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**TRANSURANIC CONTAMINATED
WASTE FORM CHARACTERIZATION
AND DATA BASE**

VOLUME 3

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APPENDIX G
TECHNOLOGIES FOR RECOVERY OF TRANSURANICS⁵¹

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1.0 INTRODUCTION

Recovery of transuranium elements from non-high-level waste and scrap materials has been routinely practiced at many DOE laboratories and commercial mixed-oxide fuel fabrication facilities. Plutonium is the major transuranium element recovered, and most of the following discussion is devoted to techniques used for plutonium recovery. Americium-241, a decay product of plutonium-241, can be recovered as a by-product from plutonium-recovery operations by solvent-extraction and ion-exchange methods comparable to those used for plutonium purification. Other transuranium elements are seldom present in non-high-level scrap or waste in quantities warranting recovery, although technologies are available and have been used in DOE fuel-reprocessing facilities for the recovery of neptunium, americium, and curium from high-level wastes.

The techniques in use provide recovery of about 90 to 99 percent of the plutonium, which is usually present in solid wastes as the refractory oxide, PuO_2 . The treated wastes are seldom decontaminated to levels of plutonium (or TRU) that would permit unrestricted release, although this objective may be approached for surface-contaminated metals, glassware, and equipment of simple shape.

2.0 TRU RECOVERY

An outline of typical plutonium recovery techniques used in DOE laboratories is shown in Figure G-1. The most rigorous recovery techniques are those required for plutonium impregnated materials, such as rags and paper wipes used for surface cleaning. These are typically burned in plutonium scrap recovery incinerators, and the ashes are ground and leached in a mixture of hot nitric and hydrofluoric acids ($\text{HNO}_3\text{-HF}$). Undissolved plutonium in the ashes may be recovered by fusion with a suitable salt, such as a 10 to 1 potassium pyrosulfate-sodium fluoride mixture, to produce a nitric acid soluble melt.

Combustion followed by acid leaching can also be used to recover plutonium from shredded rubber gloves, plastics, and the wooden-framed HEPA filters used to remove plutonium aerosols from glovebox ventilation exhausts. More often, however, these wastes are leached (pickled) in heated nitric acid or $\text{HNO}_3\text{-HF}$ mixtures for plutonium recovery.

In addition to conventional heated pickling vats, DOE laboratories have used ultrasonic energy, hot water ball milling, electropolishing, and steam and water jet sprays to physically remove the plutonium from surface contaminated metals, glassware, plastics, and rubber gloves. The dislodged plutonium oxide is filtered or centrifuged from the cleaning solution and dissolved by methods similar to those described above.

Plutonium-contaminated oils and solvents can be treated by contacting them with a suitable aqueous solution to transfer the plutonium to the aqueous phase. The oil is decanted or filtered to separate it from the aqueous phase and plutonium residue. Alternatively, the oil may be burned in the combustible waste incinerator.

Once the plutonium is in solution, it can be recovered and purified for recycle by well-established solvent extraction and ion exchange techniques. Aluminum nitrate is added to the feed to complex the fluoride to decrease its interference with plutonium recovery. Tri-n-butyl phosphate (TBP) in an inert diluent is the

FIGURE G-1
 TYPICAL PLUTONIUM RECOVERY OPERATIONS
 (HANFORD ENGINEERING DEVELOPMENT LABORATORY)

most commonly used solvent for solvent extraction processes, and strong base anion exchange resins are used for the ion exchange processes.

The Plutonium Reclamation Facility (PRF) at Hanford incorporates many of the previously described plutonium recovery operations. Much of the plutonium recovery equipment is located in a canyon-type process cell. Dissolution and solvent extraction equipment is mounted in plug-in modules that allow piping and valve connections to be made through glovebox ports outside the cell. Geometrically favorable process equipment and storage tanks are used to assure criticality safety.

The solvent used at PRF is 20 volume percent TB[®] in carbon tetrachloride diluent. The feed is a mixture of nitric acid solutions from the scrap dissolution operations with aluminum nitrate added to complex the fluoride. A scrub of dilute nitric acid is used to remove weakly extracted impurities from the plutonium extract. Extracted plutonium is removed from the solvent by stripping with hydroxylamine nitrate reducing solutions which convert the extracted Pu(IV) to inextractable Pu(III). A small solvent flow is added to reextract uranium impurity from the stripped plutonium product. Spent solvent is treated with HNO₃-HF to remove residual plutonium, which is returned for rework. The solvent is treated further to remove uranium and solvent degradation products before being recycled.

The PRF also recovers Am-241 from the raffinate of the plutonium recovery process. The process employs 30 volume percent dibutylbutyl phosphonate in CCl₄ as the solvent to extract both americium and residual plutonium from the high nitrate feed solution, neutralized to a pH of about one by addition of NaOH. The americium is selectively stripped from the solvent with dilute nitric acid and concentrated and purified by a cation exchange procedure. Plutonium is removed from the solvent by stripping with a HNO₃-HG solution.

Various alternative methods of plutonium recovery can be devised depending on the waste sources and concentrations of isotopes. An alternative is briefly outlined below.

Within this plutonium recovery operation, impure plutonium metal is either (1) purified through a pyrochemical (molten salt) process, or (2) converted to an oxide and then processed (together with other plutonium compounds) through a series of wet and dry chemical steps to produce a plutonium metal button of high purity. The general steps required for processing the oxide and other compounds to metal are (1) dissolution, where impure metal and compounds are dissolved in nitric acid, (2) ion exchange, where plutonium ions are selectively removed from the acid solution, (3) evaporation, where the plutonium-rich eluate is concentrated, (4) precipitation, where the plutonium is chemically converted to plutonium peroxide, (5) calcination, where the plutonium peroxide is converted to plutonium oxide by heating, (6) fluorination, where the plutonium oxide is converted to plutonium tetrafluoride, and (7) reduction, where the plutonium tetrafluoride is mixed with calcium metal and heated, causing a reduction reaction that yields a pure plutonium metal button and calcium fluoride slag.

The americium-rich solutions isolated during the ion exchange step are processed through additional ion exchange steps, concentrated by evaporation, and chemically converted to an americium oxalate precipitate. The precipitate is calcined to americium oxide, which is disposed as a by-product.

Secondary plutonium recovery, also sometimes called "waste polishing," involves cycling the various solutions remaining from the primary recovery processes and other sources through additional steps (filtration, ion exchange, precipitation), thus reducing the residual plutonium and americium content to a level sufficiently low (typically 10^{-5} gram per liter or less, as determined by precise laboratory analyses) to permit transferring the waste solutions for conventional wash treatment. Any residues (or solutions) containing plutonium or americium in excess of that limit would be recycled back through the primary or secondary recovery operations.

APPENDIX H

NONDESTRUCTIVE ASSAY OF TRU CONTAMINATED WASTE^{7, 51}

TERA CORPORATION

1.0 INTRODUCTION

Nondestructive-assay methods are used to estimate the transuranic content of scrap and wastes from plutonium facilities. The results of the assay are used for plutonium inventory control, to determine whether sufficient plutonium is present to warrant recovery, and to assess the results of the recovery operation.

The methods in use are based on one or more of the following reactions of transuranium elements: radioactive decay, spontaneous fission, and induced fission. None of the methods based on these properties entirely covers the range of application, and none is without specific interference. In practice, several methods may be used to confirm the analysis. Most commercially available nondestructive-assay systems screen packages or drums for milligram to multi-gram quantities of plutonium, but techniques are being developed and are in limited use for screening specially packaged wastes containing plutonium-239 in the nanocurie per gram of waste concentration range.⁵¹

2.0 ANALYTICAL METHODS AND TECHNIQUES

Nondestructive analytical methods for TRU isotopes in solid waste fall into two categories: passive and active analyses. Passive methods use the natural radiation emissions to identify and quantify the isotopes that are present. In active analyses, external radiation is used to induce a measured response or change in the TRU emissions.

The sensitivity for detection, i.e., measuring the nature and amount of radioactivity present, depends primarily on these factors:

- The specific activity, i.e., radioactivity per unit measure of the radiation to be detected
- The nature of the extraneous or matrix solidification material
- The package size or form in which material is available at time of measurement
- The external background from the facility's environment
- The time allotted and accuracy required for the individual measurement

Sophisticated instrumentation will be required to measure the events and skilled personnel will be needed to operate and maintain the equipment as well as to analyze the resulting data.

2.1 PASSIVE ANALYSES TECHNIQUES

NEUTRON EMISSION FROM SPONTANEOUS FISSION

Two groups of neutrons are considered: those that are emitted at the time of fission (prompt or fission neutrons) and those that are emitted at some time after fission (delayed neutrons). On an average, more than two prompt neutrons are emitted per fission. Those prompt neutrons cover a broad energy spectrum, ranging from less than 0.05 MeV to greater than 15 MeV with the average

prompt-neutron energy between 1 and 2 MeV. Delayed neutrons, however, are emitted from several of the fission product isotopes and are emitted individually as single particles. Average energies of these delayed neutrons are generally less than 0.5 MeV. Because more than two prompt neutrons are emitted simultaneously during fission, coincidence counting may be used to discriminate against the neutron background that is caused by the delayed neutrons and the (α ,n) reactions.

PROMPT GAMMA-RAY EMISSION FROM SPONTANEOUS FISSION

About three times more prompt gammas than prompt neutrons are emitted during fission. These gamma rays are emitted simultaneously and have energies in the range of 0.3 to 10.5 MeV. Counting the prompt gammas in coincidence with the prompt neutrons is a possible technique for measuring the quantity of TRUs present in the solid waste.

NEUTRON EMISSION FROM (α , n) EMISSIONS

Many light elements yield neutrons when bombarded with energetic alpha particles. The emitted neutron energy depends on the energy of the bombarding alpha particle, the binding energy of the neutron, and the energy excitation of the residual nucleus. A rather broad continuous energy spectrum results with a maximum energy from 1 MeV for lithium to 10 MeV for beryllium. The neutron yield depends on the energies of the bombarding alpha-particles and on the composition of the target nucleus. For example, the alpha particles of Pu-238 bombarding the oxygen atoms in PuO₂-238 will yield about 1.4×10^4 n/sec-g whereas PuO₂-239 will yield only 45 n/sec-g. Thus, a measurement of the neutron yield from the (α , n) reaction can perhaps be used to measure TRU isotopes in waste.

PRODUCTION OF HELIUM FROM α -DECAY

Alpha particles are helium nuclei. Measuring the production of helium from alpha decay in the TRU-laden waste may provide a method of determining the amount of TRUs in a container.

PRODUCTION OF KRYPTON AND XENON BY SPONTANEOUS FISSION

Many isotopes of krypton and xenon are TRU fission products and most are radioactive. Thus, measuring the production of these gases through the spontaneous fission of the TRUs may be used as a method for detecting the TRU isotopes in a waste container.

GAMMA AND X-RAY EMISSION

Almost all of the TRU isotopes emit gamma rays and fluorescent X-rays during decay. These characteristic emissions can also be used to identify and quantify the TRU isotopes in solid waste.

A gamma-ray spectroscopy system complements the potential of other assay methods by providing the capability to nondestructively determine the content and the isotopic composition of various TRU isotopes. High-resolution gamma-ray systems are capable of extracting the maximum amount of information (isotopic composition, isotopic content, presence of extraneous gamma-ray sources) from an assay, but content density severely affects the accuracy of quantitative predictions based on this assay method.

2.2 ACTIVE ANALYSES TECHNIQUES

NEUTRON EMISSION FROM INDUCED FISSION

For most of the TRU isotopes with odd mass numbers, the spontaneous-fission rate is so low that the fission neutrons, particularly in quantities as small as 10 nCi/g, cannot be detected above the (α , n) background. Introducing neutrons or high-energy photons from an external source increases the fission rate. If a sufficient neutron or photon flux can be applied to the internal volume of the waste, it is possible to detect the induced fission neutrons. Counting the fission neutrons individually and in coincidence pairs yields the quantity of TRU isotopes present. Also, with increased fissioning, the yield of delayed neutrons is increased. Thus, the quantity of TRU isotopes present can perhaps be determined by counting the delayed neutrons following a specified irradiation time.

If neutrons are used as the irradiation source, the neutron energy should be in the thermal or epithermal range for greatest sensitivity; if photons are used as an irradiation source, the energy of the photons must be greater than 8 MeV to induce fission in the TRU isotopes.

PROMPT GAMMA-RAY EMISSION FROM INDUCED FISSION

The techniques used to count the prompt gammas from induced fission are the same as those used to measure spontaneous-fission gamma rays.

PRODUCTION OF GASEOUS KRYPTON AND XENON BY INDUCED FISSION

Increasing the fission rate by irradiation with neutrons or with high-energy photons results in an increased production of the fission-product gases. Because the fission yields differ for the isotopes of krypton or xenon for different TRU isotopes, identification of the fissioning TRU nuclei may be possible by determining the ratios of the fission-gas isotopes.

NEUTRON ACTIVATION

It may be possible to transmute the TRU isotopes that are difficult to detect into isotopes that are easily detectable. Transmutation is accomplished by irradiating the atoms with thermal neutrons.

3.0 FACTORS AFFECTING MEASUREMENT ACCURACIES³¹

Certain sample characteristics and measurement practices can affect the response of NDA systems. If these are not controlled or properly accounted for in determining the quantity of TRU from the measured activity, errors will be introduced into the final results.

The technical factors (excluding personnel related factors) contributing to the overall uncertainty associated with an NDA measurement are identified in the following four areas:

- The operational characteristics of the NDA systems
- The isotopic composition of the TRU waste
- The TRU waste and matrix materials
- The composition and dimensions of the waste container

3.1 OPERATIONAL CHARACTERISTICS

The operational characteristics of the NDA system, together with the ability of the system to resolve the desired response from a composite signal, determine the ultimate usefulness of the system. These operational characteristics include: operational stability, geometric effects, stimulating radiation uniformity, and energy of the stimulating radiation.

OPERATIONAL STABILITY

The ability of an NDA system to reproduce a given measurement may be sensitive to fluctuations in the operational environment. Temperature, humidity, and line voltage variations affect NDA systems to some extent. These effects may be manifested through the introduction of spurious electronic noise or changes in the high voltage applied to the detectors or amplifiers, thereby changing the detection efficiency.

The environment must be controlled if such fluctuations result in severe NDA response variations that cannot be eliminated through calibration and operational procedures.

GEOMETRIC EFFECTS

The concern in the geometry of counting is: What portion of the radiations that are emitted by a TRU waste package actually enters the sensitive volume of the detector? This portion ranges from a very small fraction, when the distance from package to detector is large, to 100% for some 4π -detectors, when the TRU waste package being counted is completely inside the detector.

Also, for some detectors such as the well-type gamma and neutron counters, the response of the gross count rate is a function of the position of a point source within the well. This implies that the size and distribution of the sample being counted within the well may have an important bearing on the detector response. To make the necessary error corrections, therefore, it is important to predetermine the geometry effect of a counting system.

STIMULATING RADIATION UNIFORMITY

It is important that the stimulating radiation field (i.e., interrogating neutron or gamma-ray flux) in active NDA systems be designed to be uniform in intensity and energy spectrum throughout the volume of the irradiation chamber. The residual effect can be measured by using a TRU waste package that is small in comparison with the dimensions of the irradiation chamber. The response can then be measured with the TRU waste positioned in different locations within the irradiation chamber.

Various methods, including rotating and scanning the container, scanning the source, distributing sources, and combinations of these methods, must be investigated to reduce the response uncertainty attributable to a nonuniform stimulating radiation field. Scanning a rotating container while the detector and source positions are fixed appears to offer an advantage in response uniformity.

ENERGY OF THE STIMULATING RADIATION

If the energy of the stimulating radiation is as high as practicable but below the threshold of any interfering reactions such as the neutron-induced fission in U-238, the penetration of the stimulating radiation will be enhanced throughout the volume of the irradiation chamber.

The presence of extraneous materials, particularly those of low atomic number, lowers the energy spectrum of the interrogating neutron flux in active neutron NDA systems. Incorporating a thermal neutron detector to monitor this effect and thereby provide a basis for a correction to reduce the response uncertainty caused by this effect is probably feasible.

4.0 ISOTOPIC COMPOSITION OF TRU WASTES

The TRU waste analysis response observed by an NDA system is usually a composite of contributions from more than a single isotope of plutonium or other TRU element. These sources of radiation are described briefly below.

4.1 MULTIPLE GAMMA-RAY SOURCES

The plutonium isotopes Pu-238 through Pu-241, as well as other TRU isotopes, are spontaneous gamma-ray emitters. The observed spontaneous gamma-ray spectrum from a TRU sample must recognize the contribution of gamma rays from these TRU isotopes. The uranium isotopes U-233 and U-238 spontaneously emit a gamma-ray spectrum and one gamma ray from U-238 (~766 keV, which is really from the Pa-234 daughter nuclide) is nearly of the same energy as one emitted by Pu-238. Uranium-232, occurring in combination with U-238, has a series of prolific gamma-ray-emitting daughter products, including Th-228. These and other sources must be recognized in accurately assessing the TRU contribution from a particular container.

4.2 MULTIPLE SPONTANEOUSLY FISSIONING ISOTOPES

Plutonium-240 is the principal spontaneously fissioning isotope in the plutonium fuel now used in the nuclear fuel cycle. A few percent of the total fission signal observed is due to Pu-238 and Pu-242.

Uranium has a much lower spontaneous fission rate than plutonium, but in mixed-oxide fuels the spontaneous fission yield from U-238, which is the predominant isotope present, may approach one percent of the Pu-240 yield.

4.3 MULTIPLE FISSILE AND FERTILE ISOTOPES

In active NDA assay systems, the observed fission response may come from more than one radioisotope. When a sample of plutonium or uranium mixed-oxide fuel is actively interrogated, the measured response will include contributions from the plutonium, uranium, and other fissile isotopes and, if the energy of the interrogating neutrons is high enough, the response will include contributions from both the fissile and fertile isotopes of plutonium and uranium.

5.0 ANALYSIS RESPONSE DEPENDENCE³¹ ON THE TRU AND MATRIX MATERIALS

If an NDA system is sensitive to the geometry of the detection system and the field of interrogating radiation, variations in the observed response may be attributed to the attenuation of emitted gamma rays, neutron multiplication, alpha-neutron reactions, attenuation of the interrogating radiation, and isotopic equilibrium.

5.1 ATTENUATION OF EMITTED GAMMA RAYS

The intensity of gamma rays is attenuated as they pass through matter. The magnitude of this attenuation depends on the energy of the gamma rays, as well as the thickness, density, and atomic number of the absorbing material. Low-energy gamma rays are much more severely attenuated than those of high energy. Measuring gamma rays of energies below approximately 80 keV is difficult and usually impractical because of severe attenuation problems.

Plutonium and other TRU isotopes have high mass absorption coefficients; therefore, self-absorption of gamma rays by these two elements can severely limit the application of passive gamma-ray spectrometry of relatively dense samples.

5.2 NEUTRON MULTIPLICATION

Neutrons from spontaneous or induced fission reactions can be absorbed by other nuclei, subsequently causing these nuclei to fission and release additional neutrons. This multiplication results in an increased sample response and therefore should be considered in all active and passive NDA systems.

5.3 ALPHA-NEUTRON (α, n) REACTIONS

Neutrons are randomly generated through interaction of alpha particles with light elements such as oxygen, fluorine, nitrogen, carbon, and beryllium.

Isotopes of TRU elements emit large quantities of alpha particles, which can cause (α, n) reactions and produce neutrons that increase the response of fission measurements.

5.4 SAMPLE SELF-SHIELDING

When performing an active assay of dense TRU contaminated metals or heterogeneous samples containing lumps of TRU elements, self-shielding of these isotopes against the interrogating neutrons will occur to varying degrees. Penetrability of the interrogating neutrons into a waste package is dependent on the energies of these neutrons, the density of the waste, and the type and amount of matrix material present. Matrix materials containing neutron moderators such as hydrogen will attenuate the interrogating neutrons to lower energy levels and increase the sample self-shielding effect.

5.5 ISOTOPIC EQUILIBRIUM

Some gamma-ray signatures involve gamma rays emitted from a daughter product of the fissioning isotope in the waste. These signatures can be accurately measured only when the isotopes in the waste and its daughter are in equilibrium.

5.6 EFFECT OF MATRIX MATERIALS

Matrix materials, which can be considered as all materials present in the sample other than the TRU isotopes, can have various effects on the NDA results. Matrix materials of low atomic number, particularly hydrogenous materials, reduce the energy of neutrons by elastic collision. The lower-energy neutrons are more likely to interact with other nuclei in the sample and thus affect the observed spontaneous fission response.

Matrix materials of high atomic number cause attenuation of gamma rays, particularly gamma rays of low energies. This can cause decreased response during an NDA measurement.

6.0 COMPOSITION AND DIMENSION OF THE CONTAINER

Variations in thickness of the waste container walls and structural composition can significantly affect the accuracy of NDA measurements. Therefore, the same type of container should be used, if possible, for the standard and the unknown waste package. Otherwise, a calculated or measured correction must be applied to the measured result to take into account the difference in container wall thickness and structural composition.

7.0 TRU DETECTION STATUS^{28,27,31}

The NDA techniques selected should reflect a consideration of the accuracy requirements for the assay and the type of TRU isotopes and containers in the inventory. No single NDA method is capable of universal application, and frequently more than one NDA technique is required to perform the job.

The above mentioned nondestructive analytical methods for measuring low-level TRU contamination can be grouped into four basic detection schemes: neutron counting, photon counting, fission-gas production measurements, and helium production measurements.

Table H-1 is a summary of the minimum theoretical detection limits that are possible for each alpha-emitting TRU isotope ($T_{1/2} > 100$ d) for each of the detection methods. Where blank spaces exist, insufficient data were available on the isotope to calculate a detection level. A conservative approach was taken for the calculations. Therefore, these levels should be achievable with instrumentation and techniques presently available.

Three of the eight methods presented in this report involve irradiating the waste material with thermal or epithermal neutrons at a flux density around 10^6 n/cm²-sec. Computer neutron diffusion codes have shown that a reasonably uniform flux (within $\pm 20\%$) can be obtained over the volume of a 210-liter (55-gal) waste container.

A suggested test procedure for neutron counting and krypton or xenon sampling required that five separate neutron counts be made on each waste container. The neutron-count data yield the spontaneous-fission rate of the material in the container, the delayed-neutron count rate decay, and the effect of the waste matrix on the neutrons. The total time for the count analysis for each waste container was approximately 60 minutes.

Krypton and xenon sampling take about two hours, but sampling can be conducted in parallel with several containers sampled simultaneously. The

TABLE H-1

**SUMMARY OF MINIMUM-DETECTION LEVELS^a*
FOR ALL TRU ISOTOPES BY NON-DESTRUCTIVE
ASSAY AT A PACKING DENSITY OF 50 KG/M³**

TRU	SF Neutron ^b (Ci/g)	Kr-Xe(SF) ^c (Ci/g)	Kr-Xe(IF) ^d (Ci/g)	X Ray or Gamma Ray ^e (Ci/g)	Delayed Neutrons ^f (Ci/g)	He ^g (Ci/g)	Prompt Gamma (SF) ^h (Ci/g)	Prompt Gamma (IF) ⁱ (Ci/g)
²³³ U	—	—	1×10^{-9}	9×10^{-9}	5×10^{-9}	—	—	1×10^{-6}
²³⁷ Np	$>3 \times 10^{-2}$	3×10^{-2}	2×10^{-6}	5×10^{-10}	1×10^{-5}	—	4×10^{-2}	3×10^{-5}
²³⁸ Pu	9×10^{-4}	8×10^{-1}	2×10^{-4}	7×10^{-7}	9×10^{-4}	—	1×10^{-1}	3×10^{-3}
²³⁶ Pu	4×10^{-4}	4×10^{-1}	7×10^{-5}	1×10^{-6}	3×10^{-4}	—	5×10^{-2}	9×10^{-4}
²³⁹ Pu	2×10^{-1}	2×10^{-2}	5×10^{-9}	10^{-7}	2×10^{-8}	—	2×10^{-1}	7×10^{-8}
²⁴⁰ Pu	2×10^{-5}	2×10^{-2}	$>2 \times 10^{-4}$	9×10^{-2}	$>9 \times 10^{-4}$	—	2×10^{-3}	$>2 \times 10^{-3}$
²⁴² Pu	1×10^{-7}	1×10^{-4}	1×10^{-6}	—	$>6 \times 10^{-6}$	—	2×10^{-5}	$>2 \times 10^{-5}$
²⁴⁴ Pu	2×10^{-10}	2×10^{-7}	—	4×10^{-10}	—	—	3×10^{-8}	—
²⁴¹ Am	3×10^{-1}	3×10^{-2}	7×10^{-5}	1×10^{-10}	3×10^{-4}	$>10^{-8}$	4×10^{-1}	9×10^{-4}
^{242m} Am	—	—	1×10^{-7}	8×10^{-8}	5×10^{-7}	but	—	1×10^{-6}
²⁴³ Am	—	—	$>2 \times 10^{-4}$	1×10^{-10}	$>8 \times 10^{-4}$	probably	—	$>2 \times 10^{-3}$
²⁴² Cm	1×10^{-5}	1×10^{-2}	$>4 \times 10^{-2}$	2×10^{-7}	$>2 \times 10^{-1}$	$<10^{-6}$	1×10^{-3}	$>6 \times 10^{-1}$
²⁴³ Cm	—	—	5×10^{-6}	3×10^{-9}	2×10^{-5}	for all isotopes	—	6×10^{-5}
²⁴⁴ Cm	5×10^{-7}	5×10^{-4}	—	6×10^{-6}	—	—	6×10^{-5}	—
²⁴⁵ Cm	—	—	5×10^{-9}	1×10^{-9}	3×10^{-8}	—	—	7×10^{-8}
²⁴⁶ Cm	2×10^{-9}	2×10^{-6}	—	—	—	—	3×10^{-7}	—
²⁴⁷ Cm	—	—	—	—	—	—	—	—
²⁴⁸ Cm	7×10^{-12}	7×10^{-9}	—	$<10^{-8}$ SF γ	—	—	8×10^{-10}	—
²⁵⁰ Cf	3×10^{-13}	3×10^{-10}	—	$<10^{-8}$ SF γ	—	—	8×10^{-11}	—
²⁴⁷ Bk	—	—	—	2×10^{-9}	—	—	—	—
²⁴⁸ Cf	1×10^{-8}	1×10^{-5}	—	—	—	—	1×10^{-6}	—
²⁴⁹ Cf	3×10^{-6}	3×10^{-3}	2×10^{-7}	6×10^{-10}	7×10^{-7}	—	3×10^{-4}	2×10^{-6}
²⁵⁰ Cf	9×10^{-10}	9×10^{-7}	$>2 \times 10^{-5}$	—	$>1 \times 10^{-4}$	—	1×10^{-7}	$>3 \times 10^{-4}$
²⁵¹ Cf	—	—	4×10^{-8}	—	2×10^{-7}	—	—	5×10^{-7}
²⁵² Cf	1×10^{-11}	2×10^{-8}	—	$<10^{-8}$ SF γ	—	—	3×10^{-9}	—
²⁵² Es	—	—	—	4×10^{-8}	—	—	—	—
²⁵⁴ Es	6×10^{-7}	6×10^{-4}	—	2×10^{-9}	—	—	8×10^{-5}	—

* To convert these minimum-detection levels to Ci/cm³, multiply by 0.05.

SUMMARY OF MINIMUM-DETECTION LEVELS^a FOR ALL TRU ISOTOPES BY NON-DESTRUCTIVE ASSAY AT A PACKING DENSITY OF 50 KG/M³

Notes

- ^a Minimum-detection levels are used here as the minimum levels that appear to be obtainable with reasonable effort. Because none of the methods (except gamma-ray analysis) has been demonstrated, these values are calculated estimates. A conservative approach was taken in the calculations and in most cases, these values are expected to be bettered.
- ^b Determined by coincidence counting of spontaneous-fission prompt neutrons.
- ^c Determined by measurement of the buildup of noble-fission-gas concentration as spontaneous fission takes place in a sealed container. Analysis is made of Kr-88 concentration after equilibrium has been established.
- ^d Determined by measurement of the amount of noble fission gases produced from induced fission by an irradiating neutron flux of 10^6 n/cm²-sec. An irradiation time of 30 minutes and a decay time of two hours are assumed; Kr-88 is the chosen isotope.
- ^e Determined by gamma-ray analysis of one selected photon energy in presence of a natural background of 20 R/h. Count time is taken as 1,000 seconds in each case.
- ^f Determined by counting delayed neutrons after container is subjected to a neutron irradiation-flux density of 10^6 n/cm²-sec until equilibrium is established for ⁸⁷Br (~10 min). Delayed-neutron yield data for thermal fissions are not available for isotopes other than U-233 and Pu-239. Values for other isotopes are calculated from estimated yield values.
- ^g Determined after sealing drum for 10 d followed by purging with nitrogen and measuring the helium concentration.
- ^h Determined by counting prompt gammas from spontaneous fission. Only photons of > 3 MeV are counted after passing through a collimator and 2-cm thick lead window.
- ⁱ Determined by counting prompt gammas from induced fission by thermal or epithermal neutrons with a flux density of 10^6 n/cm²-sec. Only photons with energies of > 3 MeV are counted after they pass through a collimator and 2-cm thick lead window.

average production rate is then approximately six containers per 8-hr shift 80 minutes per container. The minimum crew required is one trained technician to operate the neutron generators, take the counts, and collect the samples plus a scientist to calibrate the systems as well as analyze and interpret the data. Because of the hazard associated with the neutron generators, elaborate safety procedures and interlocks are needed to prevent occupational radiation injury.

Ten of the twenty-seven TRU isotopes can be detected at a 10-nCi/g level using these neutron methods. The main uncertainty with neutron counting arises from the effect of the neutron background (e.g., from the (α, n) reactions) on the detection sensitivity. The added analytical complexity from the presence of several TRU isotopes in the waste can be handled with a computer program. The ratios of the various isotopes must be determined by other means; neutron counting cannot identify the specific isotopes present.

The helium production measurement method is not as sensitive as neutron or gamma counting but it appears to have considerable potential. It was estimated that one trained technician could test six to eight containers by 8-hr shift after the containers have been prepared, sealed, and stored for ~ 10 d to permit helium buildup. The major uncertainty involved with this method is whether the waste container can be sealed tightly enough to contain the helium. Any leak of helium will cause the calculated amount of TRU in the container to be less than what was actually present.

If Pu-239 or U-233 alone are the major TRU isotopes to be tested, the production of krypton or xenon by induced fission appears to be an attractive method. As an estimate, one technician can test about four containers per 8-hr shift. The major problem with this method is the complexity of interpreting the gas-analysis data.

In the absence of a gamma-ray background, photon counting is a feasible method. One trained technician can count ten to twelve containers per 8-hr shift. Scientific support is required to calibrate the equipment and to review the analysis methods. The major uncertainty with this method arises from the effect

of the waste matrix as it attenuates the low-energy photons before they are counted. The non-uniform distribution of TRU in the waste also causes problems.

The remaining three methods (krypton and xenon production for spontaneous fission, prompt-gamma counting from spontaneous, and from induced fission) are not attractive, mainly because of low sensitivity. If the minimum detection level is raised to 1 $\mu\text{Ci/g}$ (1000 nCi/g), prompt-gamma counting from induced fission provides a method for measuring U-233 and Pu-239,

The following observations were made concerning the measurement of small quantities of TRU in waste material using nondestructive testing techniques:²⁸

- No simple method exists for measuring the quantity of a TRU in a package of waste in the presence of a gamma-ray background greater than a few milliRoentgen/hr.
- When an interfering background is not present, gamma-ray spectroscopy provides the best method for identifying and quantifying the TRU present in the waste. Several such systems have been developed and are in use today. Major research efforts will continue toward the development of greater sensitivity and better resolution. However, improvements within the next few years are not expected to provide an increase in sensitivity to reduce the detection level of TRU by tenfold.
- Monitoring the production of helium from the alpha decay of the TRU is an untried method that has the potential to measure all TRU isotopes present in waste. The major technical difficulty with this method involves the naturally occurring helium in the air. However, detection sensitivity of the technique appears to be close to the 10 nCi/g level.
- The only other viable measurement method at the 10 nCi/g level involves complex procedure of spontaneous-fission neutron counting, and krypton-xenon sampling and analysis. The delayed-neutron counting is not required because it does not add new data. However, it does provide a confirmation of the krypton-xenon sampling results. Ten TRU isotopes can be measured at the 10 nCi/g level including Pu-239. Elaborate counting and electronic circuits are required to operate the system as well as to collect and analyze the data. This method has not yet been demonstrated experimentally on small quantities of TRU and technical difficulties are more pronounced with this technique than with the other practical methods.

- Excluding the gamma-analysis method, neither of the other two proposed methods will identify the TRU isotopes present. In the neutron irradiation and counting as well as in the krypton-xenon sampling methods, a foreknowledge of the TRU isotopes present and their relative abundance is required even to quantify the amount of TRU present. If this foreknowledge is unattainable, these methods are useless.
- Counting prompt neutrons from induced fission is not feasible, even when counting in coincidence pairs, because interference from the source neutrons completely masks the prompt-neutron count. No technique has been discovered to overcome this difficulty.
- Raising the minimum detection level to $1 \mu\text{Ci/g}$ (1000 nCi/g) will permit the detection of all 27 TRU isotopes by the helium detection method and 19 of the isotopes by gamma-ray spectroscopy (i.e. the absence of an interfering background).
- If the minimum-detection level were raised to $1 \mu\text{Ci/g}$ (1000 nCi/g), measurement of the prompt fission gammas would be feasible, even in the presence of a 1-R/hr gamma background; additional energy discrimination could be accomplished with shields. However, the isotopes thus detected can be measured at lower activity levels by other methods.
- Lowering the minimum-detection level to 1 nCi/g will make it impossible to measure all TRUs except the five isotopes having the highest spontaneous-fission rates (i.e., Pu-244, Cm-248, Cm-250, Cf-250 and Cf-252).

A discussion of a typical TRU Waste Assay Facility is provided in Reference 7.

APPENDIX I
MISCELLANEOUS WASTE CHARACTERISTICS

TERA CORPORATION

The following tables represent various physical and chemical characteristics of material which are utilized to process TRU contaminated waste streams.

TABLE I-1
DIATOMITE FILTER AIDS

Chemical Composition	An amorphous form of silica, containing small amount of microcrystalline material; low solubilities in mineral and organic acids.
Organic Matter	0%
Dry Loose Weight, pcf	9-12
Average Filter Cake Density, pcf	23
Median Particle Size, microns	18.0 - 23.0

TABLE I-2
PERLITE FILTER AIDS

Chemical Composition	An amorphous mineral consisting of fused sodium potassium aluminum silicate.
Specific Gravity	2.34
Apparent Density	
Dry Loose Weight, pcf	4 to 11
Dry Tamped Weight, pcf	13 to 20
Typical Filter Cake Density, pcf	17
Organic Matter	Nil
Hygroscopicity	Nil
Wettability	Easily dispersed in aqueous or non-aqueous liquids
Mean Particle Size, micron	15.0

TABLE I-3
CELLULOSE FIBER FILTER AID

Chemical Composition	Organic material derived from wood pulp; practically ashless, 99.5% cellulose, non-abrasive and reasonably inert to most acidic and basic liquors.	
Approximate Average	<u>BW-40</u>	<u>BW-100</u>
Length (microns)	80	55
Thickness (microns)	16	19
Approximate Screen Analysis		
% on 40 mesh	0.8 - 1	1
% thru 100 mesh	83 - 90	92 - 95
% thru 200 mesh	25	75 - 80
Density, pcf	11 - 13	17 - 19
Iron %	.0150	.0200
Lignin %	0.2 - 0.4	0.2 - 0.4
Sulfur %	.0060	.0060
Ether Solubles %	0.2	0.2
Copper %	.0006	.0006
Viscosity cps	13	17

TABLE I-4
MICRO-CELE

Chemical Composition	Synthetic, hydrous calcium silicate
Bulk Density, pcf	5.4
Water Absorption, wt. %	560
Oil Absorption, wt. %	490
pH, 10% Water Slurry	8.4
Surface Area, m ² /gm	95
Specific Gravity	2.45
SiO ₂ , wt. %	54.3
CaO wt. %	25.1
AL ₂ O ₃ , wt. %	3.6
Fe ₂ O ₃ , wt. %	1.2
MgO, wt. %	0.5
Na ₂ O + K ₂ O, wt. %	1.3
Ignition Loss, wt. % (Volatile Matter)	14.0

TABLE I-5
OIL-SORBENT

Dosage Rate	One cubic foot absorbs 3-5 gallons of light to medium viscosity oils. One cubic foot will absorb 2-3 gallons of heavy fuel oils.
Chemical Composition	Mixture of expanded perlite and cellulosic fiber that is treated to render product extremely hydrophobic.
Density	Loose bulk weight 4.5 pcf.
ICC Class	NMFC - No. 1 Item 50170; UFC - Item 39075
Flash Point	Not Applicable (NA)
Viscosity	NA
Miscibility	NA
Solvent Compatibility	NA

Effectiveness/Disposal Condition -

<u>Type of Oil</u>	<u>Oil Retained</u>	
	<u>% by Weight</u>	<u>% by Volume</u>
Lube Oil, SAE 10	736	61
Lube Oil, SAE 20	745	63
Lube Oil, SAE 30	760	65
Lube Oil, SAE 40	775	65
Lube Oil, SAE 50	635	52
Industrial Oil, AA	585	48

TABLE I-6
ACTIVATED COCONUT SHELL CHARCOAL

Physical Properties:	Activated Charcoal BC Type 727 Size Distribution by Weight Percent
Retained on #6 ASTM E11 Sieve	0%
Retained on #8 ASTM E11 Sieve	5% Max
Through #8 and retained on #12 Sieve	40-60%
Through #12 and retained on #16 Sieve	40-60%
Through #16 ASTM E323 Sieve	1% Max
Through #16 ASTM E11 Sieve	5.0% Max
Packing density, bone dry charcoal, nominal, lb/cu ft	28 to 30
Based on apparent density (lab) measurement, "free fall" range lb/cu ft	26 to 32
Hardness Number	MIL-C-17605B para. 4.6.4
Ignition Temperature	340°C minimum at 100 tpm
Surface Area	1000 m ² /gr minimum
Moisture Content Efficiency	3% maximum
Ash Content	6% maximum

TABLE I-7

RESINS

Anion (Typical)

Chemical Composition	Cream-colored, opaque beads of cross-linked polystyrene with quaternary ammonium functional groups.
Specific Gravity	1.08 (Cl form, fully hydrated)
Apparent Density, pcf	44-46
Void Volume, gal/ft ³	2.5
Particle Size, range	16-50 mesh (U.S. Standard Sieves)
Effective size, mm	.50-.55

Cation (Typical)

Chemical Composition	Tan opaque beads of sulfonated styrene DBV Copolymer.
Specific Gravity	1.30 (Na form)
Apparent Density, pcf	48-50
Void Volume, gal/ft ³	3
Particle Size, range	16-50 mesh (U.S. Standard Sieve)
Effective size, mm	.45 - .55

Mixed Powdex (Typical)

Chemical Composition	Finely ground anion/cation resin
Specific Gravity	1.05 at 80% moisture
Density, Free Settled Suspension, pcf	13.1 dry
Density, Centrifuged Suspension, pcf	25.2 dry
Particle Size, range	200-400 mesh (U.S. Standard Sieves)

APPENDIX J
ACCEPTANCE CRITERIA FOR TRU WASTE^{11,82,77}

TERA CORPORATION

1.0 INTRODUCTION

The following is the verbatim text of the "WIPP Acceptance Criteria for Defense Low-Level TRU Waste, July 1, 1977." These are draft criteria for waste acceptance at the Waste Isolation Pilot Plant (WIPP), a proposed federal repository. Although the criteria are subject to change, they are presented here as background material to amplify the processing discussions in the past report. Indeed, in the recent Draft EIS on the WIPP facility⁸² modifications were made and are included herein. Further additional proposed criteria are also included.

2.0 WIPP ACCEPTANCE CRITERIA FOR DEFENSE LOW-LEVEL TRU WASTE

(JULY 1, 1977)

This document delineates the acceptance criteria proposed for defense low-level TRU waste received for storage at the Waste Isolation Pilot Plant (WIPP). By intent — and by ERDA directive — these criteria are conservative; it is likely that future changes in the criteria will be in the direction of less restrictive specifications. Changes will be made only when they can be justified on the basis of more complete knowledge of the behavior of the salt storage medium and of the waste material itself. "Final" pre-operational criteria will probably not be available before July, 1979.

In this document, "TRU waste" refers specifically to the solid radioactive waste described in ERDA Manual Appendix 0511, Part I, paragraphs G-18, 22, and 23 (interpreted here to include Pu-238, but not Pu-241, among the transuranic isotopes). "Low-level" refers to waste packages which exhibit surface dose rates no greater than 500 mrem/hour, as defined in Chapter 20 of ERDA-76--43 (TAD).

The present criteria have evolved from earlier drafts through numerous reviews by most of the agencies involved in the management of ERDA-generated radioactive wastes; the contribution of these agencies is gratefully acknowledged.

I. DEFINITIONS

Low-Level TRU Waste: Any solid waste material, other than high-level waste, which is contaminated with long-lived alpha emitters to the extent that, under the provisions of ERDA Manual Chapter 0511, it is not suitable for surface burial, but which exhibits sufficiently low radiation levels (surface dose rate levels ≤ 500 mrem/hr) that are amenable to handling by "contact" (as opposed to "remote") methods.

Waste Container: The box or drum, including any associated liner and/or shielding material, which immediately surrounds (and is considered to be an integral, disposable part of) the waste material.

Waste Package: The final configuration of the waste in its container, ready for emplacement in a suitably prepared storage site.

Overpack: A second layer of containment which may be required (and applied) by the WIPP operator because of the mechanical condition or level of surface contamination of the waste container.

Combustible materials: Materials which will sustain combustion when exposed to a temperature of 1300°F (700°C) for a period of 15 minutes or less, in atmosphere air. (Examples of combustible materials are paper, most plastics, cloth, and wood.)

Gas-Producing Materials: Materials which produce gas during their decomposition by radiolysis, pyrolysis, chemical reaction, or bacterial decay. (Gas-producing materials include virtually all combustibles and such non-combustibles as concrete, steel, and certain process sludges.)

II. ACCEPTANCE CRITERIA

It is axiomatic that no acceptance criteria document can adequately address all the special cases which may arise in the management of defense low-level TRU waste. The WIPP operator will cooperate with waste generating agencies in formulating waste treatment and packaging procedures which bring special waste forms into compliance with the spirit, if not the letter, of these criteria.

A. WASTE FORM:

1. Combustible materials: The shipment of low-level TRU waste to the WIPP will be coordinated on an ERDA-wide basis so that the total amount of combustible material in a single storage

room does not exceed 20 percent by volume (but Section 11.A.2 also applies). In the context of this criterion, the materials used in the fabrication of DOT-7A and similar non-metal containers are considered to be combustible.

When necessary to meet this specification, combustible waste will be incinerated or digested, using technology current at the time of processing, to convert the combustibles to a chemically stable form.

In order to control the radiolytic production of flammable gases, the TRU nuclide content of unprocessed combustible waste is limited to 2 Ci/ft^3 (70 Ci/m^3) of alpha emitters.

2. Gas-Producing Material: The shipment of low-level TRU waste to the WIPP will be coordinated on an ERDA-wide basis so that the total amount of combustible and gas-producing materials in a single storage room does not exceed 10 percent by weight. In the context of this criterion, the materials used in the fabrication of all present containers and liners are considered to be gas-producing.
3. Explosive and Pyrophoric Materials: Waste containing explosive or pyrophoric materials will not be accepted for storage at the WIPP.
4. Toxic Materials: Packages containing waste whose constituents are known to produce toxic fumes (e.g., by thermal decomposition or chemical reaction with other materials in the same container) when exposed to fire temperatures up to 1300°F (700°C) will be prominently labeled in a manner prescribed by the WIPP operator. The term "toxic fumes" refers to gases and vapors of moderate and severe toxicity, as defined in Section 9 of "Dangerous Properties of Industrial Materials," Library of Congress Catalog Card Number 74-17275.

5. Liquids: Waste containing free liquids will not be accepted for storage at the WIPP. Process sludges must either be dried by heating or mixed homogeneously with an appropriate drying agent; in either case, the liquid content of the product should be controlled to minimize dispersal of the waste in a handling accident.
6. Stabilization: Finely divided waste forms such as incinerator residues will be stabilized in concrete or glass (or such other materials as may be approved by the WIPP operator), or pelletized, in such a manner as to minimize the production of respirable fines in a handling accident.
7. Thermal Power Density: Individual low-level TRU waste packages in which the average thermal power density exceeds 0.1 watt/ft^3 (3.5 watts/m^3) will be prominently labeled in a manner prescribed by the WIPP operator.
8. Nuclear Criticality: The fissile isotope content of low-level TRU waste is limited to the values specified in DOT Exemption No. 5946: 200 g of fissile isotope per 55-gallon (210-liter) or larger drum, 100 g per 30-gallon (115-liter) drum, and 6 g/ft^3 (200 g/m^3) in boxes. (Note that Section II.A.7 limits the concentration of heat source plutonium to about 1 g per 55-gallon drum, 0.5 g per 30-gallon drum, and 0.2 g/ft^3 (6 g/m^3) in boxes.)

B. WASTE CONTAINERS

1. Dimensions: The largest waste container which can be accommodated inside the WIPP low-level hoist cage is 8 feet by 12 feet x 9 feet high (2.4 m x 3.7 m x 2.7 m high), including handling appurtenances. The use of waste containers smaller than the DOT 17C 55-gallon (210-liter) drum is discouraged but not prohibited.

2. Handling Appurtenances: All low-level TRU waste containers must be provided with cleats, offsets or chins which permit handling by means of fork trucks. Lifting rings and similar handling devices are permissible provided they are recessed or hinged in a manner which permits stacking in a close array.
3. Materials of Construction: Metal containers are preferred; wooden and plastic containers are permitted. In all cases, the materials used in the fabrication of waste containers are subject to the limitations for combustible and gas-producing materials defined in Sections II.A.1 and II.A.2.
4. Structural Design: The structural design of all low-level TRU waste containers must meet the requirements for Type A packages as outlined in 49CFR 173.39bb and, in addition, must permit the stacking of fully loaded containers on an empty container of the same type, to an overall height of 12 ft (3.7 m).
5. Liners: The use of drum or box liners is permitted when required because of the physical or chemical properties of the contained waste material. When used, the liners should be made of materials which minimize the rate and total quantity of gas produced as a result of radiolytic, pyrolytic and bacterial decomposition; Sections II.A.1 and II.A.2, limiting the use of combustible and gas-producing materials, apply to liner materials. The use of halogenated plastics such as PVC is discouraged but not prohibited.

C. WASTE PACKAGE

1. Weight: The weight of a single low-level TRU waste package is limited to 25,000 pounds (11400 kg), the capacity of the WIPP low-level hoist.

2. Surface Contamination: The maximum permissible levels of loose plus fixed surface contamination (above which the waste package will be decontaminated or overpacked at the expense of the shipper) are as specified in 49CFR 173.397:

<u>Contaminant</u>	<u>Maximum Possible Loose Plus Fixed Contamination Level</u>	
	<u>$\mu\text{Ci}/\text{cm}^2$</u>	<u>$\text{dis}/\text{min}\text{-}\text{cm}^2$</u>
Natural or depleted uranium and natural thorium:		
$\beta - \gamma$	10^{-3}	2,200
α	10^{-4}	220
All other $\beta - \gamma$ emitting radionuclides	10^{-4}	220
All other α emitting radionuclides	10^{-5}	22

3. Penetrating Radiation: The dose rate from penetrating radiation at the surface of an individual waste package may not exceed 500 mrem/hour. Averaged over the waste packages in a given transport vehicle, the surface dose rate may not exceed 200 mrem/hour.

An additional limit applies to agencies which generate more than 5000 ft^3 (140 m^3) of low-level TRU waste per year: averaged over the waste packages shipped in a given quarter, the surface dose rate may not exceed 10 mrem/hour.

4. Labeling: Each waste package will be uniquely identified by means of a label which is permanently attached to the container in a conspicuous location. Information obtainable from the label itself and from the records pertinent to the waste package will include the following:

Label

- Package identification number (to be standardized)
- Waste generating agency
- Date of packaging
- Radiation levels: mrem/hour of neutrons and gammas, at the surface and at a point 1 m from the surface
- Weight (in pounds and kg)

3.0 INTERIM WIPP ACCEPTANCE CRITERIA⁸²

This section describes the interim criteria for accepting the wastes that will be stored at the WIPP reference repository.

3.1 WASTE-ACCEPTANCE CRITERIA

In 1977, the U.S. Department of Energy (DOE) formed the Waste Acceptance Criteria Steering Committee (WACSC). The Committee initially consisted of technical personnel from DOE headquarters, DOE field offices controlling defense wastes, the Office of Waste Isolation, and the WIPP staff from Sandia Laboratories. The Committee has since been expanded to include representatives from the Rocky Flats Plant, the Office of Nuclear Waste Isolation, and the Westinghouse Electric Corporation (the WIPP technical-support contractor).^{39,38}

The WACSC reconciles the interests of various agencies involved with the production, treatment, and disposal of defense TRU wastes. Its ultimate goal is to formulate workable, practical criteria for the acceptance of these wastes. Data for quantifying the criteria are being developed in research and development programs at various DOE laboratories. The criteria are constantly evolving and, as described below, reflect only interim proposals.⁸²

3.1.1 DEFINITIONS

Discussions of waste-acceptance criteria frequently use several terms that need to be clearly defined: container, package, overpack, combustible material, gas-producing material, and immobilized material. Each is defined below according to its accepted meaning in this section. These are not official definitions, rather, they are abstracted versions of the official definitions; they convey concepts and avoid specific detail.

Container: A drum, box, or canister that immediately surrounds the waste is the waste container. Any associated hardware such as liner material or spiders for spacing is considered part of the container.

Packages: Once waste is placed inside the container, the container becomes an integral part of the waste. The waste and its container are called the waste package. It is the package that is employed in the repository.

Overpacks: If required by the physical condition of the container or by the surface-contamination levels, a supplementary layer of containment is placed over the original container and is then considered to be part of the waste package. The supplementary containment is the overpack.

Combustible material: Any material that will sustain combustion in air at a temperature of 802 °C for a period of 5 minutes is combustible.

Gas-producing material: Any material that produces gas during its decomposition is gas-producing. Many materials, particularly organic materials, produce hydrogen, methane, carbon monoxide and carbon dioxide by radiolytic decomposition, pyrolysis, chemical reaction (corrosion), and/or bacterial decomposition. The salt formation at the reference site has a very low permeability for these gases, and the potential may exist for producing gas pressures high enough to disrupt the rock formations immediately surrounding the repository. The rates of gas production by the various mechanisms and the permeability of the salt formation are now being studied.

Immobilized material: Any material, excluding liquids, that contains less than 1 percent (by weight) of powder (less than or equal to 10 microns in size) is considered immobilized. The intent of immobilization is to minimize the amount of respirable material in the waste packages.

3.1.2 TRANSURANIC WASTE

Transuranic waste is categorized in two classes: contact-handled (CH) and remotely-handled (RH). A qualitative distinction between contact-handled and remotely-handled TRU waste is made in this document: contact-handled waste emits so little radiation that workers can handle it without extensive shielding; remotely-handled waste requires shielding and/or remote handling to protect operating personnel. The criterion designates waste packages with surface-dose rates no higher than 200 millirem per hour (mrem/hr) as contact-handled TRU waste and those with surface-dose rates higher than 200 mrem/hr as remotely handled TRU waste.

CONTACT-HANDLED TRU WASTE

About 98 percent (by volume) of the TRU waste produced in the DOE complex is classified as CH TRU waste.

Contact-handled TRU waste exists in a wide variety of physical forms, ranging from unprocessed general trash and concrete-stabilized sludge to decommissioned machine tools and glove boxes. Most of the pre-1970 (buried) waste is in 208-liter drums. Although drums are still widely used, the present trend is toward large plywood and metal boxes, which not only cost less than drums but also make more efficient use of storage volume. At present, about 70 percent of all CH TRU waste is put into boxes, most of it in special plywood boxes, about 1.2 m x 1.2 m x 2.1 m in outside dimensions, that are covered with a 3-mm layer of fiberglass-reinforced polyester and lined with polyvinyl chloride and fiberboard. These boxes are approved by the U.S. Department of Transportation (DOT-7A containers).

REMOTELY-HANDLED TRU WASTE

A small fraction (about 2 percent by volume) of the TRU waste generated by the DOE complex exceeds the 200-mrem/hr limit on the surface-dose rate of CH TRU waste. The surface-dose rates of almost all packaged RH TRU waste range from a few hundred millirem per hour up to perhaps 100 rem/hr. This waste will be handled by shielded equipment designed especially for the purpose.

The criteria for RH TRU waste containers are generally the same as those for CH TRU waste: containers are designed to Type A specifications and are designed to be retrievable for at least 10 years. The only differences are the dimensional characteristics of the containers themselves. The shipping casks in which the containers will be transported restrict the size of the container, as does the remote-handling equipment being designed for the reference repository.

The package criteria are presented in Table J-1 for both CH and RH TRU waste.

TABLE J-1
INTERIM WASTE-ACCEPTANCE CRITERIA FOR CH TRU AND RH TRU WASTE⁸²

<u>Criterion</u>	<u>Contact-handled TRU Waste</u>	<u>Remotely handled TRU Waste</u>
	W A S T E F O R M	
Combustibility	No limit, must be packaged in steel containers or overpack	No criterion; quantities are insignificant, and processing will probably not be available
Gas generation	Gas-generating materials in any single storage room may not exceed 10 percent by weight	No criterion for above reasons
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix; double containment allowed for special cases; sludges must contain no free liquid	Same as for CH TRU waste
Explosives	Not allowed	Same as for CH TRU waste
Pyrophorics	Small quantities of radionuclide-metal pyrophorics may be accepted with other waste forms	Same as for CH TRU waste
Hazardous materials	Allowed only with special procedures and precautions	Same as for CH TRU waste

TABLE J-1

(CONT.)

<u>Criterion</u>	<u>Contact-handled TRU Waste</u>	<u>Remotely handled TRU Waste</u>
C O N T A I N E R		
Design life	10 years to allow retrievability	Same as for CH TRU waste
Structure	Type A requirements	Same as for CH TRU waste
P A C K A G E		
Structure	Type A; any damaged container must be overpacked	Same as for CH TRU waste
Handling	Devices to allow handling by means of a forklift	Axial lifting pintle
Weight	Less than 12,000 pounds	Less than 10,000 pounds
Dimensions	Not larger than 8 by 12 by 9 feet	24-inch diameter, 15-foot length
Radiation:		
Surface-dose rate	Not exceeding 200 mrem/hr; sources producing more than 5,000 cubic feet per year must produce waste with a 3-month average of less than 10 mrem/hr	Less than 100 rem/hr
Surface contamination	49 CFR 173.398	49 CFR 173.398
Criticality	49 CFR 173, Subpart H	30-gallon drum, 100 grams fissile; 55-gallon drum, 200 grams fissile; DOT-7A, 500 grams fissile
Thermal power	Color code if greater than 0.1 W/ft ³	No criterion

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TERA CORPORATION

3.2 ACCEPTANCE CRITERIA ASSUMED FOR ANALYSES REPORTED IN THE DRAFT EIS⁸²

As discussed above, the acceptance criteria for TRU waste are still being developed by the Waste Acceptance Criteria Steering Committee. For this reason, two different versions of potential waste-acceptance criteria were used in the Draft EIS. These two versions were used in ways that yield maximum environmental-impact predictions; while it is assumed that the waste-acceptance criteria finally selected will produce smaller impacts than the impacts calculated from the two sets of assumed criteria.

4.0 SUGGESTED WASTE FORM AND PACKAGE CRITERIA¹¹

The conceptual design of facilities to accept TRU waste at the WIPP has been completed and documented in a formal report. The WIPP criteria, to the extent documented and appropriate, have been reviewed and incorporated into these suggested criteria.

4.1 WASTE FORM CRITERIA

Waste to be eventually disposed at a federal repository will meet the following waste form criteria.

(1) Combustibles and Organics

Combustibles and organics will be incinerated or similarly treated and the resultant product fixed in a solid medium (matrix) prior to receipt at the repository.

(2) Liquids

Liquids and sludges will be fixed in homogeneous solids possessing low leachability in saturated salt brine or pure water.

(3) Heat Generation

Maximum thermal power per canister will be 300 W.

(4) Free Liquids

The waste shall contain no free liquid. Free liquids are defined as those not treated to eliminate the characteristics of fluidity, dispersibility or freedom of movement within the packaging.

(5) Pyrophoric or Explosive Materials

Pyrophoric or explosive materials shall not be permitted unless converted to a nonreactive form before packaging.

(6) Spontaneous Combustion

Materials shall not be combined within a waste container which could lead to spontaneous combustion or production of internal container pressure through chemical or bacteriological reactions.

(7) Toxic Materials

Highly toxic materials contaminated with TRU nuclides shall be identified. Their handling will be resolved on an individual basis.

(8) Nuclear Safety

Amounts of fissile materials shall be limited so an infinite array of such packages will remain subcritical based on a "worst case" analysis.

(9) Alpha Radiolysis

TRU materials shall be limited to prevent production of unacceptable quantities of alpha radiolysis products during storage. Such products may result in internal pressures exceeding the sealing capabilities of the container or may result in the formation of an explosive gas mixture.

4.2 PACKAGE DESIGN CRITERIA

(1) General

All waste shall be stored retrievably (minimum of 25 years) and shall be contained by at least two independent barriers throughout transport, handling, and interim storage.

(2) Container Size

All waste containers shall be small enough in volume, light enough in weight, and of uniform shape in order to be compatible with the repository design, transportation methods, and handling methods. The waste containers shall exhibit good volumetric efficiency in terms of waste containment and storage of the containers. The following criteria establish minima and maxima for the waste container size.

(a) Container Dimensions

To be compatible with the repository facility, containers shall have a minimum outside diameter that precludes two or more containers from wedging in the disposal vault. The container's outside diameter must, therefore, be greater than one-half the inside diameter of the storage vault to be utilized. The maximum outside diameter of the container will be

approximately 51 mm (2 in.) less than the inside diameter of the storage vaults. The maximum length of a waste container shall be such that the container will fit in a retrievable storage vault and still allow space for a shield plug if necessary.

The waste will be packaged in canisters 0.61 m (2 ft) in diameter x 4.6 m (15 ft) long or a similar size. (Damaged canisters received will be placed in overpack containers 0.66 m (26 in.) in diameter x 4.9 m (16 ft) long.) These values are taken from the WIPP design and are arbitrary relative to regulatory impact.

(b) Container Weight (loaded)

The weight allowable for a loaded waste container is dependent on the handling method used for placement and retrieval of the container in the disposal vault. The WIPP design criteria establish a maximum weight per canister of 4,550 kg and 5,050 kg with overpack. These values are taken from the WIPP design and are arbitrary relative to regulatory impact.

(c) Container Shape

All waste containers stored at the repository in shielded areas shall be right circular cylinders. In addition, there shall be no sharp, pointed edges on the waste container that could cause difficulty during placement of the waste in the vaults.

Wastes stored in non-shielded areas may have other physical configurations subject to restrictions by transportation criteria and the repository design.

(d) Large Items

Large process vessels, piping, concrete, etc., will be reduced in size to fit into the containers defined above. Where the size, weight, and contamination are appropriate, the object may be welded shut to form its own container.

(3) Container Strength

The waste container shall have sufficient strength to withstand stacking in the storage vault to a maximum height allowed by the design.

(4) Container Closure

Each container shall be sealed by the waste generator with a numbered seal so as to preclude removal of the lid without destroying the seal.

(5) Corrosion Protection

Waste package surfaces constructed from materials subject to corrosion shall be coated with corrosion inhibitors or otherwise protected.

APPENDIX K
TRU WASTE TREATMENT TECHNOLOGIES

TERA CORPORATION

1.0 INTRODUCTION

This appendix contains a survey of the state-of-the-art of volume-reduction technology with emphasis on those technologies appropriate and available for application to low-level radioactive and TRU-contaminated waste.

The survey of the state-of-the-art of waste volume reduction technology began with a review of the pertinent literature and publications by the manufacturers. The sources of the information and data contained in this report are identified throughout the text.

In most cases, the descriptions presented in this appendix are summaries based on available information.

The resultant data base indicates that the nuclear industry is rapidly gaining technological knowledge and experience in volume reduction processes. In many cases, experience from non-nuclear industries is being utilized and, in other instances, technology is being imported from European countries and Canada. There are over a dozen U.S. suppliers marketing volume reduction processes, each utilizing a different concept.

Practical experience is rapidly being gained either by prototype system testing or actual facility operations; however, there is still insufficient practical experience to demonstrate conclusively the technological and economic feasibility of many of the proposed volume reduction technologies.

This appendix addresses the technical and economic feasibility of the various volume reduction concepts for application to fuel cycle and non-fuel cycle waste. In this regard, the following areas are examined:

- System description, performance, capabilities and limitations
- Volume reduction capability

- Environmental effects (operational) on facility design and operability
- Waste product characteristics and final disposal
- Effect on plant effluent discharges
- Nuclear operating experience

2.0 TRU WASTE INCINERATION

Numerous types of furnaces are or may be used for TRU waste incineration. They range from single-chambered systems to complex multi-chambered units and include fluidized bed, moving grate, and rotary kiln designs. Incinerators are classified by various characteristics which have no common basis. For example, they are classified according to shape, such as open pit or multiple chamber; to the amount of air used, such as controlled air or excess air; and to moving parts, such as rotary or moving grate. A given incinerator is commonly identified by referring to only one of these classifications.

The necessary conditions for achieving complete combustion in any incinerator are: 1) adequate residence time; 2) adequate temperature (to promote complete combustion); 3) turbulence (to promote good mixing); and, 4) sufficient oxygen. Problem areas in the past have included spalling and warping of construction materials, incomplete combustion (leading to excessive carbon in the ash and creating problems for the off-gas cleanup system), clogging, fires outside the furnace chamber (including flashback in the feeder and soot fires in the off-gas cleanup system), inadequate ash handling and off-gas cleanup systems, and corrosion (particularly if sulfur or halogen-containing compounds are part of the waste).

Major design items to consider in the specification of an incinerator include: material of construction, capacity considerations, radioactivity or hazardous waste concentration, chloride effects, sulfur and nitrogen oxides effects, volume reduction, ash handling and process safety.

The choice of a particular technology is dependent on numerous factors. Typical process constraints used for TRU waste processing include:

- The incinerator must render the waste inert
- The incinerator residue must be immobilized
- The process output must satisfy the expected acceptance criteria of the federal repository

- The incinerator facility must be capable of handling at least the waste generating rate of the facility
- The incinerator must accept unsegregated waste
- The incinerator must be maintainable with a minimum of radiation exposure to personnel
- The design must provide adequate safeguards in the following areas:
 - Criticality
 - Containment of radioactive materials
 - Radiation exposure to personnel
 - Requirements for pollution control

Selection of the specific treatment process for TRU waste depends partly on the constraints placed on the feed to and output from the incinerator. Variables affecting the incinerator feed include the nature and quantity of the waste, the possible requirement to treat the contaminated soil, and the quantity to be treated. These variables will be affected by the waste management philosophy and regulations in effect at the time of waste processing. Items of interest include the following: the allowable radiation dose to workers; and the possible requirement to retrieve buried waste from the pits and trenches. Similarly, the external constraints placed on the incinerator output affect the selection of the process. The following are examples: waste acceptance criteria at the federal repository; possible acceptance of contaminated soil and the allowable contamination level; a requirement to immobilize the waste and soil; possible leachability limits on the treatment system output; and acceptable types of packaging.

National and local decisions concerning many of these factors have not yet been made. Complex interactions between the public and a number of governmental agencies may be involved.

2.1 RADIOACTIVE WASTE INCINERATORS

The following incinerators either are processing radioactive contaminated waste or are being designed and built for that purpose. Each is the result of a response to a specific set of needs for that nuclear installation.

2.1.1 ACID-DIGESTION UNIT

The acid digestion process was initially developed by HEDL and is concurrently undergoing development in several countries. The process operates at a much lower temperature than any other combustion process and does not produce tars, soot, or fly ash. This allows ready off-gas filtration and the use of conventional chemical equipment and piping. These in turn make the process potentially amenable to remote operation. The process will handle almost all combustibles, including leaded gloves, and it tolerates noncombustible solids. It can safely process levels of TRU contamination up to and including recoverable plutonium scrap. Plutonium from the waste residue is quantitatively recoverable by dilute nitric acid leaching. Use of highly corrosive hydrofluoric acid is not required. The process has been designed to handle reactive chemicals, organic liquids, and other contaminants which inadvertently find their way into the waste stream. The digester and off-gas systems are mechanically simple with a minimum of moving parts.

GENERAL DESCRIPTION

In the present system (Figure K-1), shredded wastes are discharged onto a shallow tray where they are contacted with nitric acid and recirculating sulfuric acid which is air lifted from a heated geometrically favorable reservoir. Solids which accumulate in the system are removed during operation by periodic transfer of a portion of the acid slurry to a separate evaporator pot. The sulfuric acid is evaporated and returned to the digester for reuse.

Combustible wastes are converted to gaseous products CO_2 , H_2O , HCl and sulfate residues by digestion in H_2SO_4 at 230 to 250°C in the presence of nitric acid oxidant.

CAPACITY

Five kilograms per hour or approximately 100 kilograms per day.

HEDL ACID DIGESTION PROCESS

FIGURE K-1
ACID DIGESTION UNIT

INPUT CHARACTERISTICS

Type of materials incinerated	All combustible solids except teflon, and many combustible liquids. Not advised for HEPA filters, silicones, and highly volatile liquids.
Flexibility of incinerating varying mixes of material	Average.
Processing tolerance	
- Metal	Poor.
- Large objects	Poor.
- Noncombustibles	Poor.
Material pretreatment	Combustible wastes are first sorted to remove any noncombustible or potentially hazardous constituents. Next the waste is shredded.

PROCESS OPERATING CHARACTERISTICS

Combustion chamber	
- Primary	Primary unit is the digester tray liquid which operates at 250°C with concentrated H_2SO_4 and HNO_3 oxidation process.
- Secondary (afterburner)	None.
Operating variables controlled	Operation is readily controlled. Reaction temperature, nitric acid addition rate, and feed material addition rate are the variables.
Material added	H_2SO_4 and HNO_3 .
Corrosive gas	HCl , SO_2 , SO_3 .

Off-gas treatment

- Wet scrubber

Wet scrubbing system. The off-gases are scrubbed with dilute acid and then pass through a heater and HEPA filter, through a second scrubber, and finally through another set of HEPA filters.

Secondary waste generated

Scrubbed reaction gases and spent alkaline scrub solution.

Construction material

- Incineration interior
- Incinerator hearth
- Off-gas equipment

Digester and other items are either glass, glass lined, or teflon lined.

No hearth.

A standard wet system.

Maintainability/reliability

- MTBF
- MTTR
- Corrosion
- Routine maintenance

Unknown but typical of wet, highly corrosive chemical process.

Typical of chemical process. Mechanical equipment such as pumps will require continual maintenance.

Startup/shutdown operations

Typical of chemical process.

Capability for remote operation

Typical of chemical process.

OUTPUT CHARACTERISTICS

Residue form

Dry salt cake, primarily inorganic sulfates and oxides. The product is thermally stable. This output is for combustible feed material only.

Residue inert

Yes.

Residue stabilized

No.

Process effluents

Scrubbed reaction gases and spent alkaline scrub solution containing NaCl and small amounts of NaNO_3 , NaNO_2 , and Na_2SO_4 .

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system

Low because plutonium and other materials are in liquid form and are contained within the criticality-safe geometry of the processing equipment.

Material accounting

Good inventory control system.

Criticality

Criticality is maintained by the geometrical design of containers--annular digestion vessel, etc. Close inventory control.

PRESENT STATUS

Demonstrated in a cold pilot plant at five (5) kilograms per hour, and for operation of radioactive wastes in 1978 at five (5) kilograms per hour. A radioactive pilot plant for 100 kilograms per day is being designed. Technology should be available for industry in the 1980s.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages

Handles wide variety of wastes, although waste must be sorted and shredded.

Low-temperature single-stage combustion operation.

Pu readily recovered from residue.

Reactions are readily controlled.

Disadvantages

Small maximum waste throughput of about five kilograms per hour.

Requires tight control of Pu feed material to assure criticality safety.

Requires highly trained operators to monitor process controls of acid feed material.

Volume reduction small without acid recycle.

2.1.2 AGITATED HEARTH

An agitated hearth incinerator developed by Envirantech, Inc., San Mateo, California, has been successfully tested in a cold pilot plant at about 4 kg/hr with wastes typical of the nuclear industry. Results of these tests are being used by C. F. Braun, Alhambra, California, to design a unit capable of treating about 70 kg/hr of mixed waste material. The 70 kg/hr unit will be built by Envirantech, Inc., and used at Rocky Flats to process low activity wastes containing < 0.02 g Pu/g waste.⁶

GENERAL DESCRIPTION

The Rocky Flats agitated hearth (Figure K-2) is a stationary, refractory, lined steel circular vessel 2.6 meters in diameter by 4.6 meters high with rotating rabble arms. The rabble arms tumble the waste through the combustion zone and push the accumulated ash to the output port.

Wastes are processed through the incinerator on a batch basis using a semi-continuous feed. There is a five-hour charging period during which approximately 150 two-kilogram portions of waste are batch loaded at a rate of one every two minutes. Then there is a one-hour burn-out time followed by a 1/2-hour ash clean-out operation.

The incinerator is oil-fired and is operated at a temperature of 600 to 800°C. Gases and fly ash are combusted in an afterburner operated at 1,000°C.

FIGURE K-2
ROCKY FLATS AGITATED HEARTH INCINERATOR⁶

CAPACITY

Planned capacity is 70 kilograms per hour of low-level TRU waste (1980).

INPUT CHARACTERISTICS

Type of materials
incinerated

The unit is restricted to incinerating combustible solid wastes which contain less than 3×10^{-3} milligrams plutonium per gram of waste.

Flexibility of incinerating
various mixes of material

Materials include rubber, paper, PVC, polyethylene, cloth, leather, and wood. Various mixes of material may be incinerated.

Material pretreatment

Sorting, shredding is optional.

Processing tolerance

- Metal
- Large objects
- Other
noncombustibles

Fair; no chemical reaction is involved.

Good.

Nonmetallic noncombustibles are tolerated well; however, molten glass might form a slag on the refractory lining or mix with the ash to form a sticky mass.

PROCESS OPERATING CHARACTERISTICS

Combustion chamber

- Primary
- Secondary
(afterburner)

Operates at 600 to 800°C. (Slightly reducing atmosphere.)

1,000°C.

Operating variables

Waste feed rate, fuel, air, time and controlled temperature.

Material added	None.
Corrosive gas	HCl.
Off-gas treatment	
- Dry scrubber	None.
- Wet scrubber	Wet scrubbing system. Off-gases are treated by an aqueous scrubber consisting of two potassium hydroxide scrubbing units. Each unit has a wetted throat venturi scrubber followed by a gas-liquid separator. The gases from the last separator vessel discharge through HEPA filters.
Secondary waste generated	Combustion gases and spent alkaline scrub solution.
Construction materials	
- Incinerator interior	Refractory lined.
- Incinerator hearth	Refractory lined.
- Off-gas equipment	Standard for wet scrubbing system.
Maintainability/reliability	
- MTBF	Since the incinerator is stationary and non-rotating, conditions are good for an optimal lining life. The rotating rabble arms and mechanism will require repair.
- MTTR	
- Corrosion	Rotating mechanism will become corroded and will require maintenance.
- Routine maintenance	The central rotating shaft and rabble arms in the incinerator will require routine maintenance.
Startup/shutdown procedures	No particular problems are anticipated. For maximum refractory life, on startup in the incinerator temperature should be raised slowly to equalize thermal stresses. Similarly the unit should be cooled down slowly.

OUTPUT CHARACTERISTICS

Residue form	Inert dry ash when burning combustible materials.
Residue inert	Yes.
Residue stabilized	No.
Process effluents	Process effluents are combustion gases and spent alkaline scrub solution.

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system	Plutonium and other radionuclides may possibly migrate into the refractory lining. Because of the possibility of plutonium buildup on the hearth and the large batch size used (see below), the incinerator is restricted to processing radioactive waste containing less than 3×10^{-3} grams plutonium per gram of waste.
Material accounting	A normal incinerator batch size contains approximately 300 kilograms of waste. This large batch size requires a low level of plutonium in the waste to prevent the possibility of a critical amount of plutonium in the incinerator residue at one time.
Criticality	
Containment	

PRESENT STATUS

Demonstrated in nonradioactive demonstration model rated at four kilograms per hour. A unit capable of processing 70 kilograms per hour of waste is being fabricated for combustion of low-level contaminated wastes.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages

Rotating rabble arms tumble the waste through the burner, permitting rapid and complete oxidation of the wastes.

Optimum condition for long refractory life. (No rotating refractory.)

Disadvantages

Number of moving parts (rabble arms, etc.) in the incinerator combustion zone.

Restricted to waste feed containing less than 3×10^{-3} g of Pu per gram of waste.

Possible radioactivity (TRU) migration and holdup in the refractory lining.

2.1.3 CONTROLLED-AIR INCINERATOR

In 1973, LASL was directed to evaluate current incineration and air pollution control technology for application to combustible low-level TRU waste. A controlled-air incinerator and an associated high-energy aqueous off-gas cleaning equipment were selected for development and demonstration. This system was selected on the basis of flexibility in accepting a wide range of feed compositions, ease of combustion rate control, minimum particulate emission due to low turbulence in the primary combustion chamber, combustion efficiency, ability to tolerate relatively high levels of noncombustibles, and the use of off-the-shelf technology resulting in a relatively low cost system. Although the aqueous scrubbing system results in a blowdown stream, the low carry-over of particulate in the off-gas allows treatment of the spent solution by ferric hydroxide precipitation to produce a no TRU sludge. A 45 kg/hr incinerator is being tested for disposal applications.

GENERAL DESCRIPTION

Controlled-air systems (Figure K-3) use the concept of multiple-chamber burning to achieve complete combustion of solid waste. Charges of waste enter the first chamber where they burn in the presence of substoichiometric quantities of air. The products of partial oxidation and volatilization flow into a secondary heated combustion chamber where excess air provides complete combustion. This mode of operation produces a nonturbulent combustion environment in the first chamber and minimizes the entrainment of fly ash.

Wastes are fed by a ram feeder into the primary starved air chamber and are combusted at 500 to 800°C. The volatile components and entrained solids are further oxidized in an air-rich secondary chamber at 1,000 to 1,500°C.

CAPACITY

45 kilograms per hour.

INPUT CHARACTERISTICS

Type of materials incinerated	All combustible solid wastes such as polyvinylchloride, neoprene, latex rubber, paper wood and rags.
Material pretreatment	Material must be sorted to remove hazardous materials and liquids. Removing noncombustibles (glass and metal) and shredding high-density materials, such as telephone books, are optional.
Flexibility of incinerating varying mixes of material	High flexibility. Unit can burn cleanly 0 percent to 100 percent of any type of material.
Processing tolerance	
- Metal	Good for small metal objects.

FIGURE K-3
LASL CONTROLLED AIR INCINERATOR⁶

- Large objects Good, although objects occupy space in the combustion chamber. They do not affect the process.
- Other non combustibles Fair. Glass may soften and adhere to the refractory making it difficult to remove.

PROCESS OPERATING CHARACTERISTICS

Combustion chamber

- Primary 500 to 800°C (starved air); operation is non-turbulent.
- Secondary (afterburner) 1,000 to 1,500°C (oxygen enriched). Operation is turbulent.

Operating variables controlled

Waste feed rate, fuel, and air supply are used to control the temperature and time of combustion. Temperature is modulated for improved combustion.

Material added

None.

Corrosive gas

HCl and SO₂.

Off-gas treatment

- Dry scrubber Wet scrubbing system is used.
- Wet scrubber The high-temperature incinerator exhaust is first cooled to saturation by a water spray quench system, then routed through a high-energy venturi particulate scrubber, a packed-bed absorber, a water cooled condenser, a heater, a roughing filter, and two HEPA filters in series.

Secondary waste generated

Secondary wastes generated by the process are the neutralized off-gas scrubber solutions.

Construction materials

- Incinerator interior High-density, 2,000°C refractory material line both chambers. Mineral

wool insulation is installed between the refractory and the shell. The inside of the shell is coated with five millimeters of industrial mastic. The outer shell is made of carbon steel.

- Incinerator hearth

The incinerator hearth is made of refractory material.

- Off-gas equipment

The off-gas equipment is constructed of materials resistant to HCl and other acids. Extensive use is made of fiberglass-reinforced plastics (FRP), Hastelloy, and mastics.

Maintainability/reliability

- MTBF

One of the critical components is the combustion chamber refractory lining. The life of this lining is estimated to be a minimum of one year (or 6,000 operation hours). Because the combustion unit is commercially available and is relatively inexpensive (approximately \$40,000), it is planned to scrap the old unit when it requires repair and replace it with a new unit rather than repair the old unit. This procedure should be more economical.

- MTTR

- Corrosion

The entire system (particularly the off-gas subsystem) is engineered to be as corrosion resistant as possible by extensive use of FRP, Hastelloy, mastic, and other corrosion resistant materials.

- Routine Maintenance

Normal for a controlled-air incinerator. No moving parts in the combustion zone.

Startup/shutdown operation

No particular problems are encountered in unexpected shutdown operations.

Capability for remote operation

Good.

OUTPUT CHARACTERISTICS

Residue form	When combustible materials are burned, dry ash, which is thermally and radiolytically stable is produced. Average composition contains 0.3 percent carbon.
Residue inert	Yes.
Residue stabilized	No.
Process effluents	Process effluents are combustion gases and neutralized off-gas scrubber solutions (NaCl).

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system	No positive ash removal system is provided; therefore, plutonium may be held up if the ash is not completely removed from the incinerator hearth.
Material accounting	Good.
Criticality	Good.
Containment	Because the incinerator can be relatively easily sealed, containment should not be difficult.

PRESENT STATUS

A controlled-air incinerator has been installed at LASL and is undergoing tests on nonradioactive and radioactive materials.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages	Limited air input to the primary chamber reduces ash containment while producing well-controlled reaction.
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Concept assures complete corrosion.

Concept uses commercially available incinerator.

System has large flexibility in processing varying types of waste.

Disadvantages

Possible corrosion of off-gas cleanup system due to HCl. (This has been minimized and engineered against by use of FRP and other corrosion resistant materials.)

Ash removal is not positive.

Possible migration of radioactivity (TRU) into refractory lining.

2.1.4 CYCLONE DRUM

Dissatisfaction over the incineration system in the plutonium recovery at Mound led to the search for alternatives and eventual development of the Mound cyclone incinerator. The cyclone system provides not only effective combustion but basic design, low capital cost, and the advantages of easy scaleup. The cyclone system went into operation at the end of FY 1975 to demonstrate the effectiveness of the system to incinerate materials such as paper, rags, wood, and various types of plastics and rubber. On the basis of results from this demonstration, modifications were made to permit incineration of contaminated materials. In December 1976, incineration of contaminated wastes generated at the plutonium processing facility at Mound was initiated.

GENERAL DESCRIPTION

The incinerator (Figure K-4) burns waste in a vertical chamber with air forming a swirling motion in the burning chamber. The swirling air cools the outer walls of the incinerator and provides intimate contact with the waste.

FIGURE K-4
MOUND LABORATORY CYCLONE INCINERATOR⁶

The combustible materials may be handloaded into a stainless steel burning chamber, or alternately, a preloaded 0.2-cubic-meter drum may be used as the burning chamber. The acids, gases, and fly ash in the off-gas stream are scrubbed and filtered to collect the ash and particulate matter.

CAPACITY

14 to 19 kilograms per hour when operating on a batch basis using the drums.
31 kilograms per hour when operated as a continuous process.

INPUT CHARACTERISTICS

Type of materials incinerated	The combustible contents of the 55-gallon (210-liter) drums of radioactive waste are incinerated. All combustible wastes such as cloth, paper, polyvinylchloride, polyethylene, and rubber are burned.
Flexibility of incinerating varying mixes of material	Good.
Processing tolerance	
- Metal	Good. Pieces 0.4 meters by 0.3 meters by 0.3 meters can be tolerated.
- Large objects	Good.
- Noncombustibles	Good.
- Material pretreatment	For in-situ burning, no pretreatment is used. For batch process, sorting and shredding is used.

PROCESS OPERATING CHARACTERISTICS

Combustion Chamber

- Primary	1,100°C turbulent excess air.
- Secondary (afterburner)	None.

Operating variables
controlled

Waste feed, fuel, air, temperature.

Material added

Manual ignition using torch or match is used to start the drum contents burning. Sodium carbonate is added for acidic neutralization.

Corrosive gases

HCl.

Off-gas treatment

- Dry scrubber
- Wet scrubber

Not used.

Wet scrubbing system. Off-gas is cooled and neutralized in a deluge chamber. Next it is filtered in a self-cleaning bed fiber filter. The liquid is filtered and recycled.

Secondary waste generated

Combustion gases and spent neutralized scrub solution.

Construction materials

- Incinerator interior
- Incinerator hearth
- Off gas-equipment

316 stainless steel.

Metal drum.

Standard for wet scrubbing of corrosive acids.

Maintainability/reliability

- MTBF
- MTTR
- Corrosion
- Routine maintenance

Unknown.

Unknown.

None.

Typical.

Startup/shutdown
operations

None.

Capability for remote
operation

Fair.

OUTPUT CHARACTERISTICS

Residue form	Dry ash, when burning combustibles. Salt powder is also produced from in-situ neutralization of the HCl produced.
Residue inert	Not completely.
Residue stabilized	No.
Process effluents	Combustion gases and spent neutralized scrub solution.

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system	No refractory material in the combustion chamber. Plutonium captured in leaf filter.
Material accounting	Unknown.
Criticality	Unknown.
Containment	Unknown.

PRESENT STATUS

Demonstrated in cold pilot plant at batch rates above 5 kilograms per hour. Technology should be available in 1978 commercial plants.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages	Combustion can be carried out directly in the storage container (0.2-cubic meter drum). No expensive fixed combustion equipment Adaptable for in-plant operations
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Disadvantages

Particulate in off-gas

Criticality limitation on capacity and disposal of scrubber solution.

Wastes are not completely oxidized. Some carbon remains.

2.1.5 FLUIDIZED-BED INCINERATOR

The fluidized-bed incineration system, shown in Figure K-5, was developed at Rocky Flats Plant in an effort to overcome problems experienced during several years of conventional incineration of radioactive scrap at the plant. The problems included high maintenance for equipment corrosion and refractory replacement, difficulties in recovering refractory-type plutonium oxide residues, problems with aqueous off-gas scrubbing, and production of additional waste from refractory disposal and scrubbing solutions. The fluidized-bed concept was chosen because it offers a method for low-temperature operation to eliminate the need for refractories, and it prevents the formation of high-fired PuO_2 residues. In addition, it provides a means for in situ acid gas neutralization to prevent equipment corrosion and to eliminate the need for aqueous off-gas scrubbing. The elimination of aqueous scrubbing makes the system ideal for processing scrap as well as waste. In addition, the simplicity of the system and the maintenance requirements (elimination of scrubber, less equipment corrosion, and no refractories) made the fluidized-bed incinerator an ideal candidate for remote operations. The advantages were proven by laboratory-scale work that led to the installation of a 9 kg/hr pilot unit that is still in use. The system is undergoing tests on a production-scale installation (83 kg/hr unit).

GENERAL DESCRIPTION

The fluidized-bed incinerator is a vertical cylinder made of stainless steel plates with a vee bottom. Two air distribution plates form the sides of the vee with a screw discharge conveyor forming the bottom of the vee.

FIGURE K-5²¹

FLOW DIAGRAM FOR PILOT PLANT FLUIDIZED
BED INCINERATOR

The shredded wastes are introduced beneath the surface of the fluidized bed of sodium carbonate material by a screw compression feeder. The heated combustion air introduced at the bottom of the bed agitates and causes the sodium carbonate material to act as a fluid. This action improves mixing and combustion of the feed material. The salt bed material helps stabilize the temperature because of its heat dissipation properties and mass. The sodium carbonate bed material provides in-situ neutralization of the acid combustion products, such as HCl. This neutralization simplifies the off-gas treatment system and permits use of less expensive construction materials.

CAPACITY

Planned capacity is 80 kilograms per hour (commercial application in 1980s).

INPUT CHARACTERISTICS

Type of materials

The unit incinerates all combustible solids and liquid wastes including small amounts of noncombustible liquids. Shredded solids are fed through a compression screw; liquids are fed through a pipe.

Flexibility of incinerating varying mixes of material

Good.

Processing tolerance

- Metal
- Large objects
- Other noncombustibles

Good; small metal objects fall to the bottom of the bed and are removed.

A few metal objects up to 8 inches long by 2 inches wide by 1/4 inch thick can be tolerated in the bed.

Glass in small pieces should present no process problem.

Material pretreatment

Consists of hand sorting, coarse shredding (5/8 inch wide in one dimension), air classifying, and fine

shredding (Note: The fine shredding operation might be eliminated depending upon the results of future tests.)

PROCESS OPERATING CHARACTERISTICS

Combustion chamber

- Primary Operates at 525 to 625°C (starved air) with 15 to 25 percent oxidation.
- Secondary (afterburner) A catalytic fluidized-bed afterburner operates at 550°C oxygen enriched.

Operating variables controlled

Waste feed rate, nitrogen added to air, fuel, temperature, and additional bed material, Na_2CO_3 .

Material added

The primary bed material is Na_2CO_3 ; the afterburner catalyst materials are Cr_2O_3 - Al_2O_3 . Nitrogen gas (to regulate primary bed combustion rate) is added.

Corrosive gas

No corrosive gases are produced; HCl is neutralized in situ.

Off-gas treatment

- Dry scrubber Off-gas treatment is accomplished by a dry scrubber unit consisting of a secondary cyclone filter, a sintered metal filter, and HEPA filters.
- Wet scrubber None

Secondary waste generated

Bed material (Na_2CO_3) and catalytic material (Cr_2O_3 + Al_2O_3).

Construction materials

- Incinerator interior Because of the low operating temperature the fluidized-bed reactor can be made of stainless steel plate (316). Refractory material is not required.

- Incinerator hearth

Distributor plate is made of stainless steel (316).

- Off-gas equipment

No corrosive gases are present in the off-gas. Therefore, the off-gas equipment need not be made of acid-resistant materials.

Maintainability/reliability

- MTBF

The fluidized-bed stainless steel reactor vessel is estimated to last 10 years.

- MTTR

The infeed material screw and the outfeed residue screw will require maintenance, although this should be small.

- Corrosion

No corrosion problems are anticipated.

- Routine maintenance

Because of the low operating temperatures, stainless steel linings, and in-situ neutralization of the HCl, the maintainability requirements of this system should be low and the reliability should be high.

Startup/shutdown operations

Startup and shutdown operations are normal. The reactor vessel will have to be brought up to the operating temperature slowly and uniformly. Similarly, in cooling down the unit, it should be done slowly.

Capability for remote operation

Good.

OUTPUT CHARACTERISTICS

Residue form

Inert dry oxide ash (less than 12 to 15 microns in size) mixed with dry salt powder. This is the product when burning combustible wastes.

Residue inert

Yes.

Residue stabilized

No.

Process effluents

Acid-free combustion gases.

HEALTH AND SAFETY

Possibility of plutonium
holdup or entrapment in
system

Because the fluidized-bed reactor is made of stainless steel, there will be little migration of plutonium into the metal. This plutonium migration will be less refractory materials that are used in all other incinerators.

Material accounting

Good; minimum inventory of unburned waste material in process at any one time. The material is oxidized quickly after it comes in contact with the hot bed material.

Criticality

Very good because of the small in-process material quantity and the elimination of a wet scrubbing system.

Containment

Readily accomplished.

PRESENT STATUS

Demonstrated in a nonradioactive pilot plant at 9 kilograms per hour. The plant is now burning TRU non-line-generated solid and liquid wastes. A radioactive demonstration plant is being designed to handle 80 kilograms per hour. It will be completely tested, ready for full scale operation in 1980.⁹

Aerojet Energy Conversion Corporation is marketing a fluidized-bed incinerator to the commercial nuclear industry.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages

Low uniform operating temperature (approximately 550°C); therefore, refractory linings are not required.

In-situ neutralization of HCl and other corrosive gases. This reduces corrosion problems and simplifies the off-gas system.

Half the size of conventional incinerators

The fluidized bed improves combustion efficiency

Disadvantages

Sorting and shredding required of feed waste material

For optimum operation, feed material should be free of metals and other combustibles to eliminate unnecessary loading up of fluidized bed. Therefore, good sorting is recommended.

However, because these noncombustibles do not combine with the bed material, the fluidized bed can tolerate a certain amount of tramp metal and other foreign materials and still perform satisfactorily. Periodically a portion of the bed material can be drawn off the foreign material removed, and the cleaned Na_2CO_3 returned to the bed for reuse.

2.1.6 MOLTEN-SALT COMBUSTION SYSTEM

The molten-salt combustion system was developed at Atomics International, to provide a combustion process which is applicable to a wide variety of energy-related technical objectives. One of the principal areas of application is the processing of radioactive waste. Development of the process has proceeded to the point of demonstration of TRU waste processing in a bench-scale pilot plant. A 45 kg/hr plant has been designed and is ready for installation at INEL (the DOE site at which the full-scale process would be demonstrated).

GENERAL DESCRIPTION

The combustor (Figure K-6) is an alumina brick-lined cylindrical salt incinerator. The molten salt sodium carbonate serves as a heat transfer medium and as a neutralizing agent for acidic gases such as HCl and SO₂ formed during combustion. Molten sodium sulfate is also in the molten bath and is used to catalyze the combustion reactions and to minimize the evolution of carbon monoxide and volatile hydrocarbons.

The combustible wastes are burned with air in this molten bath. Inorganic products (metallic oxides, ash, sodium chloride, and radioactive material) are retained in the melt. The salt ash product is either cast in storage drums or processed to recover the salt and the transuranics.

The off-gas cleanup problems in the molten salt process are considerably simplified due to the in situ neutralization of HCl. The non-acidic combustion off-gases pass through a mist eliminator, a water cooler, and a baghouse; then through a heater and a bank of HEPA filters before venting to the atmosphere through a stack. The particulate cake from the baghouse is recycled back to the salt reactor.

CAPACITY

Combustion has been demonstrated in a pilot plant with 50 kilograms per hour with uncontaminated waste. The system is operational for contaminated waste.

INPUT CHARACTERISTICS

Type of materials
incinerated

Combustible materials (solids, liquids, resins, and filter sludges) and many inorganic solids, including HEPA filters and metal tubings.

Flexibility of incinerating
varying mixes of materials

Good.

FIGURE K-6
AI'S MOLTEN SALT COMBUSTION UNIT⁶

Processing tolerance

- Metal Fair; all foreign materials load up the molten salt bed which has to be periodically cleaned. The time to oxidize is related to the surface area (particle size).
- Large objects Poor; because it would take too long to oxidize the material, and the present infeed is through a 12-centimeter screw feeder.
- Noncombustible Fair.

Material pretreatment

Sorting to remove large tramp metal and shredding to 1-centimeter size.

PROCESS OPERATING CHARACTERISTICS

Combustion chamber

- Primary Molten salt bath operates at 800 to 850°C.
- Secondary (afterburner) None.

Operating variables controlled

The temperature of the salt bath is monitored, and the waste feed rate is controlled. The chemical composition of the salt bath is controlled.

Material added

Salt bath (90 percent sodium carbonate, 10 percent sodium sulfate).

Fuel for bath startup is propane
Coke as a fuel is added to maintain bath temperature.

Corrosive gas

Little corrosive gases are generated because of the in-situ neutralization of the chlorine.

Off-gas treatment

- Dry scrubber A dry scrubbing system is used, with a mist eliminator, water cooler, and

a bag house. Then the off-gases are sent through a heater and a bank of HEPA filters.

- Wet scrubber

Not used.

Secondary waste generated

When the ash (residue) load in the salt bath reaches 20 to 25 percent of the total bath, it must be removed. With a bath loading of 25 percent, 3 kilograms of contaminated salt are generated for each one kilogram of residue from either oxidation or non-combustible material.

Construction material

- Incinerator interior
- Incinerator hearth
- Off-gas equipment

Refractory-alumina brick lining.

None

Standard.

Maintainability/reliability

It is estimated that the maintenance cycle for the salt bath will be the following frequency based on the 50 kilogram-per-hour rate and average waste composition:

- MTBF
- MTTR
- Corrosion
- Routine maintenance

Weekly the salt bath will be partially cleaned by draining off 1/3 of the bed and replacing it with clean material.

Monthly the salt bath will be completely drained and fresh salt used. (This operation is estimated to require 2 days downtime).

Minimized because of in-situ neutralization of the HCl.

Salt bath cleaning; see above. One shift required to draw off salt bath and recharge.

Startup/shutdown operations

Requires gradual heat up of the molten salt bath to combustion temperatures to thermally equalize the refractory. The startup rate should be 40°C-per-hour temperature rise.

The shutdown rate should be 80°C-per-hour temperature cooldown.

Capability for remote operation

Good.

OUTPUT CHARACTERISTICS

Residue form

Solidified fused salt cake contains 20 wt percent ash and 80 wt percent salt bath material. The fused salt cake may be further processed to separate the ash from the salt bath material, which may be reused.

Residue inert

Yes.

Residue stabilized

No - residue is immobilized in the salt cake.

Process effluents

Process effluents are nonacidic combustion gases. There is Low NO_x (-30 ppm in off-gas).

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system

The plutonium will stay in suspension in the salt bath increasing in concentration until the bath material is drained and the ash removed. In bench scale tests over 99.9 percent of the plutonium was contained in the salt melt.

Material accounting

No experience.

Criticality

Critical control is good. Salt bath reduces criticality problem.

Containment

No experience.

PRESENT STATUS

Demonstrated on a pilot-plant scale (50 kilograms per hour) with noncontaminated waste (1977).

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages

Practically all radioactive materials remain in the salt.

Acidic gases and some particulate matter are trapped in the molten salt.

Metals and glass are readily dissolved in the molten salt.

No contaminated liquid scrubber waste is generated.

Pu can be readily recovered from salt cake.

Disadvantages

A supplemental heat source is required to maintain salt in molten condition during short shutdowns.

Sodium chloride solid waste is generated with incinerator ash. Ash is only 20 wt percent of the output residue.

Particulate loading exists in the off-gas (primarily sodium chloride).

Possibility of some radioactive (TRU) migration into the refractory lining (99% of Pu retained within melt).

2.1.7 PYROLYSIS-CONTROLLED-AIR INCINERATOR³⁸

GENERAL DESCRIPTION

A pilot model and full-scale prototype, illustrated in Figure K-7, has been built at the Savannah River Plant for test incineration of wastes containing high specific activity contamination which create a serious hazard. The ceramic primary chamber is heated by electric heaters in the top of the chamber. This chamber has starved air atmosphere. The off-gases then pass into an oxygen rich secondary chamber for complete combustion and are scrubbed in three independent scrub systems. The ash is pushed into a vertical chute for removal as new material is positioned by the ram feeder.

FIGURE K-7

SRP CONTROLLED-AIR INCINERATOR³⁸

CAPACITY

0.5 kilograms per hour (pilot)

5.5 kilograms per hour (prototype)

INPUT CHARACTERISTICS

Type of materials
incinerated

Combustibles.

Flexibility of incinerating
varying mixes of material

Unknown at this time.

Processing tolerance

- Metal
- Large objects
- Noncombustibles

Untested.

Untested, because of size of model.

Untested.

PROCESS OPERATING CHARACTERISTICS

Combustion chamber

- Primary
- Secondary
(afterburner)
- Operating variables
controlled
- Material added
- Corrosive gases

1,000°C, electrically heated Inconel
601 roof on a U-shaped cast refrac-
tory channel.

1,000°C, eight electric heaters in a
labyrinth secondary chamber.

Temperature, time.

None.

Not tested.

Off-gas treatment

- Dry scrubber
- Wet scrubber

Experimental at this time.

Experimental at this time.

Construction materials

- Incinerator interior	Ceramic (refractory) and Inconel 601.
- Incinerator hearth	Ceramic.
- Off-gas equipment	Being developed.

Maintainability/reliability

- MTBF	Unknown.
- MTTR	Unknown.
- Corrosion	Unknown
- Routine maintenance	Unknown.

Startup/shutdown operations

No problems; just turn off electric heaters.

OUTPUT CHARACTERISTICS

Residue form	Ash with unoxidized carbon is produced when burning combustible materials.
Residue inert	No.
Residue stabilized	No.
Process effluents	Off-gas.

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system	Unknown.
Material accounting	Unknown.
Criticality	Untested.

Containment

Unknown.

PRESENT STATUS

Prototype in testing and data gathering phase.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages

Low particulates in the off-gas

Long residence time for burning the off-gas in the secondary chamber

Controlled throughput to handle safely high specific activity waste.

Disadvantages

Possible corrosion of exposed metal surfaces with large quantities of polyvinylchloride

Only combustibles are treated in pilot model.

Possible radioactivity (TRU) migration into the refractory lining.

2.1.8 ROTARY-KILN INCINERATOR

Use of a rotary kiln incinerator for combustion of radioactive wastes has been under development at Rocky Flats since about 1972. The process has been successfully demonstrated in a cold pilot plant at 2 kg/hr. An engineering-scale unit with a design capacity of 40 kg/hr is currently being designed for installation and operation at the Rocky Flats Plant for treatment of transuranic wastes containing < 0.02 g Pu/kg waste.⁶

GENERAL DESCRIPTION

The rotary-kiln incinerator (Figure K-8) is an inclined, horizontal cylindrical kiln (1.8 meters ID by 4.6 meters long) rotating on its longitudinal axis about 1 to 2 rpm.

FIGURE K-8
 ROCKY FLATS ROTARY KILN INCINERATOR⁶

The waste materials are fed by a ram feeder to the upper end of the kiln. The rotary action of the kiln exposes unburned material for combustion and causes the waste to move slowly in a cascading manner through the kiln. The ashes from the incinerator continuously discharge out the exit end into an ash hopper. Combustible wastes, solid and liquid, HEPA filters, sludges, and ion exchange resins are burned or calcined in this diesel-fired kiln at 600 to 800°C. Off-gases pass through an afterburner at 1,000°C, a wet scrubbing system, and HEPA filters prior to release to the atmosphere.

CAPACITY

A demonstration plant designed to process about 40 kilograms per hour is estimated to be operational in 1980.

INPUT CHARACTERISTICS

Type of materials	All plutonium-bearing combustible solid and liquid wastes, HEPA filters, and aqueous wastes, etc.
Flexibility of incinerating varying mixes of materials	Good.
Material pretreatment	Sorting, shredding, scarfing of graphite molds, and crushing of HEPA filters.
Processing tolerance	
- Metal	Good.
- Large objects	The rotary kiln can handle larger objects than can be handled in most other radioactive waste incinerators.
- Other noncombustibles	Tolerance to glass and other noncombustibles is good.

PROCESS OPERATING CHARACTERISTICS

Combustion Chamber

- Primary Operates at 600 to 800°C, depending on the material. Residence time is 1 hour. Atmosphere can be neutral to slightly reducing.
- Secondary (afterburner) Operates at 1,000°C. Residence time is 5 seconds. Oxygen enriched.

Operating variables controlled

Waste fed material, fuel, air, time, and temperature.

Material added

None.

Corrosive gas

HCl.

Off-gas treatment

- Dry scrubber
 - Wet scrubber
- Wet scrubbing system is used. Off-gases leave the afterburner and pass through primary and secondary venturi scrubbers for removal of HCl and fly ash. Gases are finally routed through four stages of HEPA filters.

Secondary waste generated

Spent scrubbing solutions.

Construction materials

- Incinerator interior Refractory brick-lined.
- Incinerator hearth None.
- Off-gas equipment Typical of wet scrubbers.

Maintainability/reliability

- MTBF Estimate life of a rotating refractory lining is 1 to 2 years. It is shorter than the life of linings used in stationary nonrotating incinerators.
- MTTR Repair of the refractory lining may be hazardous because of the radioactivity level buildup in the refractory caused by the penetration of the radionuclides into the lining.

- Corrosion

HCl corrosion of the mechanical items may cause maintenance problems.

- Routine maintenance

Typical for the mechanical rotating equipment used for the kiln.

Startup/shutdown operations

In an emergency shutdown, the rotary kiln must be kept rotating and gradually cooled down; otherwise thermal stresses, etc., will cause the kiln to warp and sag cracking the lining and damaging the kiln.

Capability for remote operation

Good.

OUTPUT CHARACTERISTICS

Residue form

Inert dry oxide is produced when burning combustible material.

Residue inert

Yes.

Residue stabilized

No.

Process effluents

Combustion gases and acidic and spent alkaline scrub solutions containing fly ash.

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system

The buildup of high radioactive levels in the refractory lining because of the migration of radioactive nuclides (including plutonium) into the lining could cause maintenance problems. Repairing the lining will be difficult.

Material accounting

Good.

Criticality

Continuous ash discharge reduces the problem of criticality buildup.

Containment

More complex than for other types of incinerators because of the potential leakage from the rotary seals.

PRESENT STATUS

Demonstrated in a cold pilot plant at 2 kilograms per hour. A demonstration plant is now being designed to process about 40 kilograms per hour. The plant will be installed at Rocky Flats and will be ready for processing plutonium-contaminated wastes in 1980.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages

Complete automatic ash removal

Continuous discharge of ash, minimizing criticality problem

Rotating action of kiln continually exposes fresh surface of waste, enabling more rapid and complete combustion

Will accommodate tramp metal up to 6 inches in diameter

Can burn melted or liquid materials

Minimum radioactivity (TRU) inventory in system during operation because of continuous ash removal.

Industrially proven process

Average residence time of solids is 1 hour in the kiln.

Disadvantages

Difficult to maintain good seals on the rotary kiln

Rotating kiln should result in a shorter refractory life

May have incomplete graphite combustion

Possible radioactivity (TRU) migration and build-up in the refractory linings.

2.1.9 SLAGGING PYROLYSIS INCINERATOR

A slagging pyrolysis incinerator (Figure K-9) is being considered to handle the large-scale incineration of stored and buried TRU-contaminated waste and soil.¹⁵

GENERAL DESCRIPTION

The incinerator is designed with a conical primary chamber. A burner is directed downward from the apex of the cone. The waste material is fed from a ring column confined by an outer shell. Plows attached to the outer shell force the waste toward the center of the furnace floor. A hole in the floor provides an outlet for the gases as well as the molten slag. As the waste is burned and melted a combustion chamber is formed by the waste itself. The slag residue coats the entire combustion chamber and then drips into the quenching pool below the hole in the floor. Added air is fed along the sides through the waste for combustion in the secondary chamber. Between the slagged waste surface and the waste supply are zones of pyrolysis and oxidation. The off-gas is burned in an oxygen-rich secondary chamber.

CAPACITY

100 kilograms per hour.

INPUT CHARACTERISTICS

Type of materials
incinerated

A mixture of combustible and non-combustible materials; very little PVC at this time.

Flexibility of incinerating
varying mixes of material

Some adjustment can be made to the operation when the heat content of the material drops (increase time to slagging). Supplemental fuel may be required depending upon waste fuel control. Sand can be added to the input mix to create a slag when a high percentage of combustibles is present.

Processing tolerance

- Metal	Good. Metal melts into slag.
- Large objects	Poor. Present CEN system at Mol, Belgium, requires material sized to 5 centimeters maximum dimension.
- Noncombustibles	Good. Noncombustibles are required for the slagging of output material
- Material pretreatment	Sizing; all material must be sized to 5 centimeters or less in any dimension.

PROCESS OPERATING CHARACTERISTICS

Combustion chamber

- Primary	1,500 to 1,600°C; fuel-oil-fired burner air at 30 to 60 percent excess.
- Secondary
(afterburner)	1,100 to 1,200°C; air at 40 percent excess.

Operating variables controlled

The residence time for the waste is dependent on the melting and slagging characteristics of waste. Waste feed rate, sand, fuel, air, and temperature are used as controlling variable.

A pressure rise in the primary chamber requires an adjustment in the waste feed and level control.

Material added

Sand may be added to increase slagging. Na_2CO_3 may be added to react with HCl in the primary chamber

Corrosive gases

HCl may be scrubbed in the off-gas treatment area. Other dangerous chemicals are decomposed in the pyrolysis zone.

Off-gas treatment

- Dry scrubber
- Wet scrubber

The off-gas system is a wet and dry combination. The gas goes first to an input air preheater, then to a heat exchanger. The off-gas is then filtered through a sand panel bed. From there it goes into a second heat exchanger and then to a caustic wet scrubber. From that point the off-gas goes to a preheater, through the HEPA filters, a second preheater and to the stack.

Secondary waste generated

The liquid from the wet scrubber is the only process waste because the fines from the sand filter are fed back into the incinerator.

- Incinerator interior
- Off-gas equipment

Refractory, tamped.

Standard for wet and dry systems.

Maintainability/reliability

- MTBF
- MTTR
- Corrosion
- Routine maintenance

The Mal operation has logged over 1,200 hours of batching operation. No maintenance has been required.

None.

Cleaning of the burner and viewports; removing fly ash from the secondary chamber.

Startup/shutdown

No problem; a wooden cone has been used as an aid for initial startup.

Capacity for remote operation

Yes, with maintenance by men in bubble suits.

OUTPUT CHARACTERISTICS

Residue form

Basaltic-like glassy slab.

Residue inert

Yes.

Residue stabilized	Yes, depending on leaching requirements.
Process effluents	Scrubbed gas; wet scrubber solution.

HEALTH AND SAFETY

Possibility of plutonium holdup or entrapment in system	Unknown.
Material accounting	No experience.
Criticality	No experience.
Containment	No experience; an explosion within the primary chamber could cause severe mechanical damage.

PRESENT STATUS

Mol (pilot plant) will begin test of beta-gamma contaminated material in 1978 with alpha material to follow.

SYSTEM ADVANTAGES AND DISADVANTAGES

Advantages	Control of ash leachability, radioactive material bonded physically and chemically in glass, high volume, and weight reduction.
Disadvantages	Some control of waste material mix must be maintained.

2.1.10 BPNL PYROLYSIS INCINERATOR

Development of a pyrolysis process for the recovery of silver from photographic negatives was initiated at Battelle Pacific Northwest Laboratory in 1969. This work was followed by development of a pyrolysis-incineration process for municipal refuse sponsored by the Environmental Protection Agency and the City

of Kennewick, Washington. Advantages inherent in the process, primarily production of an essentially ash-free off-gas and simple, safe operation, led to its adaptation for processing transuranic-contaminated solid wastes. Nonradioactive studies on pyrolysis of wastes typical of the nuclear industry were initiated in 1974.

PROCESS OPERATING CONDITIONS AND FEATURES

Shredded combustible wastes are fed into the top of a 28 cm diameter by 2.1 m high vertical shaft retort through a lock hopper and auger feed system, as shown in Figure K-10. The vertical retort is made of refractory-lined carbon steel. A compactor pushes the waste material down the vertical shaft and distributes the material over the cross-section of the retort. The waste materials form a deep, fixed bed in the retort. They are dried, pyrolyzed, and converted to an ash at the base of the bed as they descend countercurrent to 1200°C gases produced by combustion of carbonaceous pyrolysis products with air in the lower reaction zone. At steady state, the bed of waste material in the reactor consists of the following zones from bottom to top:

- An ash layer approximately 20 cm deep which is continuously discharged through a rotary grate and a star valve at the base of the reactor
- A 15 cm high combustion zone in which all the heat for the process is generated by reaction of the oxygen in air with carbonaceous residue from pyrolysis of waste in the next upper zone
- A pyrolysis zone, approximately 50 cm high, in which the waste material is pyrolyzed by hot gases rising from the combustion zone
- A preheat and drying zone from 40 to 80 cm high in which the waste is dried and preheated by rising hot gases as it starts its descent through the retort.

The waste is ignited initially by charging about 5 kg of ignited charcoal to the empty chamber, starting the air flow and introducing the shredded waste. Use of a heating element or external furnace at the lower end of the pyrolysis chamber would be alternative methods for igniting the waste.

FIGURE K-10

BATTELLE PACIFIC NORTHWEST LABORATORY
PYROLYSIS INCINERATOR

Superficial linear gas velocities in the upper zones of the retort are generally less than 15 cm/sec. At these low flow velocities and with the filtering action of the upper zone of waste material, very little carryover of ash material occurs. The gases are laden with pyrolysis products (HCl, moisture, and hydrocarbons) and combustion products (H_2O , CO_2 , and CO) which are burned in a low calorific gas burner. Although the gases are sufficiently low in aerosols to meet federal air quality standards for stack gas emissions, they would require treatment with absolute filters in applications to radioactive wastes.

The pyrolysis system can be altered to retain chlorides, which are currently vented with the gas stream. Solid sodium carbonate can be added to the main reactor with the combustible wastes, in which case most of the chlorides would be retained by the ash.

STATUS OF DEVELOPMENT

The basic pyrolysis-incineration process has been demonstrated using simulated non-radioactive wastes at a rate of 15 kg/hr in the pilot plant retort. A high-density, alumina refractory has been found suitable as the construction material for the main reactor vessel. Development work on the pyrolysis-incinerator for treating TRU-contaminated wastes has been suspended.

2.1.11 WINDSCALE (UK) PYROLYSIS INCINERATOR

Since 1950, various radioactive waste incinerators have been operated in the United Kingdom with mixed success. The problem of efficient combustion of heterogeneous radioactive wastes led to the development of a pyrolysis incinerator. A pilot plant test unit was constructed at Windscale and begun operation with radioactive wastes in early 1973 at an average feed rate of 5 kg/hr.

PROCESS OPERATING CONDITIONS AND FEATURES

Shredded combustible waste materials packaged in small cardboard cartons are fed to an electrically-heated, horizontal Inconel tube 30 cm in diameter by 2 m

long, shown in Figure K-11. A feed ram is used to push the material through the furnace and maintain a gas flow path. The wastes are pyrolyzed at about 900°C in the air-deficient tube. Volatilized materials pass to a secondary chamber where combustion of the off-gases occurs in an excess of air at about 1000°C. The secondary chamber is a brick-lined labyrinth containing electrical heating elements enclosed in aluminous porcelain tubes. The ashes which accumulate during the process are displaced from the furnace into an ash pit by the feed ram, which projects into the furnace. Ashes are manually raked down a 15-cm diameter Inconel tube into a container attached to a flanged opening. Ashes are usually removed about every four days.

Off-gases leaving the secondary combustion chamber are air-cooled and then passed through a water spray column which further cools the gas and removes about 90 percent of the HCl and some particulate matter. The gases leave the scrubber at about 100°C and pass through two water-cooled condensers which remove the water vapor and residual amounts of HCl. The gas is then passed through a polyethylene felt roughing filter, a heater, and finally several banks of HEPA filters.

STATUS OF DEVELOPMENT

The technology has been successfully demonstrated in plutonium contaminated waste disposal and recovery operations. Additional work to assure complete carbon burnout and to develop improved furnace materials is continuing. A scaled-up production model is planned.

2.1.12 VORTEX INCINERATOR

A commercially-available Vortex Incinerator was installed in General Electric Company's uranium fuel fabrication plant in Wilmington, N. C., in 1972. The incinerator is used to recover uranium from large quantities of combustible wastes. Operating capacity of the unit is about 450 kg/hr.

FIGURE K-11
WINDSCALE (UK) PYROLYSIS INCINERATOR

PROCESS OPERATING CONDITIONS AND FEATURES

The Vorcinerator, illustrated in Figure K-12, is a high-performance, gas-fired, solid waste disposal system capable of handling a very large workload. It consists of a single-stage combustion chamber, approximately 1.4 m in diameter by 7.4 m long, having combustion rates 10 to 20 times greater than that of conventional model incinerator systems of similar size. These high rates are accomplished by the unique utilization of a cyclonic burning pattern. Shredded combustible wastes enter the burning chamber tangentially and pass through the burning chamber in the cyclonic pattern until complete combustion is achieved. Combustion takes place at 1000-1100°C within the chamber. During combustion, the gas flows to the center of the chamber, and centrifugal force causes the ash particles to spin to the outside of the chamber where they are expelled out the exhaust tube.

The gases and entrained particles pass from the incinerator into a titanium scrubber where the gases are cooled and fly ash and acidic vapors are removed. The gases leave the scrubber at about 100°C, pass through a mist eliminator, a heater, a prefilter, and finally through a bank of HEPA filters before being discharged. The scrubbing liquid, saturated with fly ash, is pumped through an inline filter bag/pressure vessel system. The filtered solution is recycled back to the scrubber tank. Filled filter bags are reprocessed for uranium recovery.

STATUS OF DEVELOPMENT

This unit is currently operational for uranium-contaminated solid wastes at General Electric's uranium fuel plant in Wilmington, N. C. Major development programs are not under way since the present unit satisfies the uranium recovery needs for which it was built. General process improvements are continually made to the unit during routine operation and maintenance.

FIGURE K-12
VORTEX INCINERATOR

2.1.13 MOVING GRATE INCINERATOR

The moving grate incinerator was developed for use in the Hanford Plutonium Reclamation Facility and has been in use since 1961 for recovery of plutonium from combustible waste materials. Throughput on the unit is about 10 to 20 kg per 8-hour day.

PROCESS OPERATING CONDITIONS AND FEATURES

The incinerator, illustrated in Figure K-13, consists of two horizontal tubular combustion chambers mounted one above the other and connected with four flue tubes. The lower, primary combustion chamber is a flat-bottomed semi-cylinder, 0.2 m in diameter by 3 m long. The tube is fabricated of Incalloy 800 and 321 stainless steel surrounded by 30 cm of firebrick insulation. A continuous, Nichrome-V woven-wire belt moves along the bottom of the chamber receiving the wastes to be incinerated at the front end and discharging the ashes into a hopper at the tail end. The primary chamber is maintained at a temperature of 700 to 800°C by external electrical resistance heating elements. The upper (secondary) combustion chamber is a 13 cm diameter Incalloy 800 tube which is also operated at 700 to 800°C. The off-gases from the primary chamber undergo further oxidation in the secondary chamber. Both chambers are operated with excess air.

The gases existing the secondary combustion chamber pass through two low-pressure-drop cyclone separators where larger particles are removed, then into a 316 stainless steel scrubber system which uses a solution of water, sodium hydroxide, and urea to remove the fly ash, HCl, and HClO. The scrubbed gases pass through a heater and several stages of absolute filtration before discharge to the main building stack.

STATUS OF DEVELOPMENT

The present incinerator has been used in Hanford's Contaminated Waste Recovery Facility since 1961 to recover plutonium from non-leachable combustible wastes. Plastics and rubbers are avoided whenever possible because of problems

FIGURE K-13
HANFORD'S MOVING GRATE INCINERATOR

with corrosion and soot. There are no major development programs for the incineration system described since the present unit satisfies the plutonium recovery needs for which it was built. This incinerator presents a practical design, but is subject to further improvement to reduce maintenance problems and to ensure complete oxidation of combustion products.

2.1.14 SRP WASTE SOLVENT INCINERATOR

At the Savannah River Plant (SRP), approximately 570,000 liters of waste solvent (kerosene and TBP containing about 45 curies of alpha activity and 45 curies of beta-gamma activity) are stored in underground tanks. Open pan burning was used until 1971 to dispose of this solvent but has since been discontinued because of the copious quantities of black smoke involved.

A "smokeless" solvent incinerator is being developed to permit disposal of the current waste solvent inventory. Because of the high decontamination factor for radioactivity with quiescent burning (DFs of 10^3 to 10^4 were reported for open pan burning), the design includes a quiescent pan burner for the first stage of the incinerator. Cold tests using 30 to 50 percent TBP in kerosene show that *"smokeless" burning can be achieved by burning the off-gases from the first stage in an auxiliary fired, forced draft incinerator.* A scrubber is required to remove the phosphate emissions which result from burning TBP.

PROCESS OPERATING CONDITIONS AND FEATURES

As shown in Figure K-14, waste solvent is fed to an open pan contained in the first stage of the refractory-lined steel incinerator where it is ignited by a pilot burner. Air provided by a blower provides the required oxygen for the reaction and controls the reaction temperature. Burning proceeds through combustion of gases volatilized from the quiescent liquid surface, thus leaving behind nonvolatile solutes and organic polymers. The gases are carried into the second stage burner, operated at 100°C by combustion of auxiliary fuel, to complete the oxidation of organic vapors and unburned carbon.

FIGURE K-14
SRP WASTE SOLVENT INCINERATOR

The off-gas is routed to a quench scrubber where it is cooled and the P_2O_5 from combustion of TBP is removed as phosphoric acid. The contaminated scrub water and the water-soluble residue left in the burner pan are sent in the low-activity liquid waste storage tanks for concentration by evaporation.

Radioactive material content of the feed will be limited based on the overall decontamination factor afforded by quiescent burning, scrubbing, and additional deentrainment or filtration equipment that may be added to the system. The limitations will not be established until after initial operation with radioactive solvent. The major problem anticipated is removal and disposal of the residue formed in the first stage. Carbon buildup on the walls of the pan in the first stage may also occur and could affect burning characteristics.

STATUS OF DEVELOPMENT

Quiescent, open pan burning has been demonstrated as an effective method for burning contaminated TBP solvents. Acceptable smoke emission control has been demonstrated in pilot plant tests of the two-stage system. A project for design and installation of a similar incinerator has been requested using a design basis of 75 liters/hr.

2.1.15 ALLIED-GULF NUCLEAR SERVICES (AGNS) WASTE SOLVENT BURNER

Organic liquid wastes generated at the AGNS fuel processing plant will be burned in a solvent incinerator (see Figure K-15) designed by AGNS and Oxy-catalyst, Inc., of West Chester, Pa.

PROCESS OPERATING CONDITIONS AND FEATURES

The waste solvent burner is a forced convection incineration unit as opposed to a passive oil burner. The solvent burner unit is composed of two vessels: the solvent burner combustion chamber and the solvent burner quench tower. The burner nozzle is positioned at the top of the combustion chamber directed downward. The nozzle has two sets of fuel ports, one set for natural gas, and the

FIGURE K-15
AGNS WASTE SOLVENT BURNER

second set for waste solvent. The combustion air is also supplied through the burner nozzle. The combustion chamber is lined with Inconel and surrounded by 10 cm of castable refractory insulation and a 304L stainless steel outer jacket purged with air.

The operation of the solvent burner is started by bringing the combustion chamber temperature to an operating temperature of 840°C by slowly increasing the flow of natural gas to the burner. After the operating temperature has been reached and stabilized, the waste solvent flow is started to the burner nozzle. The natural gas burns as a hollow cone with the solvent burning within that cone. The flow of natural gas is controlled by the temperature of the combustion chamber. As the flow of waste solvent increases and the temperature of the combustion chamber increases, the flow of natural gas decreases down to a predetermined minimum flow of natural gas. This minimum flow of natural gas is maintained to ensure that a flame would continue if the waste solvent flow is disrupted or stopped. This feature allows a mixture of solvent and aqueous solutions to be fed to the burner or even a total aqueous solution to be fed to the burner without shutting the unit down. The design capacity of the solvent burner is $\sim 0.3 \text{ m}^3/\text{day}$.

The combustion gases from the combustion chamber are passed through a quench tower to reduce the gas temperatures and to scrub the majority of the combustion products out of the gas. The scrubber solution is continuously recycled by airlift from the bottom of the quench tower to the top where it cascades downward over chevron plates countercurrent to the flow of the combustion gases. The specific gravity of the scrubber solution is controlled by a constant bleed to the intermediate-level liquid waste treatment system. Makeup water is automatically added as required to replace the solution lost by evaporation and the bleed-off. Off-gases leave the tower through a mist eliminator pad and are routed to the vessel off-gas system for further treatment.

STATUS OF DEVELOPMENT

The system is installed for use at AGNS. Similar systems are available commercially.

2.2 INCINERATOR LOCATIONS AND MANUFACTURERS

<u>Process Name</u>	<u>Location</u>
Acid Digestion	Hanford Engineering Development Laboratory Westinghouse-Hanford Company Richland, Washington 99352
Agitated Hearth	Atomics International Division Rockwell International Rocky Flats Plant Golden, Colorado 80401
Controlled Air	Los Alamos Scientific Laboratories University of California Los Alamos, New Mexico 87545
Cyclone Drum	Mound Laboratory Monsanto Research Corporation Miamisburg, Ohio
Fluidized Bed	Atomics International Division Rockwell International Rocky Flats Plant Golden, Colorado 80401
Molten Salt	Idaho National Laboratory EG&G Idaho, Inc. (Atomics International) Idaho Falls, Idaho
Pyrolysis	Savannah River Laboratory E. I. du Pont de Nemours Aiken, South Carolina
Rotary Kiln	Atomics International Division Rockwell International Rocky Flats Plant Golden, Colorado 80401
Slagging	S. A. Belgonucleaire CEN-SCK Waste Department Mol, Belgium

2.3 TRU WASTE INCINERATOR ANALYSES^{10, 12-15}

The following is a brief comparison of the various TRU waste incinerator concepts evaluated by various DOE contractors in support of the present TRU waste management programs. This synopsis was prepared from major DOE studies and reports including References 10 and 12 through 15. Tables K-1 through K-3 present typical evaluation criteria for TRU waste incinerator analyses.

2.3.1 INPUT

A major assumption in the waste treatment process is that no sorting of the waste material will be performed prior to treatment. Sorting of the retrieved waste material would expose operation personnel to excessive hazards. These hazards include industrial-type categories such as explosions, toxic materials, and handling hazards, along with additional radioactive exposure. For this reason, an analysis was made of the incinerator processes and the requirement of each process for sorting and/or sizing (shredding) of the waste material input. Several processes require sorting of one or more of the noncombustibles and/or liquid materials.

It is anticipated that many large items (large lathes and other tools and items of laboratory equipment) retrieved from the INEL TRU waste pits will require sizing for removal from the pit. It is expected that this rough sizing at the retrieval area will probably provide waste material in pieces not exceeding one meter in any dimension. Sizing below this point is considered an additional process. Several processes require sizing down to less than one inch. This amount of sizing would require considerable preparation prior to incineration and would increase the personnel exposure to industrial-type hazards.

Table K-4 shows the various processes and the material preparation required for each process. For example, in the controlled-air incinerator process, it is desired (but not required) that the waste material be separated and blended for heat content to improve the incineration process. In addition, it is desired (but not required) that glass, metal, and other noncombustibles be removed. It is required that liquids be removed to prevent possible explosions, etc.

TABLE K-1

PROPOSED EVALUATION CRITERIA OF THE DOE TASK GROUP
ON TRU WASTE TREATMENT TECHNOLOGY ASSESSMENT

1. Safety
2. Throughput
3. Adaptability (what types of waste)
4. Containment (emissions control)
5. Shielding
6. Size
7. Maintainability
8. Operability
9. Volume Reduction
10. Flexibility (incinerate all isotopes)
11. Natural resources used (materials and energy)
12. Immobilization of final ash
13. Effluent quantity
14. Recovery of isotope material

TABLE K-2
EVALUATION CRITERIA FOR INCINERATORS

Group 1 - "Musts"

The process must:

- Inert the waste
- Stabilize the residue
- Prepare waste according to WIPP criteria
- Handle from 300 to 600 thousand cubic feet of waste per year
- Input unsegregated waste
- Be operating full-scale by 1987
- Have provision for emergency power
- Be maintainable
- Be a safe operation in terms of material accounting, criticality, confinement, radiation exposure, and DOE and EPA exhaust gas requirements

Group 2 - "Wants"

- Maximize process simplicity
- Minimize the number of process parameters requiring control
- Minimize the time to maintain
- Minimize routine maintenance
- Maximize mean time between failures
- Minimize processing (operating) cost
- Minimize capital investment
- Minimize engineering development time
- Minimize engineering development cost
- Minimize engineering development risk
- Minimize radiation exposure of operating personnel
- Minimize Pu holdup or entrapment within processing system
- Minimize particulate load on offgas system
- Maximize capability for remote operation
- Maximize the volume reduction
- Minimize the generation of additional waste during process
- Minimize the use of additional fuel during the process
- Minimize startup problems
- Minimize shutdown problems
- Minimize the leachability of output residue
- Minimize the potential production of poisonous gases

TABLE K-3
COMPOSITE CRITERIA FOR EVALUATION OF INCINERATORS

1. State of development; technological risk; throughput potential
2. Adaptability to waste of varying physical and radiological characteristics
 - Sorting requirements
 - Other preprocessing
 - Tolerance of tramp metal, etc.
3. Post-incineration Waste Form
 - Volume reduction
 - Immobilization; stabilization
 - WIPP criteria compliance
4. Process Operating Characteristics
 - Operability; control
 - Maintainability; reliability
 - Corrosive or poisonous gases
 - Generation of liquid waste
5. General Safety
 - Explosion potential
 - Emissions
 - Radiation; shielding
 - Accountability; criticality
6. Cost; materials and energy requirements
 - Development
 - Installation
 - Operation
 - Decommissioning

CATEGORY	MATERIAL PROCESSING	SORTING					SIZING							
		HEAT CONTENT	GLASS	METAL	LIQUIDS	NONCOM- BUSTIBLES	NONE*		SIZED 1/2 INCHES		SIZED 3/4 INCHES		SIZED 1 INCH	
							FOR HANDLING	FOR PROCESS	FOR HANDLING	FOR PROCESS	FOR HANDLING	FOR PROCESS	FOR HANDLING	FOR PROCESS
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION	D	R	R	D	R	R	R	R	R	R	R	R	R
	AGITATED HEARTH	D	R	R	R	R	R	R	D	D	N	N	N	N
	CONTROLLED AIR	D	D	D	D	D	R	R	D	D	N	N	N	N
	CYCLONE DRUM	N	D	D	D	D	R	R	D	D	D	D	N	N
	FLUIDIZED BED	N	D	D	N	D	R	R	R	R	R	R	D	D
	MOLTEN SALT	N	D	D	N	D	R	R	R	R	R	R	R	R
	PYROLYSIS	N	N	N	N	N	R	R	R	R	R	R	R	R
	ROTARY KILN	N	N	N	N	N	R	R	N	N	N	N	N	N
	SLAGGING	N	N	N	N	N	R	R	R	R	R	R	D	D
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR	D	D	D	R	D	R	R	D	D	N	N	N	N
	FLUIDIZED BED	N	D	N	N	D	R	R	R	R	D	D	N	N
	MOLTEN SALT	N	D	D	N	D	R	R	R	R	R	R	R	R
	MOVING GRATE	D	D	D	R	R	R	R	R	R	R	D	N	N
	MULTIPLE HEARTH	D	D	D	N	R	R	R	R	R	D	D	N	N
	PYROLYSIS (CONTROLLED AIR)	D	D	D	N	D	R	R	D	D	N	N	N	N
	ROTARY KILN	N	N	N	N	N	D	D	N	N	N	N	N	N
	SLAGGING PYROLYSIS	N	N	N	N	N	D	D	N	N	N	N	N	N
LEGEND: R — REQUIRED D — DESIRED N — NOT NECESSARY		* NO ADDITIONAL SIZING REQUIRED ASSUMING SIZING TO ONE METER IN THE RETRIEVAL PROCESS												

TABLE K-4
INCINERATOR PROCESS INPUT PREPARATION¹²

2.3.2 PROCESS

The primary concern with the process operation itself is the degree of control which must be exercised to obtain proper operation and the capability of handling the wide range of combustible and noncombustible material in the retrieved waste. The parameters of the process which are monitored and controlled are shown in Table K-5. All processes monitor temperature. Many processes monitor temperature in several zones but at least in the primary combustion chamber and the secondary or afterburner combustion chamber. Temperature control is achieved by modulating one or more of the three input parameters: waste feed rate, fuel, and air.

The operating parameters which affect the incinerator process are shown in Table K-6. The lowest-temperature operation is acid digestion and the highest is slagging and slagging pyrolysis, requiring temperatures as high as 1,600°C. The lowest-temperature incinerator is the radioactive waste fluidized-bed unit. The level of turbulence within the primary chamber produces a major effect on the particulate material being generated and transmitted to the secondary chamber. The residence time within the primary chamber is another major factor in the level of combustion achieved. These three factors, time, turbulence, and temperature, are the principal factors of complete oxidation in a primary incinerator chamber. In addition to the fuel shown in this table, a wide range of additional auxiliary fuels are commonly used.

Removing the incinerator residue on a continuous basis is important because the radioactive particles concentrate in the residue which amounts to only five to 10 percent of the original volume of the combustible TRU waste.

If residue removal is performed only on a batch basis, criticality could become a problem. Continuous waste removal is, therefore, very desirable. The matrix shows the material flow through the system from the waste feed material into the combustion chamber and to the ash removal system.

CATEGORY	PROCESS	PARAMETERS									
		TEMPERATURE	BED LOADING	PRESSURE	ACID CONCENTRATION	WASTE FEED RATE	FUEL	AIR	AIR/N ₂ MIXTURE	TIME	ADDITIONAL BED MATERIALS
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION	X			X	X	X				ACIDS
	AGITATED HEARTH	X				X	X	X		X	
	CONTROLLED AIR	X				X	X	X			
	CYCLOPE DRUM	X				X	X	X			
	FLUIDIZED BED	X	X			X			X		SALT
	MOLTEN SALT	X	X			X	X	X			SALTS
	PYROLYSIS	X				X	X	X			
	ROTARY KILN	X				X	X	X		X	
	SLAGGING	X		X		X		X			SAND
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR	X				X	X	X			
	FLUIDIZED BED	X	X			X			X		SALT
	MOLTEN SALT	X	X			X	X	X			SALTS
	MOVING GRATE	X				X	X	X		X	
	MULTIPLE HEARTH	X				X	X	X		X	
	PYROLYSIS (CONTROLLED AIR)	X				X	X	X			
	ROTARY KILN	X				X	X	X		X	
	SLAGGING PYROLYSIS	X		X			X	X			

TABLE K-5
INCINERATOR PROCESS PARAMETER CONTROL¹²

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[illegible]

The reliability and maintainability of the incinerator process are significantly affected by the equipment materials and the construction of these systems. Table K-7 presents some details of process equipment within the chamber. Refractory linings for the primary chamber are used in all incinerators except the fluidized-bed and cyclone-drum units.

Secondary combustion chambers are specified for all radioactive waste incinerators except acid digestion and molten salt. In commercial incinerators the secondary combustion chambers are usually not specified except for the controlled-air and pyrolysis units in which they are an integral part of the incinerator. In other commercial incinerators, they are not an integral part of the incinerator and are considered a separate element. In municipal waste incineration, the secondary combustion chamber is not always used.

Mechanisms located outside the process chamber are also factors in the extent and difficulty of maintaining the incinerator system. Table K-8 shows the operating equipment used outside the process chamber.

Elements located inside the combustion chamber are subject to degradation by acidic environment because of the HCl generated from the PVC oxidation, the high temperatures within the combustion chamber, and the effects of heating and cooling during startup and shutdown. The equipment located outside the combustion chamber is significantly easier to maintain and replace should failure occur. Material preparation (sorting and sizing) requires additional machinery and maintenance activity.

The most favorable systems are those with the least amount of equipment within the combustion chamber and the least amount of total equipment required for the system. Only the equipment required for the minimum operating system is shown. A proposed system would probably include additional equipment beyond this complement.

The operating characteristics of the incinerator processes are shown in Table K-9. The basic startup operations are shown for each process.

CATEGORY	PROCESS	EQUIPMENT				
		GRATE	MATERIAL HANDLING	RESIDUE REMOVAL	REFRACTORIES	ROTATING SEALS
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION					
	AGITATED HEARTH		RABBLE ARMS		X	
	CONTROLLED AIR			VACUUM	X	
	CYC ONE DRUM			VACUUM/ BARREL REMOVAL		
	FLUIDIZED BED			SCREW		
	MOLTEN SALT				X	
	PYROLYSIS			RAM	X	
	ROTARY KILN				X	X
	SLAGGING				X	
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR			VACUUM CHAIN	X	
	FLUIDIZED BED			DISTRIBUTOR PLATE	X	
	MOLTEN SALT				X	
	MOVING GRATE	X	GRATE	GRATE	X	
	MULTIPLE HEARTH		RABBLE ARMS	RABBLE ARMS	X	
	PYROLYSIS (CONTROLLED AIR)			RAM	X	
	ROTARY KILN				X	X
	SLAGGING PYROLYSIS				X	
NOTE: BLANKS INDICATE NOT REQUIRED.						

TABLE K-7
INCINERATOR OPERATING EQUIPMENT REQUIRING MAINTENANCE -
INSIDE THE COMBUSTION CHAMBER¹²

TERA CORPORATION

CATEGORY	PROCESS	EQUIPMENT							MATERIAL PRETREAT	
		ROTATING MECHANISM	MOTOR	AIR BLOWERS	ACID CIRCULATING PUMP	WASTE FEED	FUEL FEED	COARSE SHREDDER	FINE SHREDDER	
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION				X	X		X	X	
	AGITATED HEARTH		ROTATE ARMS	X		X	LIQUID	X		
	CONTROLLED AIR			X		X	GAS	X		
	CYCLONE DRUM			X				X		
	FLUIDIZED BED		FEED SCREWS	X		X	LIQUID	X	X	
	MOLTEN SALT			X		X	GAS, COKE	X	X	
	PYROLYSIS			X		X		X	X	
	ROTARY KILN	KILN	ROTATE KILN	X		X	LIQUID			
SLAGGING	FUEL FEED		X		X	LIQUID	X	X		
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR			X		X	LIQUID, GAS	X		
	FLUIDIZED BED			X		X	LIQUID, GAS	X	X	
	MOLTEN SALT			X		X	GAS, SOLID	X	X	
	MOVING GRATE		MOVE GRATE	X		X	LIQUID, GAS	X		
	MULTIPLE HEARTH		ROTATE ARMS	X		X	GAS	X	X	
	PYROLYSIS (CONTROLLED AIR)		RAM	X		X	LIQUID, GAS	X	X	
	ROTARY KILN	KILN	ROTATE KILN			X	LIQUID, GAS			
	SLAGGING PYROLYSIS			X		X	LIQUID, SOLID			
NOTE: BLANKS INDICATE NOT REQUIRED										

TABLE K-8

INCINERATOR OPERATING EQUIPMENT REQUIRING MAINTENANCE -
OUTSIDE THE COMBUSTION CHAMBER¹²

CATEGORY	PROCESS	NORMAL OPERATION										EMERGENCY SHUTDOWN							
		STARTUP				PROCESS					SHUT-DOWN	STOP FLED	CONTINUE COMBUS- TION AIR	CONTINUE OFF-GAS ROTATION	CONTINUE ROTATION/ BATH AIR	URAIN HOLD	OPTIONAL		
		PREHEAT UNIT	OPERATE MECHANISM	FLUIDIZE BED	START OFF-GAS SYSTEM	FLED MATERIAL	MONITOR COMBUSTION VARIABLES	STARTUP OFF-GAS VARIABLES	ADJUST MATERIAL	STOP FEED									
RADIOACTIVE WASTE INCINERATION	ACID DIGESTION	X			X	X	X	X		X	X	X	X						
	ROTATED HEARTH	X	RABBLE ARMS		X	X	X	X		X	X	X	X	ROTA- TION					
	CONTROLLED AIR				X	X	X	X		X	X	X	X						
	EXPOSE TRUM	X			X	X	X	X		X	X	X	X						
	FLUIDIZED BED	X		BED	X	X	X	X	X	X	X	X	X	BED AIR	X				
	MELTED SALT	X		MELT SALT	X	X	X	X	X	X	X	X	X			X			
	PI-POLYSIS	X			X	X	X	X		X	X	X	X						
	ROTARY KILN	X	ROTATE KILN		X	X	X	X		X	X	X	X	ROTA- TION					
SLAGGING	X			X	X	X	X		X	X	X	X							
CONCENTRATED WASTE INCINERATION	CONTROLLED AIR	X			X	X	X	X		X	X	X	X						
	FLUIDIZED BED	X		BED	X	X	X	X	X	X	X	X	X	BED AIR	X				
	MELTED SALT	X		MELT SALT	X	X	X	X	X	X	X	X	X	X	X	X			
	MOVING GRATE	X	GRATE		X	X	X	X		X	X	X	X	GRATE TRAV- EL					
	MULTIPLE HEARTH	X	RABBLE ARMS		X	X	X	X		X	X	X	X	ARM ROTA- TION					
	PI-POLYSIS	X			X	X	X	X		X	X	X	X						
	ROTARY KILN	X	ROTATE KILN		X	X	X	X		X	X	X	X	KILN ROTA- TION					
	SLAGGING EX-POLYSIS	X			X	X	X	X		X	X	X	X						

TABLE K-9

INCINERATOR STARTUP/SHUTDOWN OPERATION CHARACTERISTICS¹²

However, many variations for each process are associated with each specific design and manufacturer. The emergency shutdown procedures are shown to indicate portions of the system which require a redundant or backup system to prevent damage or significant difficulties associated with the emergency occurrence. The specific details of the emergency shutdown procedure would be related to the design of the particular incinerator along with the operating experience of the manufacturer.

2.3.3 OUTPUT

The output form of the incinerator process is important because it determines the amount of additional processing required to prepare the final output for deposit at WIPP. Table K-10 shows the output form of both the combustible and noncombustible input materials. Only the following processes render the combustible material inert and significantly change the metal and glass:

- Slagging
- Molten salt
- Acid digestion

The acid digestion system can oxidize metals, but a long time period is required for the process.

The molten-salt process can oxidize metals with large surface areas, i.e., in small pieces. In the molten-salt unit, the glass material melts into the bed and affects bed viscosity.

The slagging or slagging pyrolysis system melts metal, glass, soil, and other residue into a basalt-like glassy slag.

Other incinerator processes such as the controlled-air and rotary-kiln units do not affect the metals and glass. These materials move through these incineration processes essentially unchanged. Additional operations are therefore required to accomplish stabilization and meet WIPP criteria.

CATEGORY	INPUT FORM	COMBUSTIBLE INPUT	NONCOMBUSTIBLE INPUT									
			METAL			GLASS			SOIL			
	OUTPUT FORM	CHAR, TAR, AND ASH RESIDUE	CARBON AND ASH RESIDUE	INERT ASH/RESIDUE	NO CHANGE	MELT	OXIDE FORM	NO CHANGE	SOFTEN	MELT	NO CHANGE	MELT
PROCESS												
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION			X			X	X			X	
	AGITATED HEARTH			X	X				X		X	
	CONTROLLED AIR			X	X			X	X		X	
	CYCLOPE DRUM		X		X				X		X	
	FLUIDIZED BED			X	X			X			X	
	MOLTEN SALT			X			X			X	X	
	PYROLYSIS	X			X			X	X		X	
	ROTARY KILN			X	X				X	X	X	
	SLAGGING			X		X				X		X
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR			X	X				X		X	
	FLUIDIZED BED			X	X			X			X	
	MOLTEN SALT			X			X			X	X	
	MOVING GRATE			X	X			X	X		X	
	MULTIPLE HEARTH			X	X			X	X		X	
	PYROLYSIS (CONTROLLED AIR)			X	X			X	X		X	
	ROTARY KILN			X	X				X	X	X	
	SLAGGING PYROLYSIS			X		X				X		X

TABLE K-10
INCINERATOR PROCESS OUTPUT FORM¹²

2.3.4 PROCESSING FOR WIPP CRITERIA¹²

This section discusses processing for WIPP criteria as applied to the incinerated waste. Factors influencing this process include waste content, WIPP criteria, and incinerator output.

The stabilization requirements as defined in the WIPP Acceptance Criteria for Defense Low-Level TRU Waste dated July 1, 1977 are as quoted below:

- Stabilization: Finely divided waste forms such as incinerator residues will be stabilized in concrete or glass (or such other matrices as may be approved by the WIPP operator), or pelletized, in such a manner as to minimize the production of respirable fines in a handling accident.

This specification has both short- and long-term safety implications. The short-term concern is, again, the release of fines in a handling accident. The long-term concern is the leachability of the waste form: this is taking on a greater and greater importance in Sandia's risk assessment activities. Unfortunately, present technology will not support a meaningful specification for leachability, but it should not be dismissed as an objective. By way of providing reassurance to waste generators, it is pointed out that, from the standpoint of leachability, ordinary concrete is probably adequate as a stabilizing matrix; glass is better, and recent work at Rocky Flats indicates that "glassification" of incinerator residues is feasible both technologically and economically.

For the purposes of this report, summary and interpretation of the factors is as follows:

- Gas Formers. The WIPP criteria place a content limit of 10 percent by weight on gas formers. It is now assumed that all residue shipped to WIPP will be in metal containers. Because metal is a defined gas producer, the metal container will equal and in some cases exceed the 10 percent acceptance criteria. Because of this fact, the allowable gas formers in the waste residue must be zero, which implies that all waste residue must be chemically inert.

- Combustibles. The WIPP criteria permit a certain percent combustibles in the waste residue. For the purposes of this study, it is assumed that the WIPP criteria on gas formers take priority. It is also assumed that all combustibles are gas formers. Under these two assumptions, and the assumption that a metal WIPP container will be used, the allowable percent of combustible material in the residue is zero.

The stabilization process will depend on the incinerator output. If an incinerator can be developed that will produce an acceptable stabilized output, then further processing is not required. However, many of the incinerator processes investigated do not produce a stabilized output.

Several methods of stabilizing radioactive waste have been developed by DOE and foreign governments. Stabilization processes having application to the INEL incinerated residue are listed below. A brief description of each process follows:

- Bitumen. A process of encapsulating the residue in bitumen. Used primarily for sea disposal. Any form of residue may be used so long as it can be handled by the bitumen mixer.
- Cement. Hydraulic cement may be used to stabilize ash, salt, or even small pieces of metal and other noncombustibles so long as these materials can be handled by the mixer. The cement with the waste materials embedded in it may be cast into any desired form for handling. Steel reinforcements are used to increase the strength of the package.
- Ceramic. In this process, the waste material in the form of a calcine is combined with glass frit to produce thin-walled glass ceramics. The output is utilized primarily for immobilizing high-level waste in the ceramic and then embedding the ceramic in a metal matrix for heat dispersion.

- Clay Fixation. Radioactive wastes in the form of sodium salt solutions chemically combine with clays to immobilize the waste. In other experiments the clay is formed into bricks which are fired at 700 to 900°C; this firing improves the leach rate.
- Glass Encapsulation. Small pieces of metals and other noncombustible materials are encapsulated by molten glass being poured over them.
- Metal Matrix. Metals are used to stabilize the radioactive waste materials that are in the form of vitrified pellets or beads or in some other calcined form. The principal advantages of the metal matrices are high impact strength and high thermoconductivity.
- Pelletization. The radioactive material and ash are ground very finely and mixed with high-alumina cement. This powder is then pressed into pellets and sintered. The principal advantage of this process is that the concentration of radioactive waste in the pellets (80 percent) is higher than with other techniques. For example, in the glass solution process the radioactive waste concentration is 50 percent maximum.
- Plastic Materials. A variety of resins and plastic materials have been used as matrices to immobilize ash, salts, and oxides. These materials could be used to stabilize small pieces of metal and noncombustibles. The primary disadvantage is that these resins are combustible.
- Salt Cake. The cast salt cake taken directly from the output of the molten-salt incinerator or the acid-digestion process adequately immobilizes the fine ash material. However, the salt cake exhibits a very high leach rate and thus will not meet stabilization requirements.
- Slagging. The output of the slagging incinerator is a granular basalt-like glassy slag. It is expected that this output will be satisfactory to WIPP. Glass formers may be added to the waste material feed in the incinerator to improve the vitrified nature of the output.

The stabilization processes will be combined with the incinerator processes for evaluation.

2.3.5 COMBINED INCINERATION/STABILIZATION TRU WASTE TREATMENT PROCESS PERFORMANCE¹²

Once the investigation of the various incineration processes was complete, it became obvious that a minimum amount of preparation is necessary for any incineration process. The incinerator would have been required to handle a wide range of combustibles and noncombustibles, and also to accept retrieved 210-liter drums filled with sludge.

Criteria which must be met by any feasible alternative (constraints) are evaluated first. A more specific evaluation was made for one of the constraints related to WIPP criteria. Both incineration and stabilization processes were evaluated against the WIPP criteria.

The second step in the evaluation process first required the development of waste treatment systems consisting of an incinerator, a stabilization process, and other preparation or processing as required to meet all of the constraints and the WIPP criteria. These systems were then evaluated as to how well they met the desired characteristics. This approach provided a common baseline for all potential treatment systems and made possible a more objective evaluation.

Each incinerator process was first evaluated against the constraints. This evaluation was first made using the existing operating systems for both radioactive waste incinerators and commercial/municipal waste incinerators. These are the units of the development programs now underway, and the commercial units available and in use for municipal solid waste disposal. Because a constraint is a go/no-go question, the matrix, Table K-11, shows simple yes or no answers for the constraints.

The same evaluation was performed for potential incinerator systems. These systems are the same categories previously evaluated, but assuming the use of the full scope of incinerator technology, along with a scaling of the system to meet the production requirement. This evaluation is summarized in Table K-12.

CATEGORY	PROCESS	CONSTRAINTS							
		MUST RENDER RESIDUE INERT	MUST IMMOBILIZE RESIDUE	MUST PREPARE RESIDUE TO MEET WIPP CRITERIA	MUST PROCESS AT LEAST 8,500 CUBIC METERS/YEAR (1 METRIC TON/HOUR)	MUST INPUT UNSEGREGATED WASTE	MUST BE IN FULL SCALE OPERATION BY 1987	MUST BE CAPABLE OF BEING MAINTAINED	MUST BE A SAFE OPERATION
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION	Y	N	Y	Y	N	Y	Y	Y
	AGITATED HEARTH	Y	N	N	N	N	Y	Y	N (1)
	CONTROLLED AIR	Y	N	N	N	N	Y	Y	Y
	CYCLONE DRUM	N	N	Y	N	N	Y	Y	Y
	FLUIDIZED BED	Y	N	N	N	N	Y	Y	Y
	MOLTEN SALT	Y	Y	N	N	N	Y	Y	Y
	PYROLYSIS	N	N	N	N	N	Y	Y	Y
	ROTARY KILN	Y	N	N	N	N	Y	Y	Y
COMMERCIAL MUNICIPAL WASTE INCINERATORS	SLAGGING	Y	Y	Y	N	N	Y	Y	Y
	CONTROLLED AIR	Y	N	N	Y	N	Y	Y	Y
	FLUIDIZED BED	Y	N	N	Y	N	Y	Y	Y
	MOLTEN SALT	Y	Y	N	Y	N	Y	Y	Y
	MOVING GRATE	N	N	N	Y	N	Y	Y	Y
	MULTIPLE HEARTH	Y	N	N	Y	N	Y	Y	N (2)
	PYROLYSIS (CONTROLLED AIR)	N	N	N	Y	N	Y	Y	Y
	ROTARY KILN	Y	N	N	Y	Y	Y	Y	Y
LEGEND	Y — YES	(1) POSSIBLE CRITICALITY PROBLEM BECAUSE OF LARGE BATCH SIZE.							
	N — NO	(2) CRITICALITY PROBLEM BECAUSE OF POSSIBLE HOLOUP OF PLUTONIUM IN THE ASH WITHIN THE SYSTEM.							

TABLE K-11

PRESENT INCINERATOR PROCESSES - CONSTRAINT EVALUATION¹²

CATEGORY	PROCESS	CONSTRAINTS							
		MUST REMAIN RESIDUE INERT	MUST IMMOBILIZE RESIDUE	MUST PREPARE RESIDUE TO MEET WIPP CRITERIA	MUST PROCESS AT LEAST 8,500 CUBIC METERS/YEAR (1 METRIC TON/HOUR)	MUST INPUT UNSEGREGATED WASTE	MUST BE IN FULL SCALE OPERATION BY 1987	MUST BE CAPABLE OF BEING MAIN- TAINED	MUST BE A SAFE OPERATION
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION	Y	Y	N	Y	N	Y	Y	Y
	AGITATED HEARTH	Y	N	N	Y	Y	Y	Y	1
	CONTROLLED AIR	Y	N	N	Y	Y	Y	Y	Y
	CYCLONE DRUM	N	N	N	Y	Y	Y	Y	Y
	FLUIDIZED BED	Y	N	N	Y	Y	Y	Y	Y
	MOLTEN SALT	Y	Y	N	Y	Y	Y	Y	Y
	PYROLYSIS	N	N	N	Y	Y	Y	Y	Y
	ROTARY KILN	Y	N	N	Y	Y	Y	Y	Y
	SLAGGING	Y	Y	Y	Y	Y	Y	Y	Y
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR	Y	N	N	Y	Y	Y	Y	Y
	FLUIDIZED BED	Y	N	N	Y	Y	Y	Y	Y
	MOLTEN SALT	Y	Y	N	Y	Y	Y	Y	Y
	MOVING GRATE	N	N	N	Y	Y	Y	Y	Y
	MULTIPLE HEARTH	Y	N	N	Y	Y	Y	Y	2
	PYROLYSIS (CONTROLLED AIR)	N	N	N	Y	Y	Y	Y	Y
	ROTARY KILN	Y	N	N	Y	Y	Y	Y	Y
	SLAGGING PYROLYSIS	Y	Y	Y	Y	Y	Y	Y	Y
LEGEND: Y — YES N — NO									
(1) POSSIBLE CRITICALITY PROBLEM BECAUSE OF LARGE BATCH SIZE. (2) CRITICALITY PROBLEM BECAUSE OF POSSIBLE HOLDUP OF PLUTONIUM IN THE ASH WITHIN THE SYSTEM.									

TABLE K-12

POTENTIAL INCINERATOR PROCESSES - CONSTRAINT EVALUATION¹²

It should be noted that in the first evaluation of existing systems, only the slagging pyrolysis commercial-scale incinerator met all constraint criteria. In the second evaluation, both that unit and the slagging incinerator for radioactive waste met all constraint criteria.

The potential incinerator processes were then evaluated by the aforementioned interpretation of the WIPP criteria. This evaluation is summarized in Table K-13. Only two processes, slagging and slagging pyrolysis, meet the criteria. The incineration process is only one step in the total treatment process; therefore, its ability to meet these criteria can be modified by the addition of other functions.

A stabilization process may be used in combination with an incineration process to provide a treatment system which meets the constraint criteria. For this reason the stabilization processes were evaluated against the WIPP criteria.

Table K-14 shows the evaluation of the stabilization processes against the WIPP criteria. Only three of the stabilization processes met all WIPP criteria:

- Ceramic
- Glass solution
- Slagging

These two evaluations were summarized by asking the question, "What system functional elements are necessary for each of the incineration processes to meet the WIPP criteria?"

Table K-15 summarizes data for these waste treatment systems. These systems consist of the minimum functional elements which are technically required to

PROCESS		WIPP CRITERIA					DOES THE PRODUCT MEET WIPP CRITERIA
		IMMOBILIZED (RESPIRABLE DUST CAPTURED)	LEACH RATE (LOW IS DESIRED)	OUTPUT (NON- COMBUSTIBLE)	MUST NOT FORM GAS	MUST BE INERT	
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION	YES	HIGH	YES	NO	YES	NO
	AGITATED HEARTH	NO	HIGH	YES	NO	YES	NO
	CONTROLLED AIR	NO	HIGH	YES	NO	YES	NO
	CYCLONE DRUM	NO	HIGH	NO	NO	NO	NO
	FLUIDIZED BED	NO	HIGH	YES	NO	YES	NO
	MOLTEN SALT	YES	HIGH	YES	NO	YES	NO
	PYROLYSIS	NO	HIGH	NO	NO	NO	NO
	ROTARY KILN	NO	HIGH	YES	NO	YES	NO
	SLAGGING	YES	LOW	YES	YES	YES	YES
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR	NO	HIGH	YES	NO	YES	NO
	FLUIDIZED BED	NO	HIGH	YES	NO	YES	NO
	MOLTEN SALT	YES	HIGH	YES	NO	YES	NO
	MOVING GRATE	NO	HIGH	NO	NO	NO	NO
	MULTIPLE HEARTH	NO	HIGH	YES	NO	YES	NO
	PYROLYSIS (CONTROLLED AIR)	NO	HIGH	YES	NO	YES	NO
	ROTARY KILN	NO	HIGH	YES	NO	YES	NO
	SLAGGING PYROLYSIS	YES	LOW	YES	YES	YES	YES

TABLE K-13
INCINERATOR PROCESSES - WIPP CRITERIA EVALUATION¹²

STABILIZATION PROCESS	WIPP CRITERIA (AS INTERPRETED BY EG&G AND FMC)					DOES THE PROCESS MEET WIPP CRITERIA
	IMMURILIZED (RESPIRABLE DUST CAPTURED)	LEACH RATE (LOW DESIRED)	OUTPUT NON- COMBUSTIBLE	MUST NOT FORM GAS	INERT (MUST BE INERT)	
B.TUMEN	YES	LOW	NO	NO	YES	NO
CEMENT	YES	MEDIUM- LOW	YES	NO	YES	NO
CEMENT	YES	LOW	YES	YES	YES	YES
CLAY FIXATION	YES	MEDIUM- LOW	YES	NO	YES	NO
GLASS SOLUTION	YES	LOW	YES	YES	YES	YES
GLASS, ENCAPSULATION	YES	UNKNOWN	YES	YES	YES	UNKNOWN
METAL MATRIX, SINTERED	YES	MEDIUM	YES	NO	YES	NO
METAL MATRIX, CASTING	YES	MEDIUM	YES	NO	YES	NO
PELLETIZATION	YES	UNKNOWN	YES	UNKNOWN	YES	UNKNOWN
PLASTIC MATERIALS	YES	LOW	NO	NO	NO	NO
SALT CAKE	YES	HIGH	YES	NO	YES	NO
SLAGGING	YES	MEDIUM- LOW	YES	YES	YES	YES

TABLE K-14
STABILIZATION PROCESSES - WIPP CRITERIA EVALUATION¹²

WASTE TREATMENT SYSTEM		SYSTEMS PROCESS STEPS REQUIRED								
		MATERIAL PREPARATION			INCINERATION PROCESS	STABILIZATION PROCESS				
		SORTING	SIZING			COMPLETE OXIDATION	SIZE METALS AND NON-COMBUSTIBLES	MIX WITH GLASS FORMERS	HEAT TO MAKE GLASS	
			ROUGH	FINE						
RADIOACTIVE WASTE INCINERATORS	ACID DIGESTION	X	X	X	X			X	X	
	AGITATED HEARTH	X	X		X		X	X	X	
	CONTROLLED AIR	X	X		X		X	X	X	
	CYCLONE DRUM		X		X	X	X	X	X	
	FLUIDIZED BED		X	X	X		X	X	X	
	MOLTEN SALT		X	X	X			X	X	
	PYROLYSIS		X	X	X	X	X	X	X	
	ROTARY KILN		X		X		X	X	X	
	SLAGGING		X	X	X					
COMMERCIAL/MUNICIPAL WASTE INCINERATORS	CONTROLLED AIR	X	X		X		X	X	X	
	FLUIDIZED BED		X	X	X		X	X	X	
	MOLTEN SALT		X	X	X			X	X	
	MOVING GRATE	X	X	X	X	X	X	X	X	
	MULTIPLE HEARTH	X	X	X	X		X	X	X	
	PYROLYSIS (CONTROLLED AIR)		X		X		X	X	X	
	ROTARY KILN				X		X	X	X	
	SLAGGING PYROLYSIS				X					

TABLE K-15

WASTE TREATMENT SYSTEMS THAT MEET WIPP CRITERIA
(Showing Material Preparation and Stabilization Process Steps Required)¹²

accomplish an output acceptable to WIPP. Additional elements might be desirable from the viewpoint of additional control, greater processing throughput, or improved physical characteristics of the output product.

Only one process can stand alone without the support of additional functions. That process is the slagging pyrolysis commercial incinerator. The slagging radioactive waste incinerator requires waste material sizing to provide proper material feed. The rotary kiln requires material sizing of the output along with vitritication for a reduced leach rate. All other incineration processes require both preparation prior to incineration and a stabilization process following incineration.

At this point several incineration processes were eliminated from further consideration on the basis of inability to meet some of the constraints required of the total treatment process.

After these processes* were eliminated, the remaining systems were viewed as total treatment processes. The treatment process evaluated was as described in Table K-15, showing the waste processing system for the minimum process requirement. These systems included both preparation and stabilization; therefore, they completely met the WIPP criteria with the output product. The rating for each process as described by the primary incinerator process included 22 desired characteristics which were rated on a scale of high, medium, or low for each potential system.

* Agitated hearth, cyclone drum, pyrolysis, moving grate and multiple hearth.

The resultant matrix showed quite clearly processes which provide the greatest number of desired characteristics. Three treatment systems ranked highest in the following order:

- Slagging pyrolysis
- Controlled air
- Rotary kiln

These three processes are to be considered further as viable alternative treatment systems for the retrieved waste at INEL with major emphasis upon slagging pyrolysis. Such analysis could be used by other TRU waste generators. The results might be different depending upon desirable characteristics, facility restraint and other tangible and intangible factors.

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3.0 EVAPORATORS

Evaporation is the vaporization of a liquid from a solution or a slurry for separation of a liquid from a dissolved or suspended solid or liquid. The objective of evaporation is to concentrate a solution consisting of a nonvolatile solute and a volatile solvent. In the overwhelming majority of evaporations, the solvent is water. Evaporation is conducted by vaporizing a portion of the solvent to produce a concentrated solution or a thick liquor.

In designing evaporators for concentrating radioactive liquids, vapor-liquid separation is the most important factor, because decontamination of the liquid is the most important objective, and heating cost is relatively less important. A small amount of entrainment can contaminate the condensed vapor to unsatisfactorily high levels. The decontamination factor for evaporation is normally defined as the ratio of the contaminant concentration in the evaporator bottoms to the corresponding contaminant concentration in the overheads condensate. These decontamination factors normally fall within the range of 10^4 to 10^6 for a single stage of evaporation and de-entrainment. Evaporator type and design, the design and performance of associated liquid droplet de-entrainment devices, and the volatilities of feed solution contaminants are the most significant influences upon the attainable decontamination factors. Radioactive iodine, ruthenium, and tritium are the most notable elements for which evaporative decontamination can be difficult.

Evaporation is most suitable for processing liquid waste which has a high total solids concentration and which requires a high degree of decontamination from its radionuclide content. The volumes of such liquid wastes are normally low in comparison to those of lower-activity liquid wastes from nuclear plants. Economic considerations generally favor methods of liquid waste treatment other than evaporation (e.g., ion exchange, flocculation and filtration, etc.) for large-volume treatment of low-level radioactive liquid wastes. In cases in which liquid wastes contain scaling, foaming, or corrosive materials, some form of pretreatment (normally by chemical addition) or combination with other waste treatment methods is often desirable.

3.1 GENERAL DESCRIPTION OF RADWASTE EVAPORATORS

Evaporation is the process by which the volatile and nonvolatile components of a solution or slurry are separated by boiling away the volatile component. It is a unit operation that has wide application at fuel cycle waste processing facilities for concentrating basic and acidic waste solutions, and for reducing both waste volumes and the amount of radioactivity in liquid effluents. Evaporation can be used on solutions or slurries having widely different compositions and concentrations; however, it is most effectively used on liquid radwastes having high concentrations of impurities.

Among the important elements involved in evaporator design are heat transfer, separation of evolved vapor from residual liquid, volume reduction, prevention of fouling of the heating surface, and conservation of energy. In the design of evaporators for radwaste processing, vapor-liquid separation is the most important factor, because decontamination of the liquid is the most important objective. In this application, the heating costs and volume reduction are relatively less important. Selection of construction materials is also important since corrosion can be a problem which reduces the life of an evaporator.

An evaporator is a device designed to transfer heat to a liquid (solution or slurry) that boils and to separate the vapor thus formed from the boiling liquid. The unit or building block in which heat transfer takes place may be called a calandria, heating element, heat exchanger, heater, or tube bundle. The unit in which vapor-liquid separation takes place may be called a body, flash chamber, or vapor head. The term "body" is also used to denote the minimum basic units needed to form an evaporator, i.e., one heater and one flash chamber.

Evaporators that are used at LWRs employ tubular heating surfaces. Tubes may be long or short, straight or bent, and may have uniform or tapered cross-sections. The heat-transfer medium or fluid (usually steam) may be inside or outside the tubes. The flash chamber and heater may be an integrated unit (integral or internal heater), or they may be separate units (separate or external heater). The heater may be horizontal or vertical. The movement of liquid past

the heating surface may be induced either by gravity or the density variations brought on by boiling (natural circulation), or by mechanical means, such as a pump (forced circulation). Evaporators may be operated as once-through or as circulation units. In once-through operation, the feed liquor passes through the tubes only once. In this single pass, it releases vapor and leaves the unit as thick liquor. In circulation operation, the feed mixes with liquid that has passed through the tubes one or more times, and the mixture passes through the tubes. In this mode of operation, only part of the total evaporation occurs in a single pass. Evaporator accessories include devices such as condensers, entrainment separators, feed preheaters, gas strippers, vent systems for noncondensable gases, and appropriate instrumentation.

3.1.1 NATURAL-CIRCULATION EVAPORATORS^{3,10}

Natural-circulation evaporators are generally heated by condensing steam in shell-and-tube heat exchangers, although electrical resistance heaters are also feasible. The simplest type of natural-circulation evaporator is one in which the tubes, containing the condensing steam, are contained horizontally within a horizontal cylindrical evaporation vessel and are surrounded by the liquid to be evaporated. This type of natural-circulation evaporator is best suited for installations in which a low vertical profile is required; it is unsuitable for liquids with scaling, salting, or foaming tendencies.

Vertical tube natural-circulation evaporators are more commonly used than the horizontal tube type. These evaporators are normally heated by condensing steam in the shell side of a shell-and-tube heat exchanger. Thus, liquid circulation vertically upward in the tubes is induced by vapor formation, which results in a liquid density within the tubes which is considerably lower than that of the surrounding liquid. This density difference promotes high circulation rates and correspondingly high heat transfer rates. The heat exchanger serving a vertical tube natural-circulation evaporator may be located either within the evaporator body or outside the vessel with necessary piping connections; external heat exchangers are normally preferred for ease of tube bundle maintenance or replacement.

Natural-circulation evaporators with long-tube vertical heaters may be of the type in which the liquid flows upward through the tubes (climbing or rising film) or the type in which the liquid flows downward through the tubes (falling film).

RISING FILM

Internal (Figure K-16) and external (Figure K-17) heaters can be employed with the rising-film evaporator. In these units, liquid enters the bottom of the tubes and flows upward (as liquid) receiving heat. Bubbles then form in the liquid as boiling begins, increasing the linear velocity. Near the top of the tubes the bubbles grow rapidly. In this zone, bubbles of vapor alternating with slugs of liquid rise very quickly through the tubes and emerge at high velocities from the top.

FALLING FILM

The principal disadvantage of the rising-film evaporator is poor heat-transfer performance (under some conditions) due to hydrostatic head, friction, and acceleration of the liquid by the vapor. This disadvantage can be almost completely mitigated by turning the rising-film evaporator (Figure K-16) upside down (as in Figure K-18). In the falling-film evaporator, liquid enters at the top, flows downward inside the tubes as a film, and exits from the bottom. Vapor evolved from the liquid flows concurrently. The chief problem with this evaporator is attaining uniform distribution of liquid to the top of all the tubes. Although the evaporator has a pump, it is not a forced-circulation evaporator, since mechanical energy is used merely to circulate liquid to the top of the tubes and not to improve heat transfer.

3.1.2 FORCED-CIRCULATION EVAPORATORS

In the forced-circulation evaporator, liquid is recirculated by a pump through the heating tubes at reasonably high velocities with relatively little evaporation per pass. Circulation rate is normally maintained constant and independent of the evaporation rate. The heat exchanger is normally installed as a separate unit,

FIGURE K-1b

NATURAL-CIRCULATION, RISING-FILM, LONG-TUBE
VERTICAL EVAPORATOR WITH AN INTERNAL HEATER

FIGURE K-17

NATURAL CIRCULATION, RISING-FILM, LONG-TUBE
VERTICAL EVAPORATOR WITH AN EXTERNAL HEATER

FIGURE K-18

FALLING-FILM, LONG-TUBE VERTICAL EVAPORATOR¹

rather than an integral part of the evaporator body, to facilitate cleaning, maintenance, and replacement.

This type of evaporator is suitable for processing scaling liquids, since scale deposition is decreased by the high liquid velocity through the heat exchanger tubes. By proper placement of the heat exchanger in relation to the normal evaporator liquid level, or by installing a flow-restricting device in the outlet of the heat exchanger recirculation piping, boiling within the heat exchanger tubes can be prevented, thus improving the overall heat transfer efficiency and further reducing scaling tendencies.

EXTERNAL HEATER

The heater may be either horizontal (usually two pass) or vertical (usually single pass). "Single pass" means that the fluid being heated flows through the heater in only one direction; "two pass" means that the fluid flows through part of the tubes in one direction and through the remainder of the tubes in the opposite direction.

Horizontal

Figure K-19 shows a forced-circulation evaporator with an external, horizontal, two-pass heater. The heater is placed far enough below the liquid level to ensure that there is no boiling in the tubes (submerged tubes).

Vertical

Figure K-20 shows a forced-circulation evaporator with an external, vertical, single-pass heater. The evaporator shown in Figure K-19 has the heater placed far enough below the liquid level in the flash chamber to suppress boiling in the tubes.

FIGURE K-19

FORCED-CIRCULATION EVAPORATOR WITH AN
EXTERNAL, HORIZONTAL, SUBMERGED-TUBE, TWO-PASS HEATER¹

FIGURE K-25

FORCED-CIRCULATION EVAPORATOR
WITH AN EXTERNAL, VERTICAL, SINGLE-PASS HEATER¹

EVAPORATOR/CRYSTALLIZER

Evaporation techniques for the crystallization of salts have been used for centuries. Forced-circulation evaporators are well-suited to concentrating salting liquors, and thus may function as evaporating crystallizers (or crystallizing evaporators). In this study, such a unit is referred to as an evaporator/crystallizer, since whether it is an evaporator or a crystallizer is largely a question of the shape of the solubility curve of the material on which it operates.

Crystallization is defined as the controlled precipitation of solids from a saturated solution containing water and dissolved solids. Evaporative crystallization involves generating a super-saturated solution by evaporating water from the solution, then controlling the combined effects of nucleation rate, growth rate, heat balance and material balance to provide the desired crystals and mother liquor.

A radwaste crystallizer is essentially a specially designed forced-circulation evaporator consisting of a vapor body, recirculation pipe, large recirculation pump and two-pass vertical heater. Steam is applied to the shell side of the heater where it condenses on the outside of the tubes and imparts heat to the liquor circulating inside the tubes. The steam condensate is then removed from the shell side of the heater and returned to the boiler or condensate storage tank. The liquor circulating through the tubes is not allowed to boil in the tubes due to proper layout of equipment and low rise across the heater. After the liquor passes through the heater it enters the vapor body where it releases water vapors to the condenser and subcooler system. The recirculation pump, the vapor body and the heater are all designed to handle the undissolved solids which circulate throughout the unit.

In a fuel cycle radioactive waste facility, a typical solution which can be processed by the radwaste evaporator crystallizer is the sodium sulfate, water and impurities mixture from the regenerative demineralizers.

WIPED FILM

A wiped-film evaporator may be considered to be a special variant of forced-circulation evaporators, since mechanical energy is used to improve heat transfer. The heating surface, which consists of a cylinder containing a rotating agitating blade or series of wipers, either maintains a fixed close clearance from the cylinder inner wall or rides on the liquid film on the wall. Common orientations include both vertical and horizontal, and the cylinder may be tapered slightly. The cylinder is externally heated by a steam jacket or other means. A sketch of a typical horizontal wiped-film evaporator is shown in Figure K-21.

Liquid waste is fed into one end of the cylinder and agitated vigorously by the rotating blades which wipe the waste on the heated surface in a thin turbulent film. Partial evaporation from the film occurs quickly, and subsequent blade travel continuously redistributes the concentrate film as it progresses toward the discharge end of the cylinder, from which the product is discharged through a nozzle as a liquid, slurry, or free-flowing solid. In addition to concentrate redistribution and movement, the rotating blades also remove foam and/or entrainment from the central vapor space. Advantages of this type of evaporator include high heat transfer efficiency, low product residence time (i.e., reduced thermal degradation of product), and capability to evaporate to high product concentrations.

Wiped-film evaporators have been considered by Savannah River Laboratory for evaporating alkaline intermediate-level waste streams from the processing of spent reactor fuel.^{7,8} These waste streams are associated with both the process and process support functions which include decontamination solutions, laundry wastes, wastes from all building floor drains not located in a hot (high radiation) area, and fuel storage pool wastes. These wastes are made alkaline with NaOH before evaporation to reduce corrosion. Wiped-film evaporators are also being considered for evaporating alkaline defense wastes which contain large amounts of NaNO_3 .

FIGURE K-21
WIPED-FILM EVAPORATOR¹

Test results at the Savannah River Laboratory of two small wiped-film evaporators have shown that synthetic liquid radioactive wastes containing a high concentration of sodium salts could be converted in one evaporation step to a free-flowing slurry which solidifies when cooled to room temperature. Concentration is completed in one pass without recirculation. Because there is no liquid level, elevation in boiling temperature due to hydrostatic pressure is eliminated. Because only a small amount of material is in process at any time, holdup time is extremely short. These features make a wiped-film evaporator suitable for handling highly viscous or foamy waste materials and solutions containing precipitated solid material. A vertical unit and a horizontal unit were purchased and installed in a test facility.

Based upon this experience, wiped-film evaporators with approximately 40 ft² of heat transfer surface were fabricated by Luwa Corporation (vertical) and Artisan Industries (horizontal). They are being installed at the Savannah River Laboratory to determine mechanical operability and processing characteristics with simulated alkaline defense waste. Both visual and instrument control systems will be tested during operability tests of the prototype evaporators. Wiped-film evaporators are being considered for evaporating high-alkaline LWR radioactive wastes and for distributing these wastes in the receiving vessel.⁸

SPRAY-FILM

The spray-film evaporator might also be categorized as a forced-circulation type, inasmuch as it uses mechanical energy to improve heat transfer. Energy is required to force the liquid being evaporated through spray nozzles can be atomized. The small droplets formed impinge upon the heat-transfer surface and spread over it in a thin film. The pool of liquid being circulated is below the heater. In this evaporator, the heat-transfer medium is confined within the tubes.¹⁰

SUBMERGED U-TUBE TYPE

Another type of evaporator used in LWR plants in which the heat-transfer medium is inside the tubes is the submerged U-tube. The liquid being concentrated completely covers the horizontal, U-bend heating tubes, and circulation is obtained by natural convection and boiling of the liquid (i.e., it is a natural-circulation unit). A pump is used for circulation and not for enhancing heat transfer. Operation under vacuum is not uncommon with evaporators of this type, and it is sometimes feasible to use hot water, instead of steam as the heat-transfer medium.

VAPOR COMPRESSION EVAPORATORS

Additional heat economy can be achieved by reusing the energy of vaporization to provide a heat source for further evaporation. In vapor compression evaporators, the energy potential of the low-pressure vapor from the evaporator is increased by compressing the vapor, thus making the latent heat of condensation available at a higher temperature. The compressed vapor is combined with the fresh steam input and recycled to the steam side of the evaporator heat exchanger as the heating medium. The vapors can be compressed either with a mechanical compressor (driven by an electric motor or turbine) or with a steam injector.

MULTIPLE-EFFECT EVAPORATORS

Multiple-effect evaporators provide another means of increasing energy utilization. This evaporator system uses the vapor from one effect as the heating medium for the next (more concentrated liquid) effect in the system. Vapor compression is not required, since successive effects are normally operated at lower absolute pressures. This evaporator type is normally used only for large-scale applications.

3.2 EVAPORATOR DESIGN BASIS^{5, 10, 13}

Evaporators are operated in several modes: batch and continuous, which are well-defined in chemical engineering terminology; and semi-continuous, which includes all modes of operation other than batch or continuous.

3.2.1 BATCH OPERATION

In batch operations, feed and product flows are intermittent, process conditions are generally programmed with time, and steady-state conditions are never attained. In batch operation, the quantity of solution or slurry to be evaporated at one time is charged to the evaporator; boiling is initiated; and the vapors are then continuously removed, condensed, and collected. Evaporation is continued until the desired amount of condensate (overhead or distillate) has been collected, or until the thick liquid (bottoms or concentrate) reaches the concentration, density, or viscosity desired. The thick liquor is then removed from the evaporator. This mode of operation is frequently used when a relatively small volume of material is to be processed and concentrated.

3.2.2 CONTINUOUS OPERATION

In continuous operations, feed and product flows are constant and process conditions are constant with time. The operation is at steady-state. Continuous operation is highly desirable since control is easy once steady-state has been achieved; however, it requires a large or continuous supply of feed with a uniform composition.

3.2.3 SEMICONTINUOUS OPERATION

In a semicontinuous evaporation, a predetermined quantity of solution or slurry is charged to the evaporator; boiling is initiated; and vapors are then continuously removed, condensed, and collected. Feeding of solution or slurry to the evaporator is continued at a rate approximately equal to the rate at which condensate is removed; that is, at a rate to maintain a constant liquid volume in

the evaporator. Evaporation is continued until the feed is exhausted or until a desired concentration of bottoms is achieved. The thick liquor is then removed from the evaporator. This mode of operation is widely used at nuclear installations. In one variation of this mode, only a portion of the thick liquor is removed and the feed is restarted. This seems to aid in re-establishing boil-off without too much difficulty (i.e., excessive foaming and splashing). In another variation, after partial concentration is achieved in the semicontinuous mode, the feed is stopped, and the final concentration is achieved in a batch mode.

3.2.4 FACTORS INFLUENCING THE DECONTAMINATION FACTORS (DFs)^{10, 11}

In evaporating radioactive solutions, effective entrainment separation is required to avoid contaminating the condensate. Equally important in evaporating radioactive liquids is operation under conditions (pH, redox, temperature) which suppress the volatilization of radioactive materials such as iodine and some organics that can have high vapor pressures. Evaporators can separate water from solids very effectively, and a system decontamination factor of 10^4 to 10^5 is generally expected for a single-effect evaporator separating water from a nonvolatile solute. Decontamination factors are decreased by four basic factors: entrainment, splashover, foam, and volatilization of solute.

ENTRAINMENT

Entrainment is liquid suspended in the vapor as fine droplets that are carried along with the rising vapor stream. The extent of entrainment losses from an evaporator depends, for the most part, on vapor velocity and size, size distribution, and number of droplets. The larger droplets are a major source of entrainment losses unless they settle back into the liquid or are removed by entrainment separators. Evaporators generally have devices incorporated or attached to remove the entrained larger droplets that do not settle back. Entrainment losses can be increased by flashing, which is the sudden production of copious quantities of steam bubbles. It is caused by incidents such as introducing feed that is above its boiling point or poor vacuum control (i.e., sharply varying vacuum).

At higher boilup rates, entrainment increases and thus the DF generally decreases with increasing boilup. These results could imply that at lower boilup rates the DF would be higher. However, at very low boilup rates the DF decreases with decreasing boilup rate. Smaller vapor bubbles produced by gentle boiling lead to the production of smaller droplets that are readily carried by the ascending vapor. However, the extent of entrainment losses from entrainment separators (such as wire mesh, cyclones, and trays) depends, for the most part, on vapor velocity and size, size distribution, and number of droplets. The desired optimum is the point at which the product of the DFs for the evaporator and entrainment separators is at a maximum.

SPLASHOVER

Splashover consists of the carry-over of large parcels of thick liquor into the condenser. It occurs at very high boilup rates when boiling becomes violent and erratic. Splashover losses are usually insignificant if sufficient distance between the surface of the boiling liquid and the outlet of the flash chamber is provided (so that the parcels fall back before reaching the outlet), or if an impingement baffle covering the outlet of the flash chamber is provided to deflect the parcels downward. A single large splashover can ruin a large volume of otherwise acceptable condensate.

FOAM

Foam is a mass of stable bubbles formed in or on the surface of the thick liquor. Among the causes of foam in an evaporator are traces of organics, finely divided solids, and dissolved gases. Foam leads to an increase in entrainment by raising the effective liquid level, which decreases the amount of de-entrainment space; and by supplying stable bubbles that the vapor can carry. Thus, it can lower the decantation factor markedly. Foam control measures that are sometimes effective include: the addition of chemical antifoam agents, such as silicone preparations; baffles which the foam strikes at high velocity; liquid or steam jets directed against the foam; and the sudden heating or chilling of coils located in the region where foaming occurs. Serious foam can require that an evaporator

be operated at reduced boilup rates to maintain the desired de-entrainment space and decontamination factor. If foam is anticipated, the evaporator design should provide reserve capacity, additional de-entrainment devices, or foam-breakers that will permit the boilup rate to be maintained during foaming.

VOLATILIZATION OF SOLUTE

Volatilization of solute is an important concern in the operation of evaporators with liquid radioactive waste, since the design objectives for release of radioactive materials to the environment are low. Several elements found in radwaste, such as iodine and some organics, are volatile to varying degrees. Methods for decreasing the volatility of iodine include adjusting the pH and redox potential (e.g., by the addition of sodium thiosulfate) of the solution or slurry to produce new conditions under which the species is nonvolatile. Segregation of aqueous from organic waste streams, control of pH values to high basicity, and addition of complexing or other chemical agents to hold the stable state, are measures used to improve the decontamination during evaporation. Volatilization of organics may be a problem if the condensate is to be recycled for use as a heat-transfer medium. These organics can decompose and form deposits on (foul) heating-surface walls, thus causing poor heat-transfer characteristics.

3.2.5 PRODUCT CHARACTERISTICS

The product characteristics of evaporation processes vary widely as functions of liquid feed characteristics and degree of evaporation performed. Since evaporation is seldom the final step in the overall liquid waste treatment process, the degree of evaporation is influenced by the requirements of subsequent processing operations. The chemical properties of concentrated evaporator products are basically the same as those of the nonvolatile components of the evaporator feed material, although evaporator product solutions may contain an increased amount of precipitated components. Typical evaporator product (bottoms) solutions contain from about 10 to 50 weight percent dissolved solids.

3.2.6 OTHER FACTORS

Some of the important factors that should be known or determined prior to selection of the most effective evaporator design are listed below.

PHYSIOCHEMICAL PROPERTIES

The physical and chemical properties (e.g., density, viscosity, and surface tension) of the liquid in the evaporator are needed as a function of temperature over the concentration range of the feed and the concentrated liquid.

CAPACITY

The minimum, maximum, and average capacity (mass of solvent to be evaporated per unit of time) at which the evaporator will be expected to operate is required information.

HEAT-TRANSFER MEDIUM

The temperature, pressure, and quantity of heat-transfer medium (usually steam) available must be known.

SALTING, SCALING AND FOULING

The possibility of salting, scaling and fouling must be determined and their effects evaluated.

CORROSION

Data on corrosion under the anticipated conditions of operation must be determined.

CLEANING, INSPECTION AND MAINTENANCE

Consideration must be given to ease of cleaning (chemical and/or mechanical), access for inspection and maintenance (remote and/or direct), and the time required for these operations.

UNTOWARD CONDITIONS

Possible explosion conditions due to unstable organics (e.g., amines) or combustible gases (e.g., hydrogen) must be covered.

AVAILABLE SPACE

Attention must be given to headroom and floor-space requirements. Segregation and shielding of components must be considered.

CONTROLS, INSTRUMENTATION AND SAMPLING

Adequate controls, instruments, and sampling points must be incorporated for efficient evaporator performance.

ECONOMICS

Cost of the evaporator and its operation must be taken into account.

3.2.7 EVAPORATOR COMPARISON¹⁰

A qualitative evaluation of evaporator types now in use or proposed for future use in LWR nuclear power plants is provided in Table K-16. A similar approach would be used for each TRU waste processing application.

TABLE K-16
COMPARISON OF WASTE EVAPORATOR TYPES¹⁰

	Evaporator type		
	Natural circulation	Forced circulation	Submerged U-tube
Advantages	<ol style="list-style-type: none"> 1. Low cost 2. Large heating surface in the body 3. Low hold-up 4. Small floor-space 5. Good heat-transfer coefficients at reasonable temperature differences (rising film) 6. Good heat-transfer coefficients at all temperature differences (falling film) 	<ol style="list-style-type: none"> 1. High heat-transfer coefficients 2. Positive circulation 3. Relative freedom from salting, scaling and fouling 	<ol style="list-style-type: none"> 1. Very low headroom 2. Large vapor-liquid disengaging area 3. Good heat-transfer coefficients 4. Easy semiautomatic descaling
Disadvantages	<ol style="list-style-type: none"> 1. High headroom 2. Generally unsuitable for salting and severely scaling liquids 3. Poor heat-transfer coefficients of rising-film version at low temperature differences 4. Recirculation usually required for falling-film version 	<ol style="list-style-type: none"> 1. High cost 2. Power required for circulating pump 3. Relatively high hold-up or residence time 	<ol style="list-style-type: none"> 1. Unsuitable for salting liquids 2. High cost 3. Relatively high hold-up or residence time
Best application	<ol style="list-style-type: none"> 1. Clear liquids 2. Foaming liquids 3. Corrosive solutions 4. Large evaporation loads 5. High temperature differences--rising film, low temperature differences--falling film 6. Low-temperature operation--falling film 	<ol style="list-style-type: none"> 1. Crystalline product 2. Corrosive solutions 3. Viscous solutions 	<ol style="list-style-type: none"> 1. Limited headroom 2. Small capacity 3. Severely scaling liquids
Frequent difficulties	<ol style="list-style-type: none"> 1. Sensitivity of rising-film units to changes in operating conditions 2. Poor feed distribution to falling-film units 	<ol style="list-style-type: none"> 1. Plugging of tube inlets by salt deposits detached from walls of equipment 2. Poor circulation due to higher-than-expected head losses 3. Salting due to boiling in tubes 4. Corrosion-erosion 	<ol style="list-style-type: none"> 1. Slow response to changes in control settings 2. Poor level control in vacuum units

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4.0 WASTE COMPACTION^{1,2,3} AND RELATED TECHNOLOGIES^{4,5,6}

A number of simple volume reduction technologies dealing with increasing relative waste densities are available and have been utilized to handle combustible and certain non-combustible waste. These include compaction, baling and shredding. The following discussions address the VR technologies.

4.1 COMPACTION

Compaction is a process for mechanically reducing the volume of waste so that the waste package can be subsequently handled without risk of expanding. Because of varying terminology in the industry, baling is sometimes considered to be synonymous with compacting. In compaction, the waste is compressed inside of a container (such as a 210-liter drum) which is then closed. Baling, however, usually involves compressing the waste and then banding it so that it cannot expand; the bale may subsequently be packaged for further disposition.

Much of the low-level solid waste from nuclear fuel cycle facilities is compactible. Paper, fragments of plastic or rubber, rags, glassware, and small metallic items typically make up this category. Compaction methods should not be applied to the following:

- Items so dense or so hard that there would be negligible or insignificant reduction in volume
- Items capable of damaging the presses (e.g., very long metal items which might jam between the ram and the bottom of the press) or penetrating the container
- Pyrophoric or explosive substances
- Wastes containing free liquids.

Presses with either a horizontal or a vertical ram can be used, depending on the application and the space available. The pressure used will vary between 30 and 150 kg/cm² according to the reduction factor required.

The volume reduction obtained from compacting waste depends on the applied force, bulk density of the waste material, and the springback of the material when the pressure is released. Each waste type exhibits a threshold pressure region which is limiting for volume reduction. Compaction in the higher pressure region leads to only small additional decreases in volume. The bulk density of the material is the average of the density of the individual components and the void space. Compaction is therefore limited by both the compressibility of the waste and the available void space. The latter is often the primary factor in achieving large volume reductions. Springback results from the elasticity of the compressed waste. The more elastic a waste, the greater the springback, and the lower the final volume reduction. Volume increase resulting from springback is most pronounced in the first few minutes after the pressure is released. Springback can be significantly reduced by external containment such as bands, straps, or containers. The springback from compacted paper or other waste which behaves as a semi-elastic material also can be reduced by applying higher pressure or applying pressure for a longer period of time. Adhesives are sometimes effective for decreasing springback. Size reduction by shredding prior to compression tends to increase the volume reduction obtained from compaction. Shredding machines, however, create significant amounts of airborne dust which is quite undesirable when handling radioactive wastes.

4.1.1 WASTE MATERIAL CONSIDERATIONS

The criteria for compaction as they relate to the material being handled must specify limitations on material composition, moisture content, containment, volume, etc. The materials suitable for compaction generally include paper, cloth, rubber, plastic, wood, glass, and light gauge metal objects. Large or rigid objects should be excluded because of their uncompressibility or the damage that may be done to the container.

Moisture is to be avoided both because of uncompressibility and because of the possible spread of contamination through leakage during compaction. Corrosive, pyrophoric, and explosive materials must be avoided.

The quantities of compactible wastes generated at each site must be carefully evaluated to determine whether a compaction operation is feasible.

4.1.2 COMPACTION EQUIPMENT CONSIDERATIONS

The criteria for compaction as they relate to the equipment utilized must involve such items as reliability, simplicity, and economy. The compaction chamber must be contained and have suitable off-gas treatment. Remote operation of the equipment may be necessary. Maintenance should be minimal and easily accomplished. The equipment must be protected against rigid, uncompressible materials, excessive amounts of moisture and other deleterious substances. Easy and safe operation of the equipment is mandatory. The equipment should have the capability of either compacting the material in the container or injecting the material into its container after compaction to minimize springback.

4.1.3 AVAILABLE EQUIPMENT²

DEFINITION OF COMPACTION EQUIPMENT

Commercially available compaction equipment falls into four main categories which, for this report, are defined as follows:

- Compactors - Compactors compress material into the final storage, shipping, or disposal container.
- Balers - Balers compress material into bales which can be tied, banded, wrapped, etc., to maintain volume reduction prior to placing in storage, shipping, or disposal container.
- Baggers - Baggers compress material into slugs which are injected into cylindrical or rectangular bags, metal containers, etc., to facilitate handling, storage, and transportation.
- Packers - Packers compact waste within the storage and shipping container. They differ from the compactors in that the container, when filled, is transferred to the disposal site where its contents are discharged with no

attempt to retain the waste in a compacted form. The container is then available for reuse.

Compactors

Compactors have many applications and therefore vary greatly in size and design, ranging from hand-powered units to fully automated hydraulic systems. Size and power requirements are determined by throughput, largest item to be fed, disposal or storage container, volume reduction desired, and material to be compressed.

The most common compactor used in the nuclear industry is the 55-gallon drum compactor, which usually consists of a power unit, hydraulic or mechanical drive, a platen, a base plate, structural supports, a drum positioning platform, and a control panel. This type unit has been used in nuclear facilities for compacting contaminated, low-level, dry wastes, such as paper, cardboard, gloves, plastic, glass, etc. Volume reduction factors in the range of two to six have been reported.

Operation begins with the drum being placed on a platform positioned under the platen. Waste is loaded into the drum and the power unit activated to bring the platen down onto the material in the drum. The platen is then raised, the drum recharged, and the process repeated.

High Compression Drum Compactor

The high compression drum compactor is a modification of the drum compactor. This unit incorporates a metal innersleeve which protects the drum wall from puncture and excessive pressure during the compaction cycle allowing increased platen pressures without exceeding the drum strength. Operation is similar to that of the drum compactor with the exception that the protective sleeve is positioned inside the drum before the compaction cycle begins and is removed after compaction is complete.

Drum compactors lend themselves to protective enclosures which prevent the escape of airborne particulate matter. A typical system for radioactive particulate control consists of a hood, or shroud around the drum opening, high-efficiency air filter, and an exhaust blower. The unit may also be housed in an enclosure which is maintained at a pressure lower than that outside. Since the compactor presses the material directly into a drum, the waste is contained in a final leakproof shipping container. The outside of the drum generally remains free of contamination using these systems.

Drum compactor ram pressures are usually limited by the bursting strength of the drums. Rigid metal objects in the charge are undesirable because they can be pushed through the drum walls during the compression cycle. The high compression drum compactor, not commonly used in the United States, isolates the drum walls during compaction to allow higher ram pressures and protection against metal objects.

Balers

There are five basic balers available on the commercial market. They are (a) horizontal continuous, (b) horizontal stage, (c) vertical upstroke, and (d) vertical downstroke. Models include hydraulic, electric, and hand-operated platens. The following is a brief general description of the five types:

- (1) Horizontal Continuous: This is a continuous extrusion machine which operates by compressing one bale against another. Shredding is usually required prior to baling of material. Typical feeds are restricted to heavy cloth and paper.
- (2) Horizontal Multiple Stroke: Material is charged into a chamber for compression by a horizontal hydraulically operated platen. The platen is then retracted and the process repeated until the desired bale length is obtained. This unit is available with one or several compression stages. The baler can compress all types of material, wet or dry, but is used primarily for scrap metal.
- (3) Horizontal Multiple Platen: Material is charged into a chamber from a curved skip pan which operates in con-

junction with a compression door to position and contain the material prior to baling. Compression is accomplished in two stages with two horizontal platens operating at right angles. Each platen performs a single stroke to produce a finished bale. This is used primarily for scrap metal.

- (4) Vertical Upstroke: This machine usually operates in a pit, the depth being dependent upon the length of the stroke. The waste is loaded into a hopper at floor level and when the hopper is full, hydraulic rams push the material upward against a stationary platen. This procedure is repeated until a desired bale length is obtained. This machine is capable of compressing all types of material, wet or dry.
- (5) Vertical Downstroke: Waste is placed in the baler through a side mounted chute. A hydraulic cylinder compresses the material against the bottom of a chamber. The platen is raised and the process repeated until the desired bale length is obtained. This baler handles all types of material, wet or dry.

Baling systems are manufactured in such a variety of sizes, pressure ranges, and designs as to allow baling of most materials. Most balers produce a rectangular bale, a shape convenient for further packaging (bags or boxes), storage (easily stacked), and transporting. The primary problem in using balers to compact radioactive waste is the containment of radioactive particulate matter. Commercially available units would require major modifications and/or special enclosures for contamination control. Also, the bales would still require a final container for shipment and burial.

Baggers

Baggers are stationary refuse compactors designed to compress material into slugs which are then injected into cans or bags. In operation, material is dumped into a hopper and when the hopper is filled to a predetermined level, a compacting ram compresses the material. The ram retracts and the process is repeated until the compressed material reaches a preset pressure after which it is injected into a bag or container.

This type machine could be adapted to inject into a 55-gallon drum for permanent storage.

Baggers offer a variety of other options for slug containment and would, therefore, offer waste reduction advantages to nuclear facilities in handling and packaging low-level, nontransuranic wastes for interim storage and/or burial.

Packers

Packers compress material for trash accumulation and transportation purposes. In operation, a hydraulic cylinder, platen, and associated equipment are connected to a refuse container. Waste material can be charged directly into the container or placed in a hopper over the compacting ram. The ram is then actuated and compresses the material in the container. This process is repeated until the container is full, at which time the container is detached from the compactor and transported to a refuse area where it is emptied.

Although this equipment is designed for accumulation and transportation of material only, it could be modified to pack waste into permanent storage containers.

4.1.4 TRANSURANIC WASTE COMPACTOR

CONVENTIONAL WASTE COMPACTOR^{2,3}

The compactor shown in Figure K-22 was designed for the Plutonium Finishing Plant in the 200-West Area of the Hanford Project. The wastes to be compacted initially are from the rooms and offices in radioactive areas and, therefore, are potentially contaminated. A similar device was installed at Mound Laboratory for the Plutonium Processing Building Waste.³

The prototype compactor at Hanford is a modification of a commercial compactor sold by Consolidated Baling Machine Company (Model DOS-RAW Type II(X)) of Brooklyn, New York. It is basically a two-column, open-side, downstroke,

FIGURE K-22

PROTOTYPE TRU WASTE COMPACTOR^{2,3}

hydraulic baler. The compactor is made for use with standard 210-liter drums. The total compression force is 20,000 pounds, and the compression pressure on the waste material is 50 pounds per square inch.

A "drum support plate" is mounted on spring-loaded rollers on the base of the compactor. The plate facilitates movement of the drum from under the hydraulic cylinder for repeated loading and compacting of its contents.

An air exhaust system consisting of a hood, absolute filter, and exhaust fan is incorporated with the movement of the hydraulic cylinder. This system is so arranged that when the platen descends to compress material, the air exhaust system descends until the hood rests on the drum collar. Air from the drum being compacted is then drawn off and filtered.

In operating the test unit, a 210-liter drum is placed on the drum support plate and secured with the drum clamp. A hopper is then placed on top of the drum. Waste is loaded and the full drum placed under the ram, compressed, rolled out from under the ram until no space remains to compact additional waste. The hopper is lifted from the drum, the clamp released, the drum placed on the floor where the lid is attached and secured.

The operating experience with this work compactor³ illustrated that the average drums weighed approximately 264 pounds (120 kg) and compaction resulted in a volume reduction ratio of approximately four.

HEPA FILTER COMPACTION⁴

To reduce the handling and cost of disposal of high efficiency particulate air (HEPA) filters, a pilot compactor design was developed and operated at the DOE Rocky Flats Plant.⁴

The constructed pilot model consisted of a hydraulically operated punch, rams, and an extruding die. The function of the model was to separate the filter components from the frame and to extrude them through the die. The HEPA filters were 8 by 8 by 6 inches.

In the model, a standard 5,000-pound pump is connected through a series of valves to four cylinders which can be operated and controlled independently. A ram is attached to the piston rod of each cylinder. The main cylinder has a capacity of 25 tons of force and is used to extrude the filter media through the pelletizing die. Although different configurations of dies were tested, one that produced pellets with a square cross-section proved the most satisfactory.

The overall dimension of the inside of the die is four inches and is divided into four equal sections. The leading edge of the divider comes to a knife edge where the filter media is sheared. Each of the four sections is two inches square at the knife edge. These openings are tapered down to 1.75 inches square, 1 inch into the 2-inch thick die. Because of poor flow characteristics of the filter media, the dividers and the taper provide sufficient resistance to the ram to compact the media being extruded. Attempts to produce cylindrical pellets failed because the die openings were too severely tapered for the filter media to be extruded. By moderating the taper, undoubtedly, pellets of different shapes could be produced.

The original concept involved punching the media out of the frame and shredding them before pelletizing. However, because the flow characteristics of filter media were poor, it was decided to use a shear die and eliminate the shredding operation. For the 8 by 8 by 6-inch filter, it took a force of about 2,000 pounds to separate the media from the frame. About 20,000 pounds are required to compact and extrude the media through the die.

With this system, the filter is soaked with water before compaction, otherwise, the extruded pellets tend to re-expand. Pellets resulting from soaked media expand by about 20 percent as they come out of the die. The lubricating properties of water appear to be minimal. The water serves to make the filter components pliable so that the compacted material retains its shape and size. The use of water as a rinse to partially wash off contamination will be considered in the future.

The pressure exerted on the wet media squeezes out most of the liquid and no free liquid exudes from the compacted pellet. In the current laboratory atmosphere, the exterior of the pellet is visibly dry within 24 hours. The frame of the filter can be crushed in preparation for combustion in the incinerator being planned for Rocky Flats. An 83 percent volume reduction of the media and separator is obtained.

4.2 SHREDDING

Shredding of combustible or potentially combustible waste materials into small pieces is sometimes desirable for subsequent processing or storage. The principal types of shredding equipment are hammermills, knife-cutters, and variations or combinations thereof.

Hammermills consist of pivoted or rigidly mounted hammers on a vertical or horizontal shaft or rotor. The hammers may be rectangular or chisel-shaped. Crushing or shredding takes place by impact between the hammers and a breaker plate.

Commercially available knife cutters used for size reduction fall into three broad categories: (1) fly knives mounted tangentially on a rotor to work against stationary bed knives; (2) finger knives mounted axially on a rotor to work against stationary anvils; and (3) finger knives mounted axially on two counter-rotating rotors. The first type is used for shredding plastics, rubber, and cellulose, including paper. The second type is used in rubber, pulp, and food industry applications. The third type is used for volume reduction of mixed refuse. For a given type and size of feed, knife cutters generally require less power than do hammermills. Knife-cutters have the disadvantage of being susceptible to damage from tramp metal in the feed and of requiring the knives to be re-ground or replaced periodically.

Shredders with two-stage operations, which combine features of both hammermill and knife-cutter, are also available. For example, a knife-cutter may be used in the first stage, while the more rugged hammermill serves as a second stage.

The shredded product which emerges from both hammermills and knife-cutters lends itself readily to air conveying. The air serves as a cooling medium for heat-sensitive materials, such as plastics, and thus prevents their sticking in the mill.

At Rocky Flats, a series of shredding tests was performed on typical waste materials using the following four shredders:

- A vertical-shaft hammermill with ring-type hammers.
- A horizontal-shaft hammermill with fixed hammers.
- A rubber chopper which cuts the material between rotating hammers or blades and stationary anvils. The material is forced through a stationary orifice plate and is cut again by rotating knives as it comes through the plate.
- A low-speed shredder which cuts the materials between cutters mounted on two parallel horizontal shafts rotating at different speeds and in opposite directions.

The waste materials tested included paper, plastics (PVC and polythylene), and items less commonly found in wastes, such as surgeon's gloves, leaded gloves, HEPA filters, water filtering cartridges, etc.

The most acceptable shredder was the low-speed cutter unit (the last unit above) which could be installed in a glove box for operation. (Each of the other units would require installation in a canyon or hot-cell to provide adequate operating space.) This shredder was equipped with an over-torque device to prevent damage by tramp metal which might be in the waste. A similar shredder has been satisfactorily tested at HEDL.

The rubber chopper gave superior performance but was eliminated from consideration mainly because it was not protected from damage by tramp metal. The vertical-shaft hammermill was satisfactory in all respects except that it was quite large and would require disassembly for nuclear safety inspections. The horizontal-shaft hammermill was rejected because it did not satisfactorily shred large-size packages.

4.2.1 SHREDDING AND BALING

A special application combining shredding and baling has been tested at the Rocky Flats Plant. The shredder-baler system will shred and compact non-line-

generated combustible, compressible wastes. Combustible wastes which are collected outside the dryboxes are placed in 200-liter drums. These drums are then counted using sodium iodide detectors for measuring gram quantities of plutonium. All drums containing non-detectable amounts of plutonium are sent to the shredding operation. The drums are emptied onto a sorting table where tramp materials are removed to avoid damaging the shredder. The wastes are then fed by conveyor belt to the shredder where they are reduced to an assortment of particles averaging 5 mm in size. These particles pass out of the shredder chute directly into the baler, which is capable of baling particles as fine as sawdust. Bales are wire-tied before being bagged. The bales measure about 50 cm x 60 cm x 120 cm and weigh about 90-180 kg. Eight of the bales will fit in a standard 120 cm x 120 cm x 210 cm fiberglass-coated plywood box used for waste shipments and storage.

4.3 REFERENCES

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5.0 ADVANCED COMMERCIAL LOW-LEVEL RADWASTE PROCESSING TECHNOLOGY

While there are numerous incinerators and other radwaste processing technologies operating at DOE nuclear facilities, their application in the commercial nuclear industry has been limited. However, in the past few years, incineration and fluidized-bed drying technology have come into the forefront as a potentially viable volume reduction technology for nuclear power plant applications. A brief review of these technologies is presented.

5.1 TRECAN LIMITED, INC., INCINERATOR¹⁻³

The Trecan incinerator is a batch-charge controlled-air type utilizing several custom designed features, for example, a stainless steel primary chamber in place of refractory lined to facilitate cleaning.

Trecan has had two contracts for the design and manufacture of radwaste incinerators, one for Ontario Hydro and the other for Atomic Energy of Canada Ltd., for their Chalk River, Ontario facility (see Figure K-23). The Hydro unit is operational; the AECL unit will be operational in 1980. The Hydro unit has a capacity of 600 cu.ft. per charge, while the AECL unit is half this size.

The radioactive waste incinerator at the Ontario Hydro's Bruce facility was declared in-service in September of 1977. About 1700 m^3 of combustible wastes (low-level) has been processed in about 90 burns. Experience accumulated to date suggests that the system is not effectively designed. Many modifications have been made since the system was commissioned. The system has required a high degree of maintenance. Automatic control of the incineration process has not been possible.

5.1.1 INCINERATOR DESIGN

Controlled air incineration is used to minimize radioactive particulate emissions. The incinerator's design capacity is $17 \text{ m}^3/\text{burn}$ ($600 \text{ ft}^3/\text{burn}$). About 2,200 kg of wastes can be processed in each burn cycle.

FIGURE K-2:

TRECON INCINERATOR SCHEMATIC FOR ONTARIO HYDRO²

The primary chamber of the incinerator is loaded in batch prior to ignition. Temperature in the primary chamber during the burn is maintained at 538°C ($1,000^{\circ}\text{F}$) by adjustment of the underfire air. The pyrolyzed gases generated in the primary chamber are further oxidized in the afterburner at 871 to 982°C ($1,600$ - $1,800^{\circ}\text{F}$) with the aid of a propane burner. The high-temperature flue gas from the afterburner is then cooled to 204°C (400°F), the limiting temperature of the baghouse. Despite the system's characteristically low particulate loading, a shaker type baghouse with Nomex bags is provided for further filtration prior to release. The incinerator is maintained at slightly negative pressure (-0.05 kPa(g) or -0.2 psig) by an induced draft fan.

5.1.2 VOLUME REDUCTION

The volume reduction factor achieved in incinerating the present types of wastes ranges from 40:1 to 80:1. The weight reduction factor ranges about 12.5:1. Since the use of the 2.5 m^3 rectangular containers for ash storage, the overall volume reduction factor after storage has improved to about 30:1.

5.1.3 OPERATING EXPERIENCE³

Until the end of 1977, 50 hours were required to completely process a batch of waste. This included:

- Two hours for loading the primary chamber with wastes
- Two hours for warming-up the afterburner
- Twenty-four hours for burning (from primary chamber ignition to afterburner shut-down)
- Twenty hours for cooling (from afterburner shut-down to ash unloading)
- Two hours for ash unloading into 210-liter drums

The process time has since been reduced to about 36 hours, eliminating the cooling period. Hot ash is now unloaded directly into 2.5 m^3 rectangular carbon steel containers as soon as the burning cycle is completed.

The larger, rectangular containers also have the advantage of holding several burns of ash, thus reducing the handling time and providing maximum use of storage space.

An average batch-load of waste ($\sim 16.4 \text{ m}^3$) produces about 0.4 m^3 of ash, giving an average volume reduction factor of 40 to 1. The average weight reduction factor is about 12.5 to 1. The ultimate volume reduction factor is 23:1 after storage of the 2.5 m^3 containers in engineered concrete trenches. One container occupies about 3.5 m^3 of trench space.

5.2 HELIX PROCESS SYSTEMS INCINERATOR

Helix Process Systems will offer a low-level radwaste incinerator based upon the controlled-air incinerator design developed at Los Alamos Scientific Laboratory⁴ and discussed previously. Helix design is based upon taking commercially available components and making the necessary modifications required for nuclear power plant waste. Helix's design basis includes a high PVC waste content. The proposed system feed rate is approximately 110 kg/m of combustible waste. The incinerator utilizes a refractory material and operates at a negative pressure. Off-gas processing is accomplished by gas scrubbing, chemisorption, and HEPA filtration. Volume reduction factors of 40:1 are expected based upon simulated feed tests.

5.3 AEROJET ENERGY CONVERSION COMPANY VOLUME REDUCTION SYSTEM

The Aerojet Energy Conversion Company (AECC) volume reduction systems use a fluidized-bed dryer to process evaporator concentrates and an optional fluidized-bed incinerator to handle certain wet solid wastes and dry radioactive wastes (general trash). This technology is applicable, in general, to TRU contaminated waste which might be generated in fuel cycle facilities. The present system is offered to commercial nuclear power plants to process low-level radioactive waste.

5.3.1 FLUIDIZED-BED DRYER VOLUME REDUCTION SYSTEM

The fluidized-bed dryer volume reduction system consists of a fluidized-bed dryer and an off-gas cleanup system, as shown in Figure K-24.

Liquids from the radwaste evaporators are preconcentrated and metered to the fluidized-bed dryer where they are atomized with air and injected into the fluidized-bed vessel.⁵ As the liquid droplets contact the hot salt particles in the bed, the water is flash-evaporated, and the salt is deposited on the bed particles. Fluidized air is supplied by an air blower operating in a semi-closed loop. The air, which is electrically heated, flows upward through the dryer vessel, fluidizing the bed particles. The dry granular bed particles are discharged from the fluidized-bed by the product conveyor to the product storage hopper. After accumulation in the product storage hopper, the dry product is metered to the radwaste packaging system for immobilization.

The gas stream leaving the dryer vessel consists of air, water vapor, and a few fine salt particles due to attrition within the fluidized-bed. This gas stream passes through a gas-solids separator where the bulk of the fines are removed from the gas stream and discharged to the product storage hopper. The gases leaving the gas-solids separator are subjected to further cleansing in a high-energy venturi scrubber. The scrub liquid, which is the input feed, is recirculated through the scrubber system, preconcentrated, and subsequently metered

FIGURE K-70

AECC FLUIDIZED-BED DRYER VOLUME REDUCTION SYSTEM

to the fluidized-bed dryer. The gas stream is then passed through a condenser where the water evaporated in the system is condensed by cooling with plant service or component cooling water. The condensate is recycled back to the existing plant radwaste treatment system, and the air returns to the blower for recompression and recycling. A small amount of gaseous effluent is vented from the system and passed, via an absolute HEPA filter-charcoal adsorber unit, to the facility ventilation system for treatment and release.

5.3.2 FLUIDIZED-BED DRYER/INCINERATOR VOLUME REDUCTION SYSTEM⁶

The fluidized-bed dryer/incinerator volume reduction system consists of the basic system utilized in the fluidized-bed dryer, plus an additional fluidized-bed incinerator, as shown in Figure K-25.

The fluidized-bed incinerator is a separate vessel designed specifically to incinerate the dry radioactive waste generated in a plant. The dry radioactive wastes (consisting of paper, plastic bags, plastic or rubber gloves, boots, laboratory clothing, cardboard, wood and rags) are typically collected in 210-liter polyethylene bags and passed through a metal detector, shredded, and stored in a dry waste hopper. The dry shredded waste is then pneumatically metered into the fluidized-bed incinerator. The transport air, fluidizing air, and combustion air are supplied by a small separate blower. The bed material, which is inert, is preheated for startup only by heating the fluidizing air with an electrical preheater. The shredded waste ignites upon introduction into the fluidized-bed incinerator.

The fly ash resulting from the incineration process leaves the incinerator with the exhaust gas which then passes through the gas-solids separator, wet scrubber, and condenser, along with the off-gas from the fluidized-bed dryer. The ash is removed by the gas-solids separator from which it drops into the product storage hopper along with the dry product from the fluidized-bed dryer. The gaseous effluent, equivalent to the combustion air needed for the incineration process, is vented from the system and passed, via an absolute HEPA filter-charcoal

FIGURE K-25

AECC FLUIDIZED-BED DRYER/INCINERATOR
VOLUME REDUCTION SYSTEM

adsorber unit (common with the fluidized-bed dryer), to the facility ventilation system.

The dried product, after accumulation in the product storage hopper, is metered to the radwaste packaging system for immobilization.

5.3.3 OPERATING EXPERIENCE

AECC operated a full-scale prototype fluidized-bed dryer volume reduction system in May, 1974, at its Sacramento, California facility. The initial AECC Topical Report⁵ described a fluidized-bed dryer system without the preconcentrator feature which is now incorporated in the current system design. The fluidized-bed dryer system, both with and without the preconcentrator, has now operated in excess of 3,000 hours on a wide variety of simulated (non-radioactive) liquid waste feed streams typical of wastes expected from both BWR and PWR nuclear stations. These feed streams contained sodium sulfate, sodium metaborate (product of neutralization of boric acid), sodium phosphate, and mixtures of these feed streams covering a wide range of weight % solids and containing varying amounts of lubricating oils, detergents, decontamination solutions, iron oxide, diatomaceous earth, resin beads, and other crud. The system has processed all of the waste streams, converting the liquid wastes to anhydrous free-flowing solids, thereby effecting maximum volume reduction of the wastes.

In August, 1975, a waste feed stream containing radioactive I-131 was processed in an extended test in support of the initial AECC Topical Report⁵ submitted to NRC. During this test, the decontamination factor for I-131 was measured for various hardware components and also across the total system.

AECC initially operated the full-scale system (fluidized-bed dryer/fluidized-bed incinerator) during the summer of 1979. Testing was conducted in each of the three modes of operation: (1) fluidized-bed drying of liquid wastes; (2) fluidized-bed drying of liquid wastes and fluidized-bed incineration of combustible wastes (dual operation); and (3) fluidized-bed incineration of combustible wastes. These

tests were used to demonstrate the ability of the system to process simulated wastes typical of those generated at BWR and PWR nuclear power stations in each of these three modes. Operation in Mode No. 1 was simply a reconfirmation of the previous operation (described above) on liquid waste streams.

Approximately 600 hours of successful operation have been accumulated on the fluidized-bed dryer/fluidized-bed incinerator as of October 1, 1979.⁶ The fluidized-bed dryer was initially operated on 10 percent sodium sulfate solution and also on a mixed 10 percent sodium metaborate/sodium sulfate solution (consisting of 80 weight % sodium metaborate and 20 weight % sodium sulfate) to demonstrate operation in Mode No. 1. Demonstrations of the dual mode operation were conducted, each of 100 hours duration. The fluidized-bed dryer processed a liquid feed stream consisting of a mixture of 10 percent sodium metaborate/sodium sulfate while the fluidized-bed incinerator processed dry combustible wastes. The fluidized-bed dryer also processed a liquid feed stream consisting of 10 percent sodium sulfate, while the fluidized-bed incinerator processed dry combustible wastes. The fluidized-bed incinerator, which also was operated alone (Mode No. 3), processed dry combustible wastes.

5.4 NEWPORT NEWS INDUSTRIAL CORPORATION RWR-1TM SYSTEM

The RWR-1TM system* is being developed jointly by Energy Incorporated and Newport News Industrial Corporation (NNI). The RWR-1TM system incorporates a proprietary design that combines a single-chamber fluidized-bed incinerator and calciner to reduce the volume of both liquid and solid radwastes (such as concentrated chemical wastes, filter sludges, spent ion exchange resin beads, rags, and other similar materials). Operation of the RWR-1TM system reduces all liquid and combustible solid radwaste to anhydrous granular solids. This residue is compatible with existing solidification agents, as well as with many agents currently under development.

5.4.1 DESIGN BASES⁷

The RWR-1TM system is designed to reduce the volume of radwaste through incineration of the combustible waste and calcination of the liquid non-combustible waste. The system (Figures K-26 and K-27) utilizes fluidized-bed technology for both incineration and calcination to take place in the same vessel. This is one of the critical design bases of the RWR-1TM system. The other generic design bases relate to the types and amounts of waste which the system must handle and the requirements for safe and reliable operation.

The RWR-1TM process differs from conventional fluidized-bed calcination/evaporation processes in several extremely important areas. The process uses an inert fluidized-bed medium where the liquid waste droplets are evaporated to dryness on the individual particles. The dried waste solids are then elutriated from the calciner/evaporator vessel and collected in a dry cyclone.

* RWR-1TM is a trademark of Newport News Industrial Corporation and Energy Incorporated.

FIGURE K-26
PROCESS VESSEL, FEED SUBSYSTEMS AND PRODUCT REMOVAL

FIGURE K-27
OFF-GAS CLEANUP

Heat for the endothermic calcination/evaporation reactions is supplied by burning No. 2 fuel oil, kerosene, or diesel oil directly in the fluidized bed. This approach eliminates all hot metal heat transfer surfaces, thereby eliminating coating of the heat transfer surfaces in the process, and direct combustion accommodates any organics contained in the liquid waste such as alcohols, ethers, lube oils, etc. The combustion system is self-regulated with safety cutouts and equipped with a pilot igniter.

The waste concentrates feed stream lines are all heat traced either steam or electrical. The liquid waste feed system to the calciner/evaporator is based on past experience with similar slurry transport systems in high-level waste calcination processes. If the solutions contained in the concentrates feed tank are too basic (greater than 11) acid can be added either in the feed line or in the concentrate feed tank to adjust pH. The process is designed to operate over a pH range of 0 to 11.

The system is also capable of incineration of solid combustible wastes. With this incineration capability the RWR-1 is able to not only reduce the volume of liquid waste (volume reduction factor of approximately 8) but achieves a volume reduction on combustible wastes (up to 300:1) and ion exchange resins (up to 18:1).

The key to successful operation of RWR-1TM is in the off-gas cleanup system. Ash is elutriated from the bed and separated in the off-gas system. The composition of this ash is a function of the material incinerated. Heavy non-combustible material drops to the bottom of the bed and is removed via the bed removal system. The only system modification required to use RWR-1 for incineration as well as calcination/evaporation is the addition of the appropriate radwaste and ion exchange resin feed systems. The radwaste must be shredded to allow accurate metered feed. Resins should be dewatered to give maximum system feed rate.

The off-gases and entrained solid product leaving the calciner/evaporator vessel first pass to a dry cyclone, where the majority of the solids are de-entrained

from the gas stream. The cyclone bottoms (product) fall by gravity to a transport device which transports the product to the live bottom product storage hopper. The product storage hopper is a live bottom bin designed to ensure constant product removal rates with no bridging. A metering valve is installed at the bottom of the live bottom product storage hopper to meter product to the solidification system. The fluidized-bed medium can also be routed to the live bottom product storage hopper via the product transfer device.

The wet scrubbing system consists of a scrub solution tank, with redundant strainers, scrub coolers, and scrub pumps. Provisions have been made for a routing condensate to the scrub solution tank as makeup scrub solution or to a condensate holdup tank. Condensate normally passes into the condensate holdup tank and is pumped from this tank to the main condensate tank.

Provisions have also been made for remote solution decontamination of the entire system. All process vessels exposed to radioactive solutions or solids, have been equipped with internal decontamination headers connected to the decontamination solution flush tank system. The redundant portions of the system (scrub pumps, scrub coolers, scrub strainers, and feed strainers) have all been equipped with decon flush capabilities so that one system can be decontaminated while the other is operating. Excess decon solution, such as obtained during a planned shutdown, is routed to the waste evaporator feed tank in the waste building. Provisions have also been made for drying all vessels and piping that come into contact with solids in the system (i.e., transport lines to jet, incinerator vessel, dry cyclone, and connecting duct between calciner/evaporator and dry cyclone) after a decontamination cycle.

The RWR-1TM system volume reduction factors are estimated to be:

1) Compacted dry combustible solids	80
2) Spent resin	18
3) Concentrated liquids	8
4) Filter sludge	5

Decontamination factors used for computing emissions are 4×10^4 for particles and 1×10^4 for iodine.

5.5 UNITED TECHNOLOGIES CORPORATION INERT CARRIER RADWASTE PROCESS⁸

In cooperation with the General Electric Company, the Chemical Systems Division of United Technologies Corporation has developed and demonstrated the operational feasibility of a multi-process technology to reduce the volume and solidify low-level radioactive wastes. This Inert Carrier Radwaste Process (ICRP) evaporates all of the water (or other low temperature volatiles) in the waste by mixing a small stream of cold waste into a large stream of hot inert fluid under highly turbulent flow. The water flash evaporates, is recovered as condensate, and returned to the system or further processed for eventual discharge. The dried residue (carried by the inert carrier) is coated in suspension with a small quantity of high-melting epoxy resin and separated as a stable solid for packaging and off-site disposal. The resultant product cures to form a rock-like, nonflammable solid.

Development of the ICRP is being investigated on a pilot plant basis of approximately 1/10th production scale or at liquid feed rates of 0.1 to 0.2 gpm. Design and cost data are under development for full-scale plant construction with capacities of 60 to 120 gph of liquid or 250 to 500 lb/hr of solid wastes. Full-scale and firm costs are expected to be available in 1980. A topical report is expected to be submitted to the NRC in early 1980.

5.5.1 SYSTEM OPERATION

The basic operation of the ICRP is shown by the simplified schematic diagram in Figure K-28. The mass balance and flow rate numbers shown pertain to a typical 120 gph plant. The aqueous wastes (which may contain dissolved salts, suspended resins, and other waste residues) are neutralized (if necessary), then evaporated by feeding the wastes into the scale-free evaporator where they are mixed with a very large volume of hot inert carrier. The carrier used for this operation is a liquid silicone oil that is neither a solvent for nor reactive with any of the materials in the waste. The carrier is heated to a nominal 300°F (150°C) by continuous circulation through the heat exchangers and maintained at a state of high turbulence by the high flow rate and injection process into the evaporator.

FIGURE K-28
INERT CARRIER RADWASTE PROCESS

The water in the waste is flashed off nearly instantaneously when the relatively small feed stream (120 gph) is mixed into the large amount of turbulent hot carrier (400 to 500 gallons recirculating at 15,000 gph). The dry salts and other solids in the residue remain as a suspension of fine particles in the silicone. Material balance is maintained by withdrawing a side stream of the suspension so the solids can go through the jet mixer at the same rate as in the entry feed.

The waste is solidified by adding a commercial organic resin to the side stream of dry suspension as it is passed through a jet mixer. The resin-solids matrix is then sent to a separation column where it falls to the bottom as a separate phase. This phase is withdrawn from the separator and a hardener is added as the stream is passed through a static mixer just before it enters the disposal container. Feed to the drum or cask is regulated by a Moyno pump downstream from the separator. The pump is shut off when a container has been filled and restarted when a new empty container is in place. The separator tolerates a large surge volume of the resin-coated waste product and permits it to accumulate during the time the feed pump is off.

The final product cures in its container in approximately three (3) hours. The cured product is a nonflammable, rock-like solid with high resistance to fracturing on impact.

The steam formed by flashing the water off the waste in the evaporator is condensed and fed to a separator. At this point the small amount of steam distilled silicone is separated and returned to the evaporator. The condensed water is either discarded or returned to the plant. If necessary, the trace of silicone oil dissolved in the water is removed by filtering through a bed of activated charcoal. This waste water can then be further processed if necessary before recycling back into the plant or discharging.

Presently a nominal 1/10th scale ICRP pilot plant capable of processing 6 to 12 gph of liquid waste has been demonstrated successfully. In the operation of this pilot plant, the waste slurry is fed into a 214-gallon tank of a closed system containing approximately 90 gallons of silicone fluid maintained at 350°F. The

one-year operating experience showed the basic process to be free of operational problems. There were no problems with frothing or carryover in the evaporator, no scaling or corrosion of the heat exchangers, or deposits of epoxy resin or waste accumulated in the system. Also, the current experience with practical use of remote and automated controls shows the ICRP to be amenable to remote operation with manual attention required only during startup and shutdown.

5.5.2 CURRENT STATUS

The ICRP is currently being subjected to detailed engineering design and process variable studies using a pilot plant with a capacity to process 6 to 12 gph of aqueous wastes. This study is directed toward generating detailed data needed to prepare optimized designs for 60 gph to 120 gph production plants, determining firm costs for these plants, and developing data on the properties of the final products derived from typical power plant wastes. These pilot plant and detailed design studies are expected to be completed in 1980.

5.6 WERNER & PFLEIDERER CORPORATION⁹⁻¹²

Werner & Pfleiderer Corporation (WPC) offers a volume reduction system that is also a waste solidification system, with asphalt (bitumen) as the solidification agent.

Although it was only relatively recently introduced in the United States, it has been operating routinely in Europe since 1965 and was extensively researched before then. In Europe the initial development was a joint effort between the French Atomic Energy Agency's (CEA) research center at Marcoule, France, and Werner & Pfleiderer, a West German company (with offices in the United States).

The WPC system will solidify in an asphalt binder the spent resins, liquid waste evaporator bottoms, boric acid evaporator bottoms, chemical wastes, laundry wastes and filter cartridges. In addition, other solids such as filters, rags, paper, tools, etc., may be placed in a drum for asphalt addition.

5.6.1 SYSTEM DESCRIPTION

Since the extruder-evaporator is also a solidification system, radioactive wastes go directly into the extruder-evaporator and from there into storage or transport. The extruder-evaporator simultaneously provides homogeneous mixing, liquid evaporation and solidification in one machine.

The extruder-evaporator process is broken down into four sub-units. They are the input or feed, the extruder-evaporator or processing unit, the discharge handling, and the remote control system. Sub-operations of the total process are interlocked and functionally interdependent.

FEED SYSTEM

The feed streams (see Figure K-29) consist of asphalt and radioactive wastes. Each is contained in its own holding tank equipped with remotely controlled valves and metering pumps.

FIGURE K-29

MODEL ZDS-T83 FEATURING THE
WPC TWIN-SCREW MIXER-CONCENTRATOR

The two important factors in the feed system are the pH of the radioactive liquid concentrates and the ratio of asphalt to radioactive salts fed into the extruder-evaporator. The pH should be slightly alkaline, in the range of 8 to 10.

The most favorable ratio of asphalt to radioactive salts is normally 50:50. The ratio of asphalt to radioactive salts fed into the extruder-evaporator is an important consideration in any given installation for two primary reasons. One is that it will govern the amount of volume reduction achieved and the other is it will determine the amount of radioactivity in the final solidified product.

EXTRUDER-EVAPORATOR UNIT

All of the processing takes place in the extruder-evaporator. The feed materials enter the extruder in the first and/or second barrel section where they are immediately enmeshed in the mixing action of the self-cleaning screws. A view of a complete extruder-evaporator is shown in Figure K-29.

The total residence time from feed input to discharge varies slightly depending upon the size of the unit, but is generally on the order of one minute. The total inventory of material in the extruder when full approximates one gallon even in the larger size unit. The combination of low volume and short residence time in the extruder means a low amount of activity, with respect to the feed tank or solidified drum. Maintenance exposure would be lower than for a system which has a waste inventory of several cubic feet. At discharge the radioactive salts are micro-dispersed throughout the matrix and each particle is individually asphalt coated.

Simultaneous with the mixing, the excess water is evaporated through steam domes located downstream from the feed barrel as shown in Figure K-29. The number of domes needed varies up to six, depending on the size of the extruder needed to evaporate 99.5 percent of the water out. Evaporation rates for the various size extruders range from one (1) up to 200 liters of water per hour. The evaporation rate needed to achieve a 99.5 percent moisture removal is the prime factor in determining what size of extruder is required in any given situation.

The extruder-evaporator is connected to a variable speed motor capable of turning the screws up to 300 revolutions per minute.

DISCHARGE HANDLING

The extruder-evaporator normally discharges the asphalt/salts mix into standard 210-liter drums at a rate from 1/4-gallon to 30 gallons per hour, depending upon the size and speed of the extruder and the concentration of the feed stream. However, other sizes and types of containers can be used if desired. Normally, a filled drum is allowed to cool and settle for a period up to 24 hours before it is closed for storage prior to transport to the disposal site.

The level of radioactivity in the final product is governed by the ratio of asphalt to radioactive salts fed into the extruder as well as the type and concentration of activity in the salts. At Karlsruhe, for example, the level of activity in the final product approximates 0.38 curies per gallon.

REMOTE CONTROL SYSTEM

The entire process, complete with interlocks, is controlled remotely from a central control panel, with substation controls included where needed or desired to meet individual site installation requirements. The control system allows the solidification process to be operated in total or in part, either continuously or in an on-off mode.

5.6.2 OPERATIONAL STATUS

Full-scale, routine solidification systems, as well as a bench-scale unit, are presently operating in power plants and research centers in Europe. Karlsruhe, West Germany, has both a full-scale system operating routinely with radioactive wastes, as well as a bench-scale unit used for research and development.

A demonstration extruder-evaporator capable of processing nonradioactive but power plant salt (wastes) mixtures is in operation at the WPC plant in Waldwick, New Jersey.

5.7 ASSOCIATED TECHNOLOGIES, INC. (ATI)¹³⁻¹⁵

Associated Technologies Incorporated is the American sub-licensee for the Societe Generale Pour Les Techniques Nouvelles (SGN) bitumen process. SGN is the licensee of Commissariat a L'Energie Atomique (CEA) France. This license agreement enables ATI to provide the American nuclear industry with a volume reduction/bitumen solidification system.¹⁴

The ATI process uses a Luwa thin film evaporator, which operates at a temperature high enough to result in the evaporation of the water from waste influents. The remaining solids are homogeneously dispersed in a bitumen matrix. Solidification of the end product occurs upon the natural cooling of the bitumen binder. ATI provides a complete system for processing and solidifying radwaste. Waste concentrating and feed systems are supplied complete with tanks, pumps, piping, valves, instrumentation and controls, etc., as required. Similarly, an asphalt storage and supply system, a distillate collection and treatment system, and a complete container handling, capping, monitoring and decontamination system are provided.

5.7.1 THE BITUMEN PROCESS

A flow diagram of the installed system is presented in Figure K-30. Wastes to be solidified are collected in two 1,750-gallon stainless steel tanks equipped with turbine agitators. The waste consists mainly of powdered ion exchange resins or bead resins. In the latter case the beads have been ground to a powder during transfer to one of the feed tanks.

An agent is added to pretreat the wastes (2 percent of the dry weight). Experience has shown that this pretreatment aids in forming a homogeneous bitumen film on each particle. Bitumen is stored at 250°F in two 7,500-gallon tanks. The asphalt used is straight distilled bitumen. Slurry and bitumen are fed into the Luwa thin film evaporator.

FIGURE K-30

TYPICAL ATI BITUMEN SYSTEM

The mixture flows from the bottom of the evaporator into a standard 210-liter drum. The distillate is condensed and pumped through a cooler and a filter for removal of light oils. This filtered liquid distillate is then treated with low-level liquid waste from other sources before discharge.

The drums are filled in a two-step operation. Each drum is filled, and then allowed to cool down; because the matrix volume shrinks on cooling, this procedure enables more waste to be filled into each drum. Finally, the drum is completely filled. The drum filling cell includes a turntable with eight drum positions. With this arrangement, eight positions are available for filling, cooling, crimping of lids, monitoring surface dose rate, discharging filled drums and loading with empty drums.

5.7.2 WASTE PRETREATMENT

The waste pretreatment system includes chemical addition tanks, tank agitators and chemical metering and transfer pumps for storing, mixing, and delivering chemicals required for treatment of the wastes.

5.7.3 WASTE FEED SYSTEM

The system may include concentrates and spent resin or sludge storage tanks and recirculation pumps. Evaporator feed pumps (progressive cavity) are used to feed controlled amounts of waste to the Luwa evaporator. Pumps receive feed from the recirculation pumps on the plant's concentrate tanks. Other pumps receive feed from the resin recirculation pump which would circulate the contents of a resin preparation tank.

A resin preparation tank is required for handling spent ion exchange resin and filter backwash (diatomaceous earth and crud). The tank is equipped with eductors in order to adjust the concentration of resin in the tank to an optimum for slurry pumping. A complete turbine agitator system is also required.

5.7.4 BITUMEN STORAGE AND TRANSFER SYSTEM

The bitumen storage and transfer system would include a bulk storage tank, fill and suction line strainers, and a bitumen metering pump. The bitumen storage tank is steam heated and the temperature of the tank will be controlled at about 282°F to maintain the bitumen in a liquid phase. The bitumen metering pump is a progressive cavity pump and is provided to precisely feed bitumen to the evaporator. The system includes a strainer in the fill line to the storage tank and a strainer in the pump suction line. The strainer in the pump suction line ensures that small clumps of solidified bitumen cannot reach the bitumen pump. The bitumen storage and transfer system is supplied with instrumentation and control to assure proper tank level, bitumen temperature and bitumen flow.

5.7.5 HEATING FLUID SYSTEM

The heating fluid system includes a pump and heater set, an expansion tank and a drain tank and fill pump assembly. The heating fluid system is used to provide heat to the Luwa evaporator jacket. Heating fluid enters the evaporator jacket and provides an almost constant temperature over the length of the evaporator. The fluid temperature is controlled by controlling the electrical power to the heater. A redundant interlock is provided to prevent a failure in the control system. The expansion tank assures that the system is always full. The drain tank and filling pump are used when the system is drained.

5.7.6 LUWA THIN-FILM EVAPORATOR SYSTEM

The Luwa evaporator consists of the body (heated) and the rotor-separator. Waste and bitumen enter the unit tangentially above the heated zone and are distributed evenly over the inner circumference of the body wall by a distribution ring mounted on the rotor. The rotor blades spread the waste and bitumen

over the entire heated wall and generate highly turbulent flow conditions. The blades assure even distribution of the liquid over the metal heat-transfer surface.

Waste and bitumen spiral down the wall while bow waves developed by the rotor blades generate optimum heat flux, rapidly evaporating water. Vapors flow upward through the unit into the separator. Centrifugal action returns entrained droplets directly to the heating zone. Clean vapors pass through the vapor outlet, ready for condensing.

There is a valve on the bottom of the Luwa which is closed whenever containers are changed or indexed. A drip tray is positioned under the valve when it is in the closed position. A container ventilation hood is provided below the evaporator valve to collect vapors generated from evaporation and solidification. The ventilation hood will exhaust to the plant ventilation system. Due to the relatively low process temperatures, short residence time, and complete coating of all particles with bitumen, vapor and radioactive releases from this process are minimized. The hood also acts as a splash shield to ensure that containers are not externally contaminated.

A condenser/cooler is located downstream of the evaporator to condense and cool distillate generated in the evaporator.

5.7.7 DISTILLATE COLLECTION AND TREATMENT

This system consists of two collection tanks, distillate transfer pumps, and distillate oil filters. The filters are provided to remove light oils which will be carried over in the distillate produced by the evaporator. The filter will utilize activated carbon which will be sluiced to the spent resin system when exhausted. The distillate transfer pumps will pump through the filters to the liquid waste system since it will contain trace amounts of radioactivity.

5.7.8 OPERATIONAL STATUS⁶

The ATI system is operating, successfully reducing and solidifying radioactive wastes in bitumen, at numerous power plants worldwide (including Japan and France). ATI, as a licensee of SGN/CEA, has access to a 50 liter/hr pilot plant and the capability of testing radioactive samples. This laboratory is capable of processing bitumen in either a thin film evaporator or an extruder. Luwa, the manufacturer of the thin-film evaporator, has a pilot plant test facility in Charlotte, North Carolina, capable of processing non-radioactive bitumen test samples.

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