3	446,932	4,563	2,784	8,504	13

[a]Unidentified gross beta and gamma emitters.
[b]Total rare earths.
[c]Blanks indicate that no data was reported.
[d]Data for 1963 through 1976 are estimated values disposed in sludge. Data for previous dates are for liquid discharges.
[e]All digits carried through to avoid rounding errors. Only first two are significant.

Table 5

ORNL

Estimated Quantities of Radionuclides in Liquid in Shale Fracture Facilities [a, b]
(Curies)

Year	Sr-90	Cs-134	Cs-137	Ru-106	Co-60	Pu-238	Pu-239	Cm[c]	UN-ID Alpha[d]	Mixed F.P.[e]
1964	610		317	36	4					
1965	822		4,920	4	15					
1966	3		19,950	21	8					
1967	10,050		75,500	594	642					
1968	4,800		121,300	500	100		2.2			
1969	8,900		89,000	100	200		0.2			
1970	2,747		44,830	236	72		1.8			
1971[f]										
1972	3,024		93,130	3,819	157		0.8	2.0		
1973										
1974										
1975	5,197	409	72,750	1,313	159			0.1	1.4	
1976										
1977	1,700		34,000	384	2,700	1.4	0.6	2.0		
1978	165		18,480	593	212				0.1	
1979	23	227	13,600		129				0.6	
1980										
1981										
1982	148,000		34,000					1,220.0	438.0	6,800
1983	453,000		43,300					4,510.0	1,290.0	6,500
1984	44,600		7,700					834.0	2,130.0	1,270
TOTALS[g]	683,641	636	672,777	7,600	4,398	1.4	5.6	6,568.0	3,860.0	14,570

[a] The first shale fracture facility was operated from 1964 to 1979. The second shale fracture facility was operated from 1982 to 1984.

[b] Blanks indicate that no data was reported.

[c] Cm-243 and Cm-244

[d] Unidentified alpha emitters consisting of transuranics excluding CM-243 and Cm-244.

[e] Unidentified beta and gamma emitters consisting primarily of mixed fission products.

[f] No injections during, 1971, 1973, 1974, 1976, 1980, and 1981.

[g] All digits carried through to avoid rounding errors. Only first two are significant.

Table 6

Y-12 Plant

Estimated Atmospheric Releases of Radioactivity

Year	Uranium (Ci)	Uranium [a] (kg)
1944	0.04	55
1945	0.07	102
1946	0.07	102
1947	0.04	55
1948	- [b]	-
1949	-	-
1950	-	-
1951	-	-
1952	-	-
1953	0.01	30
1954	0.14	32
1955	0.14	32
1956	0.83	43
1957	0.71	41
1958	0.71	41
1959	1.93	120
1960	0.60	99
1961	0.61	109
1962	0.66	100
1963	0.85	103
1964	0.76	170
1965	0.48	281
1966	0.51	212
1967	0.51	212
1968	0.45	211
1969	0.46	223
1970	0.47	259
1971	0.16	290
1972	0.08	222
1973	0.07	206
1974	0.13	207
1975	0.21	209
1976	0.20	207
1977	0.13	206
1978	0.07	205
1979	0.13	206
1980	0.28	218
1981	0.20	207
1982	0.20	207
1983	0.20	208
1984	0.25	329
1985	0.18	210
1986	0.19	211
1987[c]	0.14	116
TOTAL	13.87	6,296

[a] Ratio of Ci/Kg varies due to different isotopic enrichments.
[b] Data for 1948 to 1952 not available.
c Data for 1987 obtained by actual measurements made during 1987.

Table 7

Y-12 Plant

Estimated Liquid Releases of Radioactivity

Year	Uranium (Ci)	Uranium[a] (kg)	Thorium (Ci)	Thorium (kg)
CY 1944	22.30	33,000		
1945	4.70	7,000		
1946	-	-		
1947	0	0		
1948	0.10	155		
1949	0.30	454		
1950	0.10	144		
1951	0.06	98		
FY 1952	0.002	3		
1953	0.651	953		
1954	0.71	1,118	0.001	11
1955	0.62	1,058	0.003	26
1956	2.26	4,987	0.005	44
1957	5.65	8,448	0.005	49
1958	5.85	10,019	0.008	70
1959	5.15	10,410	0.367	3363
1960	4.55	10,067	0.031	283
1961	2.00	3,064	0.101	927
1962	0.86	1,333	0	0
1963	0.82	1,248	0.002	20
1964	4.42	6,605	0.001	7
1965	5.91	8,852	-[b]	-[b]
1966	5.34	7,985	-	-
1967	10.20	15,217	-	-
1968	11.75	17,525	-	-
1969	2.80	4,189	-	-
1970	5.88	8,775	-	-
1971	2.37	3,546	-	-
1972	2.03	3,042	-	-
1973	0.74	1,119	-	-
1974	1.04	1,561	0.007	65
1975	1.09	1,638	0.021	195
1976	0.91	1,368	0.020	203
1977	0.50	755	0.019	176
1978	0.27	410	0.013	120
1979	0.24	366	0.010	93
1980	0.10	158	0.009	80
1981	0.45	687	0.009	85
1982	0.56	846	0.006	52
1983	0.14	222	0.005	49
1984	1.20	1,799	0.010	90
1985	0.72	783	0.017	153
1986	0.67	652	0.007	64
1987	0.57	715	0.003	27
Total[c]	116.58	182,374	0.680	6,253

[a] Ratio of Ci/Kg varies due to different isotopic enrichment.

[b] Thorium data unavailable for 1965 to 1973.

[c] All digits carried through to avoid rounding error. Only first two are significant

Table 8

Y-12 Plant

Estimated Quantities of Radionuclides Contained in Solid Waste Buried Onsite

Year	Uranium (Ci)	Uranium [a] (kg)	Thorium (Ci)	Neptunium [b] (Ci)	Technetium [b] (Ci)
CY 1944	(2.09) [c]	(33) [c]			
1945	(16.14)	(255)			
1946	(13.23)	(209)			
1947	0.93	(371)	0.0001		
1948	4.46	203	0		
1949	1.22	(156)	0		
1950	0.74	256	0.0001		
1951	0.76	662	0		
FY 1952	3.05	1,466	0.0002		
1953	(1.30)	(624)	0	0.05	0.07
1954	1.53	2,293	0.0005	0.05	0.21
1955	9.04	21,806	0.0004	0.05	0.29
1956	9.92	22,957	0.001	0.05	0.29
1957	420.78	38,253	0.0007	0.05	1.50
1958	(42.32)	(3,763)	0.001	0.05	1.50
1959	116.63	21,931	0.062	0.05	1.50
1960	213.36	206,768	0.017	0.05	1.50
1961	558.89	1,491,895	0.103	0.05	1.50
1962	85.71	199,744	0.342	0.05	1.50
1963	111.81	325,843	0.560	0.05	1.50
1964	243.43	676,988	1.562	0.05	1.50
1965	135.73	375,841	2.076	0.05	1.50
1966	481.43	1,297,260	0.607	0.05	1.50
1967	358.80[d]	979,909	0.645	0.05	1.50
1968	99.90	237,837	0.152	0.05	1.50
1969	141.31	390,073	0.173	0.05	1.50
1970	237.19	645,940	1.050	0.05	1.50
1971	199.87	556,242	0.953	0.05	1.50
1972	370.75	988,349	1.052	0.05	1.50
1973	276.65	761,729	0.822	0.05	1.50
1974	221.87	614,406	0.012	0.05	1.50
1975	196.74	540,689	0.434	0.05	1.50
1976	168.27	457,290	0.388[e]	0.05	1.50
1977	(15.10)	(34,562)	0.194	0.05	3.29
1978	368.65	843,276	0.014	0.05	3.29
1979	51.04	12,324	0.056	0.05	3.29
1980	198.94	529,517	0.056	0.05	3.29
1981	267.33	703,601	0.023	0.05	3.29
1982	439.44	1,169,765	0.023	0.05	3.29
1983	295.11	809,790	7.001	0.05	1.50
1984	342.51	943,387	0.011	0.05	1.50
1985	266.29	730,298	0	0.05	1.50
1986	214.25	458,840	0	0.05	1.50
1987	92.20	263,070	0.196	0.05	1.50
Total [b]	7,097	17,290,523	18.588	1.75	58.10

[a] Ratio of Ci/Kg varies due to different isotopic enrichment.

[b] Discharges of neptunium and technetium were discarded to the S-3 Ponds through 1983 as solution, but were recorded as burial.

[c] All digits carried through to avoid rounding errors. Only first two digits are significant.

[d] Values for 1967 and 1968 include uranium-233 in salvage material resulting from research and development work in fabrication of U-233 parts.

[e] The quantity shown for 1976 does not include 276 kg thorium placed in the Y-12 burial ground at the request of the State of Tennessee as a result of cleanup of Nuclear Chemicals and Metals Corporation at Huntsville, Tennessee.

Table 9

Y-12 Plant

Summary of uranium discards to burial ground[a]

Record of uranium buried	19,311,853 kg[d]
Overestimate of uranium mass due to water weight[b]	- 1,499,155 kg
Total uranium	17,812,698 kg
Uranium transported to X-10 site	- 522,175 kg[c]
Total uranium buried	17,290,523 or rounded to 17,000,000 kg (37,000,000 lbs)

[a]Prior to 1972, liquid material containing uranium that was transferred from operation, offsite, etc., to the S-3 Ponds was included in accountability records and considered as solid uranium in the burial ground.

[b]Refer to Section 2.2.3 of the text.

[c]By U.S. Nuclear Regulatory Commission (NRC)/DOE transfer documents.

[d]All digits carried through to avoid rounding errors. Only first two are significant.

Table 10

Y-12 Plant

Estimated Quantities of Radionuclides Other Than Uranium Disposed Onsite[a]

	Accountability Reportable Amount (Ci)	Disposal Burial Grounds (Ci)
Cesium-137	1.45	-
Cobalt-57/60	320	-
Neptunium-237	0.053	-
Niobium-95	654	-
Plutonium-238/239	0.87	-
Ruthenium-106	0.056	-
Technetium-99	1.77	10.72 [b]
Thorium-228	13.7	-
Zirconium-95	350	-

[a] Certain transuranics and fission products were known to be present in liquid waste streams discarded to the S-3 Ponds from enriched uranium processing since 1953. Quantitative records were maintained for security accountability purposes. The annual amounts which went to the ponds were always below the threshold for reporting under accountability provisions. This table shows these threshold levels.

[b] Consists of 600 g disposed to Y-12 burial ground from the K-25 site.

Table 11

Oak Ridge Gaseous Diffusion Plant (ORGDP)

Estimated Atmospheric Releases of Radioactivity

Year	Uranium (Ci)[a]	Uranium (kg)	Technetium (Ci)	Krypton-85[b] (Ci)
1946	0.01	1		
1947	<0.01	<1		
1948	<0.01	5		
1949	<0.01	45		
1950	0.10	136		
1951	0.02	146		
1952	0.23	345		
1953	1.60	1,307[c]		
1954	0.26	68		
1955	0.26	264		
1956	0.81	225		
1957	0.15	306		
1958	1.80	2,711[c]		
1959	1.10	531		
1960	1.50	977		
1961	3.10	773		
1962	0.24	29		
1963	3.10	1,005[c]		
1964	0.01	7		
1965	0.14	269		
1966	<0.01	1[d]		
1967	<0.01	2		
1968	<0.01	<1		
1969	<0.01	9		
1970	<0.01	8		
1971	0.02	21		
1972	0.03	49		
1973	0.13	144		
1974	0.44	622	0.27	
1975	0.27	371	0.30	
1976	0.05	45	6.79[e]	6.5
1977	0.03	17	0.00[f]	18.5
1978	0.02	19	0.29	41.5
1979	0.04	25	1.34	15.0
1980	0.03	21	0.88	25.0
1981	0.01	5	0.04	
1982	<0.01	2	0.03	
1983	<0.01	2	0.02	
1984	<0.01	1	0.02	
1985	<0.01	1	<0.01	
1986	<0.01	<1	<0.01	
1987	<0.01	<1		
TOTAL	15.64[g]	10,519[g]	10.00[g]	106.5

[a] The ratio of Ci/Kg varies due to different isotopic enrichments.

[b] These emissions are due to an experiment for ORNL. The five years represented were the total time of that experiment.

[c] A major portion of the quantities reported in 1953, 1958, and 1963 resulted from accidental releases due to valve and trap failures in the K-402-1, K-113, and K-1420 feed and processing facilities.

[d] Declining production levels was a factor which reduced emissions in the 1966-70 time period.

[e] This elevated value may be due to increased purging of the cascade associated with the beginning of a large equipment change out program that began in 1976

[f] This year the purge cascade location was changed from the K-25 Building to the K-29 Building. Data for both locations were added; however, the total amount was 2×10^{-6} curies/yr.

[g] This total includes the actual stated value for any quantity which was reported as a less than (<) value.

Table 12

Oak Ridge Gaseous Diffusion Plant

Estimated Liquid Releases of Radioactivity

Year	Uranium (Ci) [a]	Uranium (kg)	Technetium (Ci)	Neptunium (Ci)
1946	<0.01	<1		
1947	--	--		
1948	<0.03	4		
1949	<0.01	3		
1950	--	--		
1951	0.05	80		
1952	<0.01	4		
1953	0.10	26		
1954	0.23	84		
1955	0.05	16		
1956	0.24	90		
1957	0.18	40		
1958	<0.01	<1		
1959	<0.01	5		
1960	<0.01	<1		
1961	0.02	2		
1962	0.01	2		
1963	5.10[b]	1,576[c]		
1964	1.10	1,826[c]		
1965	0.01	33		
1966	<0.01	21		
1967	<0.01	12		
1968	0.26	330		
1969	0.04	3,180[c]		
1970	0.86	88		
1971	0.44	76		
1972	0.40	1,601		
1973	0.44	570		
1974	0.4	508	3.5	
1975	1.70	564	9.0	
1976	0.54	306	24.1[d]	
1977	0.42	2,201[c]	5.8	
1978	0.63	688	4.0	
1979	0.47	537	7.3	0.0015
1980	0.09	803	5.1	0.0014
1981	0.18	601	3.5	0.0021
1982	0.09	114	1.7	0.0019
1983	0.18	233	17.0[e]	0.0004
1984	0.20	240	10.1[e]	
1985	0.07	80	0.03	
1986	0.04	37	0.02	
1987	0.12	116	0.07	
TOTAL	14.77[f]	16,700[f]	91.3	0.0073

-- Indicates data not available.

[a] The ratio of Ci/Kg varies due to different isotopic enrichments.

[b] Enriched material.

[c] A major portion of the quantities reported in 1963, 1964, 1969, 1972, and 1977 have from discharges to a pond from the decontamination facility.

[d] This elevated value may be due to increased decontamination efforts associated with the beginning of a large equipment change out program.

[e] In 1983 and 1984, there was a great amount of decontamination work being done on equipment from an area of the cascade that is highly contaminated with technetium-99.

Also in 1983, there occurred a larger than normal technetium-99 release from the decontamination facility. The cause of this release was never determined.

[f] This total includes the actual stated value for any quantity which was reported as a less than (<) value.

Table 13

ORGDP

Estimated Quantities of Uranium Contained in Solid Waste Buried Onsite

Year	Uranium (Ci)	Uranium (kg) [a]
1958	1.20	1,790
1963	5.50	1,700
1964	1.10	1,990
1965	<0.01	< 10
1966	0.99	1,930
1968	0.37	600
1969	1.80	4,780
1970	0.87	1,210
1971	0.08	130
1972	1.21	3,600 [b]
1973	1.80	2,460
1974	0.55	710
1975	0.59	760
1976	0.95	1,340
1977	2.50	3,180
1978	0.85	1,090
1979	1.20	1,560
1980	1.20	1,860
1981	0.83	1,060
1982	0.43	550
1983	0.18	290
1984	0.04	150
1985	0.02	60
1986	0.07	< 10
1987	<0.01	< 1
TOTAL	24.35	32,821

Note: [a] The ratio of Ci/kg varies due to different isotopic enrichments.

[b] This quantity was reported in "ORGDP Uranium Discharges" K/HS-69, May 1985, Pg. 9, Table 3 as 27,500 kg. It was determined that 23,900 kgs of the 27,500 kgs listed as buried was instead being utilized in check weight cylinders in toll enrichment. The present number of 3.6×10^3 kg is the corrected burial amount for 1972.

Table 14

Paducah Gaseous Diffusion Plant

Estimated Atmospheric Releases of Radioactivity

Year	Uranium [a] (Ci)	Uranium (Kg)	Technetium (Ci)
1952	0.02	30	-
1953	0.25	600	1
1954	2.4	4,800	1
1955	4.2	8,400	2.6
1956	5.2	10,500	2.6
1957	2.4	3,900	4.8
1958	2.2	3,600	6.3
1959	2.1	3,300	5.1
1960	2.0	3,000	4.1
1961	2.4	3,600	4.3
1962	1.3	2,400	4.1
1963	1.3	2,400	4.4
1964	0.6	900	5.3
1965	0.02	0	4.4
1966	0.02	30	0.1
1967	0.02	0	0.1
1968	0.3	600	0.1
1969	1.0	1,800	0.1
1970	0.5	900	3.2
1971	0.7	1,200	3.0
1972	0.7	1,200	0.1
1973	0.8	1,400	3.4
1974	0.6	1,100	6.0
1975	0.70	1,100	0.1
1976	0.90	1,500	0.1
1977	0.40	610	0.1
1978	0.04	96	0.06
1979	0.02	48	0.05
1980	<0.01	22	0.05
1981	0.05	140	0.01
1982	0.13	300	0.01
1983	<0.01	6	0.01
1984	<0.01	3	0.03
1985	<0.01	4	0.02
1986	<0.01	<1	<0.01
1987	<0.01	<1	<0.01
TOTAL [b]	33.26	59,451	66.25

[a] The ratio of curie/kg varies due to different isotopic enrichment.

[b] All digits carred through to avoid rounding errors. Only first two are significant.

Table 15

Paducah Gaseous Diffusion Plant Estimated Liquid Releases of Radioactivity

Year	Uranium (Ci)	Uranium (kg)	Technetium (Ci)	Neptunium (Ci)	Plutonium (Ci)
1952	0.02	30	-	-	
1953	0.08	120	46	0.040	0.370
1954	0.02	30	440	0.110	1.200
1955	0.08	120	440	0.280	1.500
1956	0.02	30	440	0.280	1.500
1957	0.5	900	310	0.280	1.500
1958	0.5	900	310	0.210	1.300
1959	0.5	900	310	0.070	0.680
1960	1.1	1,800	77	0.070	0.680
1961	0.35	600	77	0.070	0.680
1962	1.0	1,800	77	0.050	0.680
1963	0.5	900	61	0.110	0.800
1964	0.5	900	76	0.070	0.430
1965	0.5	900	76	0.050	0.130
1966	0.5	900	76	0.050	0.130
1967	0.5	900	77	0.110	0.130
1968	0.5	900	77	0.140	0.180
1969	0.6	1,200	77	0.050	0.180
1970	0.6	1,200	31	0	0.130
1971	0.6	1,200	15	0	0.060
1972	1.6	3,200	8	0	0
1973	0.5	1,100	8	0	0
1974	0.06	100	7	0	0
1975	0.1	180	6.4	0	0
1976	0.2	440	16	0	0
1977	1.3	2,400	10	0	0
1978	1.0	1,900	9.2	0.010	0.020
1979	0.5	910	7.5	0.020	0
1980	0.3	590	8.0	0	0
1981	0.2	300	2.8	0	0
1982	0.1	170	0.7	0	0
1983	0.12	220	0.7	0	0
1984	0.06	148	0.7	0	0
1985	0.04	75	0.4	0	0
1986	0.05	66	<0.1	0	0
1987	0.01	21	0.7	0	0
TOTAL [b]	5.11	28,050	3,178.7	2.070	12.28

[a] Ration of Ci/kg varies due to different isotopic enrichments.

[b] All digits carried through to avoid rounding errors. Only first two are significant.

Table 16

Paducah Gaseous Diffusion Plant

Estimated Quantities of Radioactive Material Contained in Solid Waste Buried Onsite

Year	Uranium (Ci)	Uranium (kg) [a]	Technetium (Ci)	Neptunium (Ci)	Plutonium (Ci)
1953			8	0.040	0.060
1954			34	0.070	0.310
1955 [b]	1.2	2.90	34	0.070	0.310
1956			50	0.070	0.310
1957			50	0.070	0.310
1958			50	0.070	0.310
1959			50	0.040	0.130
1960			17	0.040	0.130
1961			17	0.040	0.130
1962			17	0.050	0.130
1963			17	0.070	0.130
1964			17	0.070	0.060
1965 [b]	700	1700	14	0.040	0.020
1966			8	0.040	0.020
1967			8	0.040	0.020
1968			9	0.040	0.030
1969			9	0.050	0.030
1970			8	0.050	0.020
1971			1.7	0.050	0
1972	65	160	1.7	0.050	0.010
1973	84	210	1.7	0.050	0
1974	32	80	1.7	0.050	0.005
1975	130	310	1.7	0.050	0.005
1976	39	96	1.7	0.050	0.005
1977	140	340	2	0.050	0
1978	62	150	2	0.050	0
1979	60	150	2	0.050	0
1980	3	9.7	2	0.050	0
1981	1	3.4	2	0.070	0
1982	4	11	21	0.100	0
1983	3	7.2	2	0.080	0.010
1984	5		3	0.089	0.009
1985	3	6.0	0.1	0.080	0.008
1986	4		0.04	0.012	0.001
1987	0	0	0	0	0
TOTAL [c]	1,327	3,320.0	463.0	1.891	2.513

[a] Ration of Ci/kg varies due to different isotopic enrichment.

[b] Individual year data unavailable for 1955-1971. The values presented are cumulative for the identified periods of time.

[c] All digits carried through to avoid rounding errors. Only first two are significant.

Table 17

Portsmouth Gaseous Diffusion Plant

Estimated Airborne Releases of Radionuclides

Year	Uranium (Ci)	Uranium [a] (kg)	Uranium Daughters (Ci)	Technetium (Ci)
1955	0.547	1611.1		
1956	0.236	700.4		
1957	0.022	49.1		
1958	0.182	52.8		
1959	0.452	737.6		
1960	0.173	299.3		
1961	0.347	567.1		
1962	0.113	167.9		
1963	0.016	0.9		
1964	0.018	0.9		
1965	0.042	15.8		
1966	0.033	3.5		
1967	0.020	3.8	0.0007	
1968	0.018	7.6	0.0003	
1969	0.199	461.5	0.0038	
1970	0.032	15.7	0.0019	
1971	0.046	38.5	0.0	
1972	0.007	8.3	0.0	
1973	0.051	7.7	0.0011	
1974	0.023	14.0	0.0002	
1975	0.162	33.6	0.0	
1976	0.107	16.5	1.E-06	3.E-5
1977	0.300	94.6	0.0917	4.500
1978	3.032	5426.2	0.0856	0.823
1979	0.089	10.3	0.1248	0.170
1980	0.225	8.0	0.0807	0.210
1981	0.091	6.2	0.1192	0.108
1982	0.322	23.9	0.0862	11.1
1983	0.973	61.8	0.0249	0.561
1984	0.015	3.2	0.0246	0.127
1985	0.028	6.0	0.0154	0.123
1986	0.042	42.9	0.0282	0.122
1987	0.045	1.8	0.0022	0.169
TOTALS[b]	8.008	10,510.1	0.6915	18.013

[a] Ratio of Ci/kg varies due to different isotopic enrichment.

[b] All digits carried through to avoid rounding errors. Only first two are significant.

Table 18

Portsmouth Gaseous Difussion Plant
Estimated Liquid Radionuclide Releases

Year	Uranium (Ci)	Uranium [a] (kg)	Uranium Daughters (Ci)	Technetium (Ci)
1955	0.021	9.5	0.014	
1956	0.139	86.2	0.121	
1957	0.144	148.1	0.682	
1958	0.349	350.2	1.223	
1959	0.574	351.4	1.423	
1960	0.154	94.5	0.232	
1961	0.056	55.2	0.204	
1962	0.166	103.1	0.667	
1963	0.101	92.1	0.404	
1964	0.064	64.7	0.098	
1965	0.705	111.8	0.897	
1966	0.104	54.1	0.109	
1967	0.076	76.1	0.426	
1968	0.209	583.7	0.605	
1969	0.134	82.4	0.562	
1970	0.206	119.1	0.877	
1971	0.245	164.0	0.382	
1972	0.034	73.2	0.376	
1973	0.159	96.9	1.212	
1974	0.303	137.9	4.308	
1975	1.099	350.7	3.065	77.1
1976	0.967	425.5	3.703	15.4
1977	1.803	658.1	2.839	31.0
1978	2.180	1,802.3	2.978	17.7
1979	0.672	360.8	0.488	2.8
1980	0.713	544.3	0.561	7.7
1981	0.370	173.6	0.345	24.7
1982	0.588	150.1	0.253	11.9
1983	0.442	130.7	0.229	3.0
1984	0.442	80.9	0.370	9.3
1985	0.193	62.6	0.352	8.5
1986	0.233	74.6	0.047	2.5
1987	0.483	156.0	0.247	1.2
TOTALS[b]	14.130	7,824.4	30.299	212.8

[a] Ratio of Ci/kg varies to to different isotopic enrichments.

[b] All digits carried through to avoid rounding errors. Only first two are significant.

TABLE 19

Portsmouth Gaseous Diffusion Plant

Estimated Quantity of Radioactive Material Contained in Solid Waste Buried Onsite

Year [a]	Uranium (Ci)	Uranium [b] (kg)
1955	0.0	0.0
1956	0.0	0.0
1957	0.0	0.0
1958	0.2617	771.0
1959	0.0	0.0
1960	0.0225	46.7
1961	0.0073	9.7
1962	0.1068	178.2
1963	0.1089	251.4
1964	0.0401	96.9
1965	0.1832	125.7
1966	0.0706	102.4
1967	0.0473	118.4
1968	0.0109	20.0
1969	0.0190	3.6
1970	0.0293	57.9
1971	0.1231	265.3
1972	0.1125	136.8
1973	0.0097	2.2
1974	0.0512	152.5
1975	0.0477	42.7
1976	0.1460	137.4
1976[c]	0.0	0.0
1977	0.0	0.0
1978	0.5566	1158.4
1979	0.4143	743.0
1980	0.0698	171.6
1981	0.0599	36.2
1982	0.0	0.0
1983	0.1985	242.5
1984[d]	0.7105	249.3
1985	0.0543	19.5
1986	0.0	0.0
1987	0.0023	0.4
Total [e]	3.463	5,139.9

[a] Fiscal years instead of calendar years.

[b] Ratio of Ci/kg varies due to different isotopic enrichments.

[c] Transition from July-to-June fiscal year to October-to-September fiscal year.

[d] Includes large adjustment for material spread on oil biodegradation plot between 1974 and 1983.

[e] All digits carried through to avoid rounding errors. Only first two are significant.

TABLE 20
RMI COMPANY
EXTRUSION PLANT

ESTIMATED URANIUM RELEASES [a] TO ENVIRONMENT - LIQUID AND AIRBORNE

YEAR	AIRBORNE RELEASE (Kg.)	LIQUID RELEASE (Kg.)	TOTAL RELEASE (Kg.)
1962	13.9	79.9	93.8
1963	70.7	59.1	129.8
1964	69.1	159.2	228.3
1965	14.3	46.8	61.1
1966	44.8	6.0	50.8
1967	85.7	12.5	98.2
1968	55.2	22.3	77.5
1969	36.9	63.0	99.9
1970	55.3	92.0	147.3
1971	26.4	193.9	220.3
1972	27.4	77.7	105.1
1973	40.6	167.3	207.9
1974	35.2	128.3	163.5
1975	22.2	117.2	139.4
1976	39.6	79.9	119.5
1977	50.8	135.2	186.0
1978	30.8	201.3	232.1
1979	25.0	227.0	252.0
1980	31.0	168.8	199.8
1981	13.8	199.6	213.4
1982	26.6	208.0	234.6
1983	23.0	274.1	297.1
1984	12.7	262.5	275.2
1985	13.1	126.7	139.8
1986	21.4	119.8	141.2
1987	0.7	42.9	43.6
Total Release	886.2	3,271.0	4,156.5

[a] All digits carried through to avoid rounding errors. Only first two are significant.

Table 21

FEED MATERIALS PRODUCTION CENTER (FMPC)

Estimated Atmospheric Releases [a] of Radionuclides [b]

Year	Urium (kg)	Urium (Ci)	(Micocuries) Th-232	Ra-228	Th-228	Th-230	Ra-226
1951	123.0	0.008					
1952	499.0	0.33					
1953	2,077.8	1.87	0.16	0.90	22	5.5×10^3	4.2×10^3
1954	15,119.2	9.98	1.9	10.8	265	6.6×10^4	5.0×10^4
1955	32,976.2	21.76	1.9	10.8	265	6.6×10^4	5.0×10^4
1956	13,595.4	8.99	128.0	8.2	570	2.7×10^4	228
1957	8,045.2	5.31	549.0	35.3	2,450	1.1×10^5	980
1958	5,513.4	3.64	123.0	7.9	550	2.6×10^4	220
1959	5,127.4	3.38	67.0	4.3	298	1.4×10^4	119
1960	4,872.8	3.22	119.0	7.7	532	2.5×10^4	213
1961	3,516.4	2.32	2.0	2.4	168	7.8×10^3	67
1962	4,568.0	3.02	2.0	2.4	168	7.8×10^3	67
1963	6,036.4	3.98	0	0	0	0	0
1964	5,235.4	3.47	0	0	0	0	0
1965	7,044.8	4.65	0.38	0.46	32	1.5×10^3	13
1966	3,045.5	2.01	1.6	1.9	135	6.3×10^3	54
1967	2,924.7	1.93	0.80	0.96	67	3.1×10^3	27
1968	4,655.2	3.07	0.28	0.34	24	1.1×10^3	9.5
1969	3,898.1	2.57	0.25	0.30	20	9.6×10^2	8.2
1970	1,487.8	0.98	1.4	1.7	117	5.5×10^3	47
1971	772.0	0.51	0.78	0.94	65	3.0×10^3	26
1972	614.4	0.41	12	14.8	1,025	4.8×10^4	410
1973	496.0	0.33	5.6	6.7	465	2.2×10^4	186
1974	234.8	0.16	0.45	0.54	38	1.8×10^3	15
1975	318.0	0.21	0.28	0.33	23	1.1×10^3	9.2
1976	169.1	0.11	0.28	0.33	23	1.1×10^3	9.2
1977	191.9	0.13	0.19	0.22	16	7.2×10^2	6.2
1978	222.0	0.15					
1979	154.7	0.10					
1980	266.5	0.18					
1981	587.2	0.39					
1982	279.8	0.18					
1983	181.2	0.12					
1984	377.5	0.25					
1985	75.0	0.05					
1986	29.0	0.02					
1987	35.4	0.02					
TOTAL	135,387.2	89.35	1,018.25	120.00	7,338	5.02×10^5	1.07×10^5

[a] All digits carried through to avoid rounding errors. Only first two are significant.

[b] Data through 1984 were presented in a different format in "History of FMPC Radionuclide Discharges (FMPC 2082)" in May 1987.

Table 22

Feed Materials Production Center

Estimated Discharges of Radionuclides in Liquid Effluents[a]

Year	Thorium (kg)	(Curies) Sr-90	Tc-99	Ru-106	Cs-137	Ra-226	Ra-228	Np-237	Pu-238	Pu-239/240
1957	- [b]	-	-	-	0.5	-	-	-	-	-
1958	-	-	-	-	-	0.5	-	-	-	-
1959	-	-	-	-	-	0.5	-	-	-	-
1960	-	-	-	-	-	0.5	-	-	-	-
1961	-	-	-	-	-	0.5	-	-	-	-
1962	-	-	-	-	-	0.5	-	-	-	-
1963	-	-	-	-	-	0.5	-	-	-	-
1964	-	-	-	-	-	0.5	-	-	-	-
1965	-	-	-	-	-	0.5	-	-	-	-
1966	-	-	-	-	-	0.5	-	-	-	-
1967	27.0	-	-	-	-	0.5	-	-	-	-
1968	128.0	-	-	-	-	0.5	1.1	-	-	-
1969	63.0	-	5.0	-	-	0.2	1.6	-	-	-
1970	29.0	-	2.0	-	-	0.2	0.5	-	-	-
1971	30.0	-	20.0	-	-	0.1	4.0×10^{-2}	-	-	-
1972	18.0	-	7.2	-	-	5.5×10^{-2}	1.5×10^{-2}	-	-	-
1973	9.0	-	6.2	-	-	2.4×10^{-2}	6.0×10^{-3}	-	-	-
1974	18.0	-	[c]	-	-	8.0×10^{-3}	6.0×10^{-3}	-	-	-
1975	6.4	-	[c]	-	-	1.3×10^{-2}	1.6×10^{-2}	-	-	-
1976	5.5	-	9.0	3.0×10^{-3}	2.0×10^{-2}	7.0×10^{-3}	8.0×10^{-3}	2.0×10^{-7}	4.0×10^{-7}	2.0×10^{-7}
1977	5.1	7.2×10^{-2}	0.1	8.2×10^{-3}	8.4×10^{-2}	7.2×10^{-3}	6.9×10^{-2}	$<5.0 \times 10^{-4}$	$<2.5 \times 10^{-5}$	$<5.6 \times 10^{-5}$
1978	5.5	6.9×10^{-3}	0.1	1.1×10^{-2}	1.5×10^{-2}	3.2×10^{-3}	4.3×10^{-3}	3.2×10^{-5}	$<2.4 \times 10^{-5}$	$<3.3 \times 10^{-5}$
1979	7.0	3.2×10^{-3}	3.4	1.8×10^{-3}	6.1×10^{-3}	7.8×10^{-4}	9.3×10^{-3}	1.9×10^{-4}	1.0×10^{-5}	2.9×10^{-5}
1980	2.1	2.6×10^{-3}	0.9	8.9×10^{-4}	1.0×10^{-2}	3.5×10^{-4}	3.3×10^{-3}	$<1.0 \times 10^{-4}$	3.8×10^{-6}	1.4×10^{-3}
1981	3.0	2.5×10^{-3}	4.2	6.7×10^{-4}	2.3×10^{-3}	1.1×10^{-2}	7.0×10^{-3}	$<1.4 \times 10^{-4}$	5.1×10^{-6}	2.9×10^{-5}
1982	3.8	3.2×10^{-3}	9.8	3.4×10^{-5}	2.8×10^{-3}	2.9×10^{-3}	1.2×10^{-2}	3.0×10^{-4}	4.9×10^{-6}	1.5×10^{-5}
1983	2.1	6.0×10^{-3}	21.0	3.0×10^{-4}	5.6×10^{-3}	1.0×10^{-3}	6.0×10^{-3}	$<2.0 \times 10^{-4}$	5.0×10^{-6}	8.0×10^{-5}
1984	4.5	1.2×10^{-2}	19.0	5.0×10^{-4}	1.7×10^{-2}	$<1.7 \times 10^{-2}$	$<1.4 \times 10^{-2}$	2.0×10^{-4}	3.0×10^{-5}	5.0×10^{-5}
1985	< 10	5.2×10^{-3}	8.3	4.4×10^{-4}	9.2×10^{-3}	$<3.8 \times 10^{-3}$	$<3.6 \times 10^{-3}$	$<1.7 \times 10^{-4}$	7.5×10^{-6}	1.5×10^{-5}
1986	5.0	9.0×10^{-4}	1.5	$<1.0 \times 10^{-2}$	$<1.0 \times 10^{-3}$	$<4.6 \times 10^{-3}$	$<4.1 \times 10^{-3}$	$<1.0 \times 10^{-5}$	$<1.0 \times 10^{-5}$	$<1.0 \times 10^{-5}$
1987	< 3.3	2.2×10^{-3}	2.7	$<3.3 \times 10^{-2}$	$<7.5 \times 10^{-3}$	$<4.0 \times 10^{-3}$	$<3.9 \times 10^{-3}$	$<2.4 \times 10^{-4}$	$<5.6 \times 10^{-5}$	$<5.6 \times 10^{-5}$
TOTAL	<380.3	0.12	120.4	$<6.9 \times 10^{-2}$	6.8×10^{-1}	<6.16	<3.43	$<2.1 \times 10^{-3}$	$<1.8 \times 10^{-4}$	$<1.8 \times 10^{-3}$

[a] Data through 1984 were presented in a different format in "History of FMPC Radionuclide Discharges (FMPC-2082)" in May 1987.

[b] A dash indicates data were not collected.

[c] Data were collected but could not be retrieved.

Table 23

Feed Materials Production Center

Estimated Quantity [a] of Uranium in Wastewater Discharged to the Great Miami River[b]

Fiscal Year [c]	Uranium (kg)	Uranium (Ci)[d]
1952	11	0.01
1953	106	0.07
1954	347	0.23
1955	657	0.43
1956	1,485	0.98
1957	2,595	1.71
1958	3,712	2.45
1959	6,488	4.28
1960	4,445	2.93
1961	5,486	3.62
1962	3,543	2.34
1963	4,566	3.01
1964	10,504	6.93
1965	3,730	2.42
1966	3,740	2.47
1967	2,305	1.52
1968	1,855	1.22
1969	2,290	1.51
1970	1,914	1.26
1971	1,637	1.08
1972	1,140	0.75
1973	1,126	0.74
1974	1,066	0.71
1975	1,852	1.22
1976	875	0.58
1976A	179	0.12
1977	965	0.64
1978	880	0.58
1979	1,175	0.78
1980	685	0.45
1981	576	0.38
1982	755	0.50
1983	564	0.37
1984	1,054	0.70
1985	626	0.41
1986	473	0.31
1987	794	0.52
TOTAL	76,201	49.96

[a] All digits carried through to avoid rounding errors. Only first two are significant.

[b] Data through 1984 were presented in a different format in "History of FMPC Radionuclide Discharges (FMPC-2082)" in May 1987.

[c] 1952 through 1976, the fiscal year is from July 1 through June 31 of the next year. 1976A is a three month transition period, July 1, 1976 through September 30, 1976. From 1977 to the present time, the fiscal year is from October 1 through September 30 of the next year.

[d] Based on the mass equivalent for natural uranium (U-238 = 99.3%, U-235 = 0.7%, U-234 = 0.005%)

APPENDIX B

Definitions

APPENDIX B

DEFINITIONS

Activity: The number of nuclear transformations occurring per unit time. (See Curie.)

Alpha Particle: A charged particle emitted from the nucleus of an atom having a mass and charge equal in magnitude of helium nucleus; i.e., two protons and two neutrons.

Atom: Smallest particle of an element which is capable of entering into a chemical reaction.

Atomic Mass: The mass of an atom usually expressed in terms of "atomic mass units." The "atomic mass unit: is one-twelfth the mass of one atom of carbon-12; equivalent to 1.6604×10^{-24} gm. (Symbol: u).

Atomic Number: The number of protons in the nucleus of a neutral atom of a nuclide. (Symbol: Z.)

Background Radiation: (See Radiation.)

Beta Particle: Charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of the electron.

Compound: A distinct substance formed by a union of two or more elements.

Contamination, Radioactive: Deposition of radioactive material in any place where it is not desired, particularly where its presence may be harmful.

Cosmic Rays: High-energy particulate and electronmagnetic radiations which originate outside the earth's atmosphere.

Curie: The special unit of activity. One curie equals 37 billion nuclear disintegrations per second. (Abbreviated Ci.) Several fractions of the curie are in the common usage.

> Microcurie: One-millionth of a curie (3.7×10^4 disintegrations per second). Abbreviated uCi.
>
> Millicurie: One-thousandth of a curie (3.7×10^7 disintegrations per second). Abbreviated mCi.
>
> Picocurie: One-millionth of a microcurie (3.7×10^{-2} disintegrations per second or 2.22 disintegrations per minute). Abbreviated pCi.

Daughter: Synonym for decay product.

Decay Product: A nuclide resulting from the radioactive decay of a radionuclide. A decay product may be either radioactive or stable.

Decay, Radioactive: The decrease in the amount of any radioactive material with the passage of time due to spontaneous emission of charged particles (alpha or beta particles) and/or gamma radiation.

Depletion: Reduction of the concentration of specified isotopes in a material.

Depleted Uranium: Uranium having a percentage of uranium-235 smaller than the 0.7 percent found in natural uranium.

Dose: A quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. If unqualified, it refers to absorbed dose.

> Absorbed Dose: The energy absorbed from ionizing radiation in a gram of any material. The unit of absorbed dose is the rad. One rad equals 100 ergs per gram. (See Rad.)

Dose Equivalent: A term used to express the amount of radiation on a common scale when modifying factors have been considered. It is defined as the absorbed dose in rads multiplied by certain modifying factors. (The unit of dose equivalent is the rem.)

Dose Rate: The radiation dose delivered per unit time, measured, for example, in millirem per hour.

Element: A category of atoms all of the same atomic number.

Enriched Uranium: Uranium in which the abundance of the uranium-235 isotope is increased above the 0.7 percent found in natural uranium.

Exposure: A measure of the ionization produced in air by x or gamma radiation. The special unit of exposure is the roentgen.

Fission Products: Radioactive isotopes produced when uranium atoms fission (split apart).

Fuel: Fissionable material of reasonably long life, used in a nuclear reactor.

Gamma Ray: High energy, short wavelength electromagnetic radiation emitted from the nucleus.

Gaseous Diffusion: A method of isotopic separation based on the fact that gas atoms or molecules with different masses will diffuse through a porous barrier (or membrane) at different rates. This method is used to separate uranium-235 from uranium-238.

Half-life, Radioactive: Time required for a radioactive substance to lose 50 percent of its activity by radioactive decay. Each radionuclide has a unique half-life.

Ion: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

Ionization: The process by which a atom or molecule acquires a positive or negative charge, through adding more electrons to, or removing electrons from atoms or molecules.

Irradiation: Exposure to radiation.

Isotopes: Nuclides having the same number of protons (the same atomic number), but differing in the number of neutrons (the mass number). Almost identical chemical properties exist between isotopes of a particular element.

Mass Numbers: The number of protons and neutrons in the nucleus of an atom. Also known as the atomic weight of an atom. (Symbol: A)

Millironentgen (mR): One one-thousandth of a roentgen. (See Roentgen.)

Molecule: A group of atoms held together by chemical force. Smallest quantity of a compound which can exist by itself and retain all properties of the original substance.

Natural Uranium: Uranium as found in nature, having 0.7 percent uranium-235, 99.3 percent uranium-238, and 0.005 percent uranium-234.

Nucleus: That part of an atom in which the total positive electric charge and most of the mass is concentrated.

Nuclide: An atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N), and energy content. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time.

Organ: Group of tissues which together perform one or more definite functions in a living body.

Parent: A radionuclide which, upon disintegration, yields a specified nuclide (the daughter).

Rad: The unit of absorbed dose equal to 0.01 J/kg in any medium. (See Absorbed Dose.) (Written: rad.)

Radiation: (1) The emission and propagation of energy through space or through a material medium in the form of waves; for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves. (2) The energy propagated through space or through a material medium as waves; for example, energy in the form of electromagnetic waves or of elastic waves. The term radiation or radiant energy, when unqualified, usually refers to electromagnetic radiation. Such radiation commonly is classified, according to frequency, as infrared, visible (light), ultra-violet, x ray, and gamma ray. (3) By extension, corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown type, as cosmic radiation.

Background Radiation: Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

External Radiation: Radiation from a source outside the body - the radiation must penetrate the skin.

Internal Radiation: Radiation from a source within the body (as a result of deposition of radionuclides in body tissues.)

Ionizing Radiation: Any electromagnetic or particulate radiation capable of producing ions.

Radioactivity: Spontaneous emission of radiation.

Radionuclide: A radioactive atom.

Radioisotope: Isotope of an element which spontaneously emits radiation.

Rem: A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

Respiratory System: The group of organs concerned with the exchange of oxygen and carbon dioxide in organisms. In higher animals this consists successively of the air passages through the mouth, nose, and throat, the trachea, the bronchi, the bronchioles, and the alveoli of the lungs.

Roentgen (R): The special unit of exposure. One roentgen equals 2.58×10^{-4} coulomb per kilogram of air. (See Exposure.)

Transuranics: Elements having a higher atomic mass number than uranium (mass number 92). Transuranics include plutonium, neptunium, and americium.

X Rays: Penetrating electromagnetic radiations whose wave lengths are shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extranuclear part of the atom as x rays.

APPENDIX C

Summary of Significant Data on Isotopes Listed in Report

APPENDIX C

Summary of Significant Data on Isotopes Listed in Report

Isotope	Symbol	Half-life	Organs Principally Affected	Specific[a] Activity (Ci/g)	Type of Radiation
hydrogen-3	H-3	12.3 years	whole body	9,640	beta
cobalt-57	Co-57	270 days	lung (airborne) gastrointestional tract	8,480	gamma
cobalt-60	Co-60	5.25 years	lung (airborne) gastrointestional tract	1,130	beta, gamma
krypton-85	Kr-85	10.7 years	whole body (external exposure)	393	beta, gamma
strontium-89	Sr-89	50.8 days	bone gastrointentional tract lung (airborne)	28,200	beta, gamma
strontium-90	Sr-90	28.9 years	bone gastrointestional tract lung (airborne)	141	beta
zirconium-95	Zr-95	65.5 days	gastrointestional tract lung (airborne)	21,000	beta, gamma
niobium-95	Nb-95	35.1 days	gastrointestional tract lung (airborne)	39,200	beta, gamma
technetium-99	Tc-99	213,000 years	gastrointestional tract lung (airborne)	0.017	beta
ruthenium-103	Ru-103	39.8 days	gastrointestional tract lung (airborne)	31,900	beta, gamma
ruthenium-106	Ru-106	368 days	gastrointestional tract lung (airborne)	3,360	beta, gamma
iodine-131	I-131	8.1 days	thyroid gastrointestional tract lung (airborne)	124,000	beta, gamma
xenon-133	Xe-133	5.25 days	whole body (external exposure)	187,000	beta, gamma

Isotope	Symbol	Half-life	Organs Principally Affected	Specific[a] Activity (Ci/g)	Type of Radiation
cesium-134	Ce-134	2.1 years	gastrointestional tract lung (airborne) liver spleen muscle	1,300	beta, gamma
cesium-137	Cs-137	30.2 years	gastrointestional tract lung (airborne) liver spleen muscle	87	beta, gamma
cerium-144	CE-144	284 days	gastrointestional tract bone liver lung (airborne)	3,190	beta, gamma
radium-226	Ra-226	1,602 years	bone gastrointestional tract lung (airborne)	0.99	alpha, gamma
radium-228	Ra-228	5.75 years	bone gastrointestional tract lung (airborne)	273	beta, gamma
thorium-232	Th-232	1.41×10^{10} years	bone gastrointestional tract lung (airborne)	1.09×10^{-7}	alpha, gamma
uranium-233	U-233	160,000 years	bone kidney gastrointestional tract lung (airborne)	0.01	alpha, gamma
uranium-234	U-234	250,000 years	bone kidney gastrointestinal tract lung (airborne)	0.006	alpha, gamma
uranium-235	U-235	7.1×10^{8} years	bone kidney gastrointestional tract lung (airborne)	2.14×10^{-6}	alpha, gamma