Spent Nuclear Reactor Fuel Reprocessing: Past, Present, and Future

Raymond G. Wymer
Vanderbilt University

Why Should We Care About Reprocessing?

Today's technologically advanced world is absolutely dependent on available, abundant, environmentally acceptable and affordable energy. Nearly all of today's major sources of energy are based on fossil fuels that are either becoming environmentally unacceptable because of solid and gaseous waste products, will become depleted in the foreseeable future, or are vulnerable to adverse manipulation, both in price and availability. Energy sources such as sunlight and wind can and will make a worthwhile contribution to the energy supply mix, but they will not by themselves adequately address the problems just noted. Another major energy source has already being added to the list of viable energy sources: nuclear energy. The use of nuclear must be increased if the serious problems noted above are to be minimized or avoided entirely.

Nuclear energy is not without its drawbacks, most notably the radioactive wastes that attend nuclear energy production. There is as yet nowhere in the world a licensed and operating high-level radioactive waste repository for the spent fuel wastes from nuclear power reactors. This true whether the wastes are intact spent nuclear reactor fuel elements or are wastes from spent nuclear reactor fuel reprocessing. However, progress is being made in several countries to establish geologic repositories for High-level radioactive wastes. A repository already exists in the U.S. for alpha wastes.

In addition to the radioactive wastes there are other very serious potential drawbacks to obtaining energy from nuclear power reactors as exemplified by the catastrophic Chernobyl reactor accident in Russia and the relatively benign Three-Mile Island Reactor accident in the U.S. Major advances have been made in nuclear power reactor design in recent years that significantly reduce the likelihood of recurrence of such accidents, and reactor licensing requirements that militate against such accidents have become more stringent. In any case, the need for the energy that can be obtained from fissioning the atom must be balanced against the dangers inherent in its use. The national and international consequences of an inadequate energy supply are simply unacceptable; safe and affordable nuclear energy is subject to continuing technological advances and improvements that make its production both acceptably safe and reliable.

As informed citizens it is incumbent on us to understand the pros and cons of nuclear energy and to weigh the many and complex benefits against the risks and costs of its production and use. These are issues too important to be uninformed about. Among the most important of these issues is that of spent fuel reprocessing. To understand this issue it is necessary to know how the U.S. got to where it is.

Spent Nuclear Fuel Reprocessing: U.S. History

The U.S. entry into spent nuclear reactor fuel reprocessing came about because of the desire to create an arsenal of nuclear weapons, first for use by the U.S. to defeat its enemies during World War II (WWI), and second as a counter-force to Russia's nuclear weapons buildup during the subsequent Cold War. In the course of WWII the U.S. built and operated a large spent nuclear fuel reprocessing plant at Hanford in the southeastern corner of the state of Washington. The purpose of the reprocessing plant was to separate plutonium from irradiated uranium fuel rods. The plutonium was to be used in the manufacture of atomic bombs that it was hoped would help bring to the wars with Japan and Germany to a successful conclusion. In fact, that is what happened with Japan.

The reprocessing carried out in the Hanford plant was the first large-scale spent nuclear fuel reprocessing in the world, and for the next 25 years the U.S. led the world in developing spent nuclear fuel reprocessing.

Reprocessing to recover plutonium began with the scale up of a laboratory-scale process developed by Seaborg and associates and was based on co-precipitation of plutonium with bismuth phosphate. Although the process did work, as it turned out it was an unfortunate choice because of the large amount of phosphate ion that wound up in the reprocessing plant waste stream. The presence of phosphate significantly complicates treatment and final disposal of the reprocessing wastes. It was soon found that solvent extraction of plutonium along with uranium was a much simpler and more efficient process, and solvent extraction processes with several different organic solvents was adopted both in the U.S. and abroad. In the U.S. a process based on methyl isobutyl ketone succeeded the bismuth phosphate process, and it in turn eventually was replaced by the Purex process. The Purex process proved to be highly successful and has been used universally throughout the world for recovering plutonium both for manufacture of nuclear reactor fuel and for nuclear weapons production.

Plutonium production and its separation from uranium and fission products continued after WWII in order to build a stockpile of nuclear weapons based on plutonium. Another large reprocessing plant to recover plutonium for the same purpose was built in South Carolina. Concurrently nuclear weapons based on ^{235}U produced by gaseous diffusion were produced as was fuel for the U.S. naval fleet, notably submarines and aircraft carriers. The naval fuels were more refractory than those used in plutonium production reactors and were reprocessed in a special plant built in Idaho. None of these three reprocessing plants is now reprocessing spent fuel to produce plutonium. Two of them are totally shut down.

In addition to the U.S. government reprocessing plants there were several abortive attempts to establish commercial spent fuel reprocessing in the U.S. Initially these attempts were encouraged by the U.S. Atomic Energy Commission (AEC), the forerunner of the today's Department of Energy (DOE). A small reprocessing plant was operated for a short time in upstate New York. This plant, the West Valley Reprocessing Plant, reprocessed both commercial spent fuel and fuel for the AEC. It is now decommissioned and the site awaits cleanup. Construction of two other plants was completed or started. One, the General Electric plant in Morris, IL, was built but never operated. Construction of the other plant, the Allied General Services Plant was never completed because of the moratorium placed on U.S. reprocessing by the Carter administration. As a consequence of these actions there is at present no commercial spent nuclear fuel reprocessing carried out in the U.S.

Reprocessing has continued unabated elsewhere in the world, and as will be discussed later, there is an initiative underway by DOE to reestablish commercial spent nuclear fuel reprocessing in the U.S. as part of a larger initiative to provide complete fuel recycle services internationally.

Foreign Spent Nuclear Fuel Reprocessing

Although all attempts at spent nuclear fuel reprocessing was forcibly discontinued in the U.S. in the mid-1970s this was not the case overseas. France, Great Britain, and Russian continued major reprocessing activities in the '70s and beyond, and smaller countries like Japan and Belgium operated smaller reprocessing plants, all eventually based on the U.S. Purex process.

Today there are significant (of the order of 800 tonnes or more per year of heavy metal[1]) reprocessing plants in operation in countries ranging from those mentioned above to India and China, both of whom have large and growing nuclear energy programs. In most cases the plants have been used both for commercial power reactor spent fuel reprocessing and for spent fuel reprocessing related to government, i.e., military, activities. Japan has a large (800 metric tonnes per year of heavy metal) commercial spent fuel plant just starting operation. The current major spent fuel reprocessing capacity world-wide is given in table 1 below.

Table 1. Major Current Commercial Light Water Spent Fuel Reprocessing Capacity

Commercial Plant	**Nominal Capacity, tonnes Heavy Metal/year**
France, LaHague	1700
UK, Sellafield (THORP)	900
Russia, Mayak	400
Japan Tokai Rokkasho	 ~100 800
Approximate Sub-Total	**~3900**
Other	
UK	1500
India	275
Approximate Sub-Total	**1775**
Total Commercial Capacity	**5675**
(U.S. commercial capacity)	(0)

A U.S. Spent Nuclear Fuel Reprocessing Renaissance?

Very important changes have taken place since the 1970s in the world's energy supply situation, and in particular in the energy supply situation of the U.S., the world's largest energy user. Energy supply problems in the form of excessive reliance on oil from the comparatively unstable middle-eastern countries and from Venezuela; concerns about global warming due to carbon dioxide generated by burning fossil fuels; concerns about the eventual depletion of fossil fuel resources and reserves; concerns about radioactive wastes; and concerns about nuclear weapons proliferation have all arisen and brought about a major reappraisal of the energy supply situation in the U.S. and abroad. A desire to avoid as nearly as possible reliance on external energy suppliers has become a major driver toward energy independence among the major energy users, and to a large extent this has lead them to move toward establishment of indigenous nuclear energy in the form of large nuclear power plants.

In the year 2001 an international forum was convened to discuss the next generation of nuclear power reactors with the goal of making available safer, more reliable, more versatile and more proliferation resistant reactors to help address the large and growing energy supply problems. In addition, this forum, the Generation IV International Forum, discussed the potential eventual need for spent nuclear reactor fuel recycle when the cost of uranium reached levels making recycle economically viable or the cost of recycle itself was low enough to make recycle viable.

[1] By convention reprocessing plant capacity is stated in terms of the amount of uranium present in the spent fuel before irradiation, which is referred to as "heavy metal."

The Forum settled on development of five reactor types that it felt could best meet the spectrum of reactor properties likely to be needed for the future supply of commercial nuclear energy. These needs include reliability, low cost, safety, high-temperature heat (for industrial applications), actinide burning[2], and ease of reprocessing. Table 2 lists the reactors selected by the Forum and some characteristics related to their selection.

Table 2. Generation IV Reactors Selected by the International Forum

Reactor Type	Characteristics
PWR PWR	Universal acceptance and ease of evolutionary development
FBR	Breeds Pu from ^{238}U; efficient actinide burner
HTGR	Produces high temperatures useful industrially and for thermochemical hydrogen production; graphite-based fuel
MSR	Circulating molten salt fuel; very proliferation resistant; on-line reprocessing

Fuel Cycle Studies and Initiatives

Concurrent with the cessation of all commercial spent nuclear fuel reprocessing activity in the U.S. in the '70s, a study called International Nuclear Fuel Cycle Evaluation, INFCE, was started. This was a multi-nation study that produced a series of documents on all aspects of nuclear fuel cycles, including both the uranium and the thorium fuel cycles[3]. The five elements of the study were:

An assessment of the nuclear fuel cycles
Improving availability to developing nations of plutonium for use in nuclear reactor fuel
Providing secure spent nuclear fuel storage
Improved nuclear safeguards
Alternatives to a plutonium and highly enriched uranium economy

A major conclusion of INFCE was that plutonium in excess of current national needs should be safeguarded by the International Atomic Energy Agency (IAEA).

Although INFCE did nothing to change the situation with respect to fuel reprocessing in the U.S. it did make a thorough study of the above elements of the study and produced valuable documents for future reference. The results of the study are as relevant today as they were when they were written. In fact, two current new initiatives to establish international fuel recycle centers contain much of what was studied and reported in INFCE, although there s little if any attribution to the earlier study.

There are two new initiatives to establish international fuel recycle centers, one being promoted primarily by the U.S. and the other by Russia. However, these initiatives are not entirely separate, and they have essentially the same goals and substantial collaboration exists.

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[2] The term "actinide burning" refers to the destruction of actinide elements by fissioning them in reactors. This destroys the long-lived actinides and produces the more manageable fission products. Actinide destruction is beneficial both because of the additional energy produced by fission and because their destruction helps reduce the heat load in a geologic repository from actinide alpha decay. Reducing the heat load permits emplacement of more waste in a given volume of repository.

[3] The uranium fuel cycle uses uranium as its essential element and produces additional fuel as plutonium by irradiation of uranium in reactors. The thorium fuel cycle uses thorium as its essential element and produces additional fuel as ^{233}U by irradiation of thorium in reactors.

The U.S. initiative is called Global Nuclear Energy Partnership (GNEP). The Russian initiative is called Global Nuclear Infrastructure (GNI). The central idea of both is establishment of fuel recycle centers within the major nuclear weapons countries that already have fuel recycle activities. These centers would for a fee provide fuel recycle to countries possessing nuclear power reactors, but having no indigenous recycle capability. Recycle activities would include fuel fabrication, spent fuel reprocessing and uranium enrichment. The issue of waste disposal has not yet been addressed in any detail. Russia has already designated a uranium enrichment plant at Angarst in Siberia. This plant is already under IAEA supervision.

The stated goals of GNEP are as follows:

- Expand domestic use of nuclear power
- Demonstrate proliferation-resistant fuel cycles
- Minimize nuclear waste
- Develop and demonstration fast burner reactors[4]
- Establish international lease and return fuel cycle services
- Demonstrate small-scale, modular power reactors
- Design nuclear safeguards into nuclear fuel recycle facilities and reactors

An important part of GNEP is the Advanced Fuel Cycle Initiative (AFCI) whose goal is to develop reprocessing and waste management approaches that will help meet the GNEP broader goals listed above. AFCI is primarily a U.S. domestic program. At the outset of GNEP construction and operation of a large U.S. reprocessing plant (at least 800 MTHM per year) was envisioned, but as a consequence of a National Academies report and Congressional actions the reprocessing plant was put on hold.

The stated goals of the Russian BNI are as follows:

- Establish full-service international fuel cycle centers
- Have nuclear centers only in nuclear weapons states
- Plan a shareholding structure for countries involved in centers
- Coordinate with the U.S. GNEP initiative

As can be seen, the Russian initiative is more sharply focused on the international fuel cycle center concept than the U.S. initiative is. The major difference is that the U.S. initiative has a strong focus on re-establishing the nuclear energy fuel cycle within the U.S. in addition to establishing international. Russia does not need this focus because it never abandoned the fuel cycle.

Reprocessing

Types of Commercial Power Reactor Fuel

The reason for commercial reprocessing is to recover valuable materials from spent nuclear reactor fuel and separate them from the wastes that are produced by reprocessing. The valuable materials are uranium, plutonium, and in some cases, other actinide elements such as neptunium, which is the feed material for ^{238}Pu production.[5] Although not practiced to a significant extent there is some reason to believe that other material of value may also be

[4] Fast burner reactors are liquid-metal-cooled reactors with fast neutron energy spectrums that are designed specifically to burn (fission) actinide elements such as Np, Pu, Am and Cm to produce the more manageable fission product waste.

[5] ^{238}Pu is used as a heat source for thermoelectric power generation in space applications.

recovered during reprocessing. Such material includes the Zircaloy cladding which potentially could be recovered for use in fabricating new fuel. Also, radioisotopes such as cesium-137 could be recovered for use in gamma irradiators.

Reprocessing wastes include the fission products and, for the time being, spent fuel cladding. The cladding is Zircaloy in the case of LWRs and stainless steel in the case of fast reactors, whether burners or breeders. In the future as fuel burnup goes to higher levers it is very likely that new, more refractory alloys will be needed for fast reactor fuel cladding. In the case of more advanced reactors such as the high-temperature-gas-cooled reactors graphite replaces metal as the fuel material containment material.

The principle reactors and their reactor fuel types are listed in Table 3.

Table 3. Principle Commercial Power Reactors and Reactor Fuel Types

Reactor Type	Fuel Type	Operating Properties
LWR		
PWR	UO_2/Zircaloy clad	Water cooled and moderated
BWR	UO_2/Zircaloy clad	Water cooled and moderated
FBR		
LMFBR	UO_2/PuO_2/SS clad	Liquid metal cooled
GCR	UO_2/PuO_2/SS clad	Gas cooled
HTGR		
Pebble bed	UO_2/graphite balls	Gas cooled/graphite moderated
Prismatic	UO_2 graphite prisms	Gas cooled/graphite moderated

The type of head-end treatment used to prepare the several fuel types differ significantly (see, *Head-end operations hot cell and equipment* below) but after the head-end treatment the rest of the reprocessing operations are very similar. The major differences are whether or not PuO_2 is present initially in the fuel and the degree of fuel burnup. In the case of FBR fuel the PuO_2 fraction may be as high as 20%, and this higher Pu content must be taken into consideration. The degree of burnup is typically in the 35 to 55 MWD/te for LWR fuels, and may exceed 100 MWD/te for FBR fuels. HTGR fuels also tend to have higher burnups than LWR fuel. The higher burnups produce larger amounts of fission products whose higher radiation intensity is more damaging to the organic extractants.

Features of Reprocessing

The two major classifications of nuclear fuel reprocessing are 1) aqueous and 2) non-aqueous. Aqueous reprocessing can be by either of two approaches, viz., solvent extraction or precipitation. As noted earlier the first large-scale nuclear fuel reprocessing was by precipitation to recover plutonium from irradiated fuel rods. Subsequently solvent extraction replaced precipitation as the reprocessing method of choice.[6]

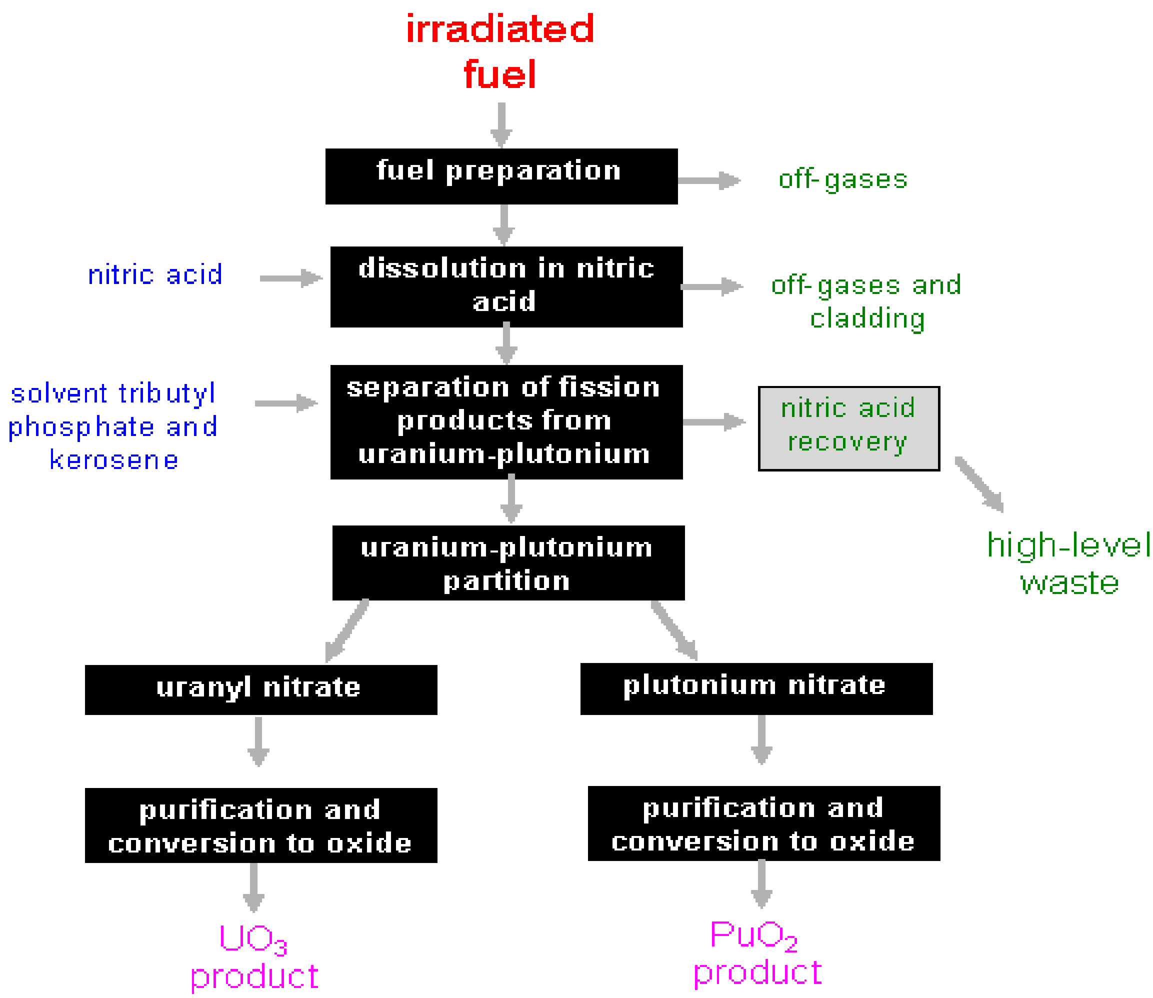
Non-aqueous reprocessing typically employs molten salts, molten metals, or volatilization. Separation of the desired substances is usually effected either by selective chemical, electrochemical, or volatility methods. Although non-aqueous methods have found some

[6] Solvent extraction is a method whereby one or more substances in one liquid phase move selectively into a second, immiscible liquid phase during contact between the two phases.

applications, at present by far the largest amount of spent nuclear fuel reprocessing is by an aqueous method, i.e., solvent extraction.

The Purex process is the reprocessing method most used. It is an aqueous solvent extraction process that employs an acidic aqueous phase and an immiscible organic phase made of tri-n-butyl phosphate (TBP) mixed with an organic diluent such as dodecane or kerosene. The concentration of TBP is about 30% by volume. Figure 1. is a very simplified representation of the Purex process. It does, however, show all of the basic operations of the process.

Figure 1. Greatly Simplified Purex Process Flowsheet



There are nine major process areas and their related process steps associated with reprocessing plants based on the Purex process. These are discussed below:

<u>Spent fuel receiving and interim storage areas</u>
Spent fuel is received from reactors in shipping casks. Typically the shipping casks are unloaded under water where the spent fuel is inventoried and stored until it is time to reprocess it. Water is a convenient storage medium because it is easily cleaned up if it becomes contaminated and it inexpensive and versatile.

Head-end operations hot cell and equipment

Head-end operations are carried out in a heavily shielded hot cell[7] to protect the plant operators from the intense radiation from the spent fuel. The primary purpose of the head-end operations is to dissolve the fuel material. To accomplish this, the fuel element may be disassembled and/or segmented and chopped into small pieces that will fit in a dissolver vessel. The purpose of chopping the spent fuel into small pieces, typically one to two inches long, is to expose the actual fuel material, which is nearly always an oxide composed primarily of UO_2. The oxide is charged into the dissolver and dissolved in nitric acid. Any of several configurations and types of dissolvers may be used. The current movement is toward continuous dissolving. The first major waste stream is produced in the form of pieces of cladding hulls in this operation.

Solvent extraction hot cell and equipment

After dissolution in nitric acid the resultant solution is assayed to determine its composition, especially the amounts of uranium and plutonium. The acidic solution of uranium, plutonium, other actinide elements and fission products is then transferred to a hot cell where it is treated by solvent extraction of the desired actinides into the TBP solvent to separate them as products from fission product wastes and other actinides if desired. Additional process steps are carried out to further purify and solidify the products.

Solvent extraction equipment may be pulse columns, centrifugal contactors or mixer-settlers, depending on the level of radiation (centrifugal contactors minimize radiation exposure), presence of solids (pulse columns handle solids well and have few mechanical parts subject to failure) and nature of the separation needed (mixer-settlers are sometimes used for solvent cleanup and recycle).

Solvent cleanup/recycle equipment

Solvent cleanup is an important operation and is necessary for efficient separation of products (actinides) from wastes (fission products). Some TBP/kerosene destruction occurs due to radiolysis and chemical attack during the extraction step and liquid waste streams are produced when the degradation products are washed out of the extractant. These aqueous streams are customarily concentrated by evaporation to reduce their volume. Solvent cleanup equipment can consist of liquid-liquid contactors to bring solvent and wash solution, often sodium carbonate, into contact or of columns of solid sorbent such as silica gel that selectively remove fission contaminants such as zirconium and ruthenium.

Off-gas treatment equipment

Large amounts of water vapor and nitrogen oxides come off the dissolver and are mixed with air that is circulated through the head-end operations hot cell. Volatile fission products such as iodine, oxides of ruthenium and of technetium, krypton-85, carbon-4 dioxide and tritiated water are also present in the off-gas. In addition, a large volume of air that circulates though other process hot cells enters the off-gas stream. In the past off-gas treatment was limited to removal of iodine and recover of oxides of nitrogen to reconstitute nitric acid for further use. In the future it is probable that tritium will be removed and recovered from the spent fuel before it is dissolved and that krypton-85 will be recovered from the dissolver off-gas.

[7] A hot cell is a fairly large room surrounded by thick concrete shielding walls that are usually fitted with manually operated manipulators that can perform operations within the cell while the operators are safely outside the shielding.

Equipment used for off-gas treatment includes traps such as sodium hydroxide solutions for iodine recovery and column scrubbers to sorb the nitrogen oxides. Cryogenic processes equipment is being considered for krypton-85 recovery.

Uranium product storage area
Uranium from the TBP extraction process is converted to UO_2 and stored in a designated storage area for further disposition. Because the uranium is still slightly enriched some attention must be paid to criticality.

Plutonium product storage area
Plutonium from the TBP extraction process is converted to PuO_2 and stored in a designated storage area for further disposition. Because the plutonium is highly fissionable great attention must be paid to criticality. This is achieved through use of specially designed containers whose construction maintains safe spacing between them.

Waste treatment area
The Purex process produces a variety of waste types, as do all reprocessing methods. The exact nature of the wastes depends somewhat on the type of fuel reprocessed. However, for most LWRs the wastes are very similar, varying mostly in the amount and nature of the metal cladding and fuel element structural materials that become waste. Besides these metal wastes there are high-level liquid wastes that contain the fission products, solvent recycle wastes, ion exchange resin wastes (primarily from plutonium final purification and fuel element storage pool water cleanup), off-gas cleanup wastes and a variety of wastes produced in cleanup operations throughout the reprocessing plant. An area is designated for treating these wastes to put them into a form suitable storage pending their final disposition. Treatment consists of evaporation of high-level wastes and solvent recycle wastes to reduce their volume before transfer to storage tanks, and solidification of most other wastes in concrete.

Waste storage and shipping areas
An area is designated for storing all but the liquid wastes prior shipping them to an off-site disposal area such as the Envirocare waste site in Utah.

Commercial Reprocessing Plant Requirements and Considerations

There are important legal requirements as well as important considerations that must be factored into any plans to build and operate a spent commercial nuclear reactor fuel reprocessing plant. Some of the most important of these are listed in Table 4 below.

Table 4. Commercial Reprocessing Plant Requirements and Considerations

Legal Requirements
An environmental impact statement
An NRC license for construction and operation
Meeting EPA radioactivity release limits at the plant site boundary
Decontamination and decommissioning friendly
Considerations
Factors impacting plant siting
Plant design considerations
Anti-terrorism features
Nuclear non-proliferation attributes
Economical
Minimal waste production
Storage and shipment of high-level wastes, low-level wastes, alpha wastes and mixed wastes

The legal requirements must be promulgated in federal regulations that have yet to be modified or written for reprocessing plants. Both the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA) will be involved in this exercise.[8]

Some of the more important physical and geographic plant siting considerations and issues are listed in Table 5 below.

Table 5. Plant Siting Considerations and Issues

Proximity to nuclear reactors: relates to transportation of spent fuel and wastes
Geology/nature of rock/soil: relates to ease of transport of radionuclides
Hydrology: the principle pathway for radionuclide transport
Seismology – fault lines; history of earthquakes: impacts siting and construction
Climatology – rainfall: relates to atmospheric inversions; transport of radionuclides
Topography – natural and man-made features of the land: relates to drainage of water and containment
Demographics – population distribution and density: relates to extent of impact of radioactivity release
Agriculture – magnitude of farming and nature of crops: relates to ingestion of contaminated food
Proximity to industry: relates to cost of an accident; interruption of supply of vital materials

[8] NUREG-1909 is an NRC document written in part specifically to address problems associated with licensing reprocessing plants.

Wastes

Typical Reprocessing Plant Waste Streams

Reprocessing plants produce wastes in liquid, solid and gaseous forms. Each type of waste must be dealt with an environmentally acceptable, economical and safe manner and in accordance with regulations. This is a challenging task because there are many difficulties with managing each type of waste. The reprocessing waste types are listed in Table 6.

Table 6. Typical Reprocessing Plant Waste Streams and possible Treatments

Waste Type	**Source**	**Possible Treatment**
Liquids		
HLW	First extraction cycle raffinate	Vitrify
LAW	Solvent scrub solution	Evaporate to concentrate
Gases		
Krypton-85	Dissolver off-gas	Remove cryogenically
Iodine-129	Dissolver off-gas	Capture on zeolite or in caustic solution
Carbon-14	Dissolver off-gas	Capture as the carbonate
Hydrogen-3 (T)	From voloxidation or as HTO	Capture as a hydrate or in concrete
Solids		
HLW	Contaminated cladding hulls	Compact as metal
LAW	Miscellaneous process wastes	Fix in concrete

Managing Plant Wastes

Management of plant wastes depends on the type and properties of the waste. It is anticipated that the wastes will ultimately be disposed of in a geologic repository, in a near-surface disposal site or stored until radioactive decay has reduced the radioactivity to innocuous levels.

In the past at the government reprocessing sites and under the pressures of WWII and then of the Cold War with the USSR many wastes, both radioactive and toxic, were managed poorly. High-level acidic radioactive liquid wastes were put into large (million gallon) tanks where sodium hydroxide was added to neutralize the waste to prevent corrosion of the tanks by the acid. Most of the fission products and residual actinides formed insoluble solids that precipitated to the bottom of the tanks. In addition neutralization of the nitric acid produced sodium nitrate the formed salt crystals. The result of this type of treatment of high-level wastes was that a very large amount of solids was formed in many of the tanks. The internal structure of the tanks is such that there are many obstacles to removing the solids. A variety of expensive and complex approaches, both physical and chemical, are being resorted to remove the solids so that they can be vitrified in preparation for final disposal.

Many of the lower activity wastes and toxic wastes were simply put into “cribs”, ponds and pits. In most cases these were large excavations in the ground, most of which were unlined with any sort of membrane to contain the wastes other than clay linings in some cases. Hanford for example has 21 cribs and 19 ponds. Types of waste ranging from alpha contaminated wastes to carbon tetrachloride were handled in this way, in some case many tonnes.

Table 7 lists current representative management approaches and waste treatment and disposition methods according to waste types and properties.

Table 7. Current Representative Waste Management Approaches

Waste Type	Property	Treatment	Disposition
Liquid HLW	Highly radioactive	Vitrify as borosilicate glass	Interim storage and final geologic disposal
LAW	Low level of radioactivity; some may not fit NRC waste categories (GTCC)	Stabilize in concrete	Send to Envirocare or a DOE site
Alpha	Alpha activity >100 nCi/gram	Convert to solid	Send to WIPP
Various, mostly FPs	Decays to innocuous level quickly	Convert to a safe form	Store until decayed to an innocuous

Waste Transportation

Transportation of wastes from the reprocessing plant site to disposal sites is an issue that, although not specifically a reprocessing plant waste issue, is nonetheless a very important issue closely related to reprocessing and to wastes. A reprocessing plant cannot operate indefinitely without disposing of its wastes. In the past and up to the present time liquid high-level wastes have been stored on site in large metal tanks. This is true of the liquid wastes at the government reprocessing plants at Hanford, Savannah River and Idaho Falls and it was true of the partially commercially operated reprocessing plant at West Valley. Progress is being made with the current stored tank wastes. They are being vitrified to put them into a concentrated solid glass and await establishment of permanent disposal sites for their final disposal. Low-level wastes and alpha wastes are already being sent to existing disposal sites. In all case, transportation is required to get the wastes to the disposal sites.

Transportation issues center about licensable shipping casks and containers, methods of transportation such as trains, trucks and barges, and transportation routes over which the wastes must travel. The NRC, federal and local departments of transportation, and citizens groups all have a stake in and bear responsibility to see that waste transportation is carried out safely, legally, and with due regard for the rights, economical well being, and desires of the citizens directly impacted by the waste transported.

Major Conclusions

- Spent nuclear fuel reprocessing is an established industry world-wide
- DOE has launched a major initiative to institute international centralized fuel cycle services and to re-establish indigenous reprocessing
- Waste management and disposal remains as an important issue
- There are significant licensing issues both for commercial spent nuclear fuel recycle and for waste disposal

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