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RISKS OF NUCLEAR FUEL REPROCESSING (U)

by

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The Savannah River Site is located about 25 miles southeast of Augusta, Georgia along the Savannah River in South Carolina. The site's primary function is the production of weapons materials. It consists of four reactors, two fuel reprocessing facilities, a fuel fabrication facility, a nuclear fuel facility for the Navy and a heavy water recycle facility. Under construction is a facility to convert the site's liquid wastes into borosilicate glass.

Our topic today is risks of nuclear fuel reprocessing. Nuclear fuel reprocessing has about as much real engineering in the operations as one could expect to find in any industry. I'll point these areas out as we go through the discussion. Before the risks are discussed, however, let's take a quick look at what goes on inside this type of facility. Reactor fuel is received in the facility in heavily shielded casks that are mounted on either trucks or rail cars. In a commercial fuel facility, the cask is washed, purged to remove any radioactive gases that might have leaked into the cask and then cooled, if necessary, for the fuel temperature to equilibrate with the temperature of the storage pool. The cask is lowered into the pool, the lid removed and the fuel discharged into storage racks that are spaced to prevent the fuel from being too close. The fuel pieces are removed from the pool, the end pieces are chopped off, the assembly air dried, and the active core is sheared into short lengths. The fuel then goes into a nitric acid-filled dissolver where the core material is dissolved. The hulls are washed and packaged for eventual disposal.

These head end steps are omitted in processing fuels at the Savannah River Site. Some of the fuel, which is aluminum clad uranium metal is discharged directly from the cask into a dissolver containing sodium hydroxide which removes the aluminum. The fuel is flushed with water, and nitric acid is added to dissolve the fuel core. At this stage, commercial and weapons fuel are processed similarly. Although there are some specific variations, in general the solution is clarified by adding a precipitant or coagulant and then centrifuged. The valence of the product in the clarified solution is adjusted and the solution is fed to solvent extraction vessels, either mixer-settler, centrifugal contactors, or pulse columns. In the first stage of these vessels, the uranium and plutonium are extracted into a solution of tributyl phosphate and kerosene and the fission products go into the aqueous phase. In the second stage the plutonium is stripped into the aqueous phase, leaving the uranium in the organic. In the third stage, the uranium is stripped back into an aqueous phase. Both the plutonium and uranium are then separately further decontaminated in subsequent stages to remove trace fission products.

At Savannah River, the depleted uranium, which is a by-product in the form of uranyl nitrate, is evaporated and calcined to uranium trioxide by thermal denitration.

The aqueous waste stream is evaporated, neutralized with caustic, and then stored in large carbon steel tanks. Overheads are re-evaporated to recover the nitric acid. At the present time, we are constructing a facility to convert the waste to borosilicate glass for ultimate disposal deep in the earth. This facility is scheduled to be on line in 1991.

The primary product, plutonium, is recovered from the plutonium nitrate solution. Plutonium nitrate is concentrated by ion exchange, precipitated, filtered, dried, and converted to either an oxide powder or the metallic plutonium. The plutonium may be used as a nuclear reactor fuel, for heat sources in space applications, or for nuclear weapons.

Now that I have briefly covered the general process, let's examine the risks of nuclear fuel reprocessing. By risk one means the frequency of some undesired event multiplied by the consequences. Frequency is expressed as occurrences per unit time or chance for occurrence. Consequences may be in any unit of cost to those involved such as loss of money, death, injury, flunking out of school, rejection, or simply fear. The most common form of risk unit for the nuclear industry is in radiation units per unit time such as millirems per year. This unit enables a comparison of accidents with routine discharges or with natural background radiation with which we all live.

In determining risks, the first step is to ascertain those initiating events that can impose a consequence to either operating personnel, or to an off-site population. At the Savannah River Site we have a series of computerized data banks to enable us to do this. The first of these is called the Generic Incidents Data Bank and contains a listing of every incident that anyone in the U.S. nuclear industry has experienced or even postulated could occur. This data bank defines each unit operation that might be utilized in fuel reprocessing. For each of these operations, the data bank defines the applicable incidents, the causes, the consequences, and safety features to prevent, detect, or mitigate the incident. About 1,000 generic incidents are listed in this bank.

The second data bank is called the 200 Area Fault Tree Data Bank. This is a listing of everything that has gone wrong in the fuel reprocessing plants at Savannah River. The data bank contains about 230,000 entries that range from minor equipment malfunction and process deviations to incidents with significant potential for injury to personnel or damage to equipment. Note, however, that less than one percent of the entries are significant safety items. This is the only data bank of its kind for reprocessing plants in the United States.

Each entry in the bank is coded by site area, facility, unit operation, date, and source of data. The data are sorted by any combination of the above using either "or", "not", or" and" logic. Given a particular incident to be analyzed for frequency, the data for that incident are sorted and a computer statistical analysis code is evoked to act upon the sorted data. The code determines the time between occurrences for each incident, fits the data to five standard distributions, selects the best equation, calculates mean, median, and error bounds for the frequency, and constructs a trend plot to determine if the frequency is increasing or decreasing.

Where incident frequency is not available from the data bank, it is determined by a technique called Fault Tree Analysis. FTA combines a logic diagram with Boolean Algebra to calculate the overall frequency based on the frequency of secondary events leading to the top event.

Given the frequency of an event, the next step is to determine the consequence of the event. This is also done by computer modeling. For example, if a spill occurs, the model accounts for the internal heat generation caused by radioactive decay of materials involved, the partition factors between the liquid phase and the vapor phase as the spilled material evaporates, and the efficiencies of the air filtration systems between the location of the spill and the stack from which the ventilation air is released. Filter efficiencies are based on the 97th percentile worst measured test efficiencies to assure a high degree of conservatism. To this point, one has determined the curies of each radioactive species that is released.

After the radioactivity is released from the stack, it is diluted as it travels from the stack to a potential recipient. This dilution is calculated from a statistical analysis of meteorological data taken every three seconds for five years from towers located on the site. An additional degree of conservatism is built in by using the 99.5th percentile worst measure meteorology for the sector through which the air is moving. From breathing rates and dose conversion factors, the millirems of dose that the individual might receive is calculated.

This procedure is repeated for each incident that is identified as applicable to fuel reprocessing until the entire spectrum is covered. Let's now examine some of these incidents. As a matter of convenience, they are divided into three broad categories: natural phenomena, incidents affecting operating personnel, and process incidents potentially affecting an off-site population.

In the first category, natural phenomena, one considers such events as earthquakes, tornadoes, hurricanes, floods, snow, and temperature extremes. Most of these events are handled by conducting reprocessing operations in thick-walled, heavily reinforced concrete buildings that are designed to withstand the maximum forces from each expected in a given geographic location.

The most significant incident from a consequence point of view that can affect operating personnel is a nuclear criticality accident in unshielded facilities. This is caused by bringing an excessive amount of fissile material, such as plutonium, into close proximity. The initial burst typically is about 2×10^{17} fissions, by no means an explosion, but may be accompanied by a blue flash. Such an accident would be fatal to anyone within about seven feet due to neutron and gamma radiation. Beyond about 50 meters, the effects of direct radiation would be small. For work with plutonium in unshielded facilities, much effort is expanded to assure that this accident will not occur. Several of these accidents have occurred in reprocessing activities across the country, but never at Savannah River because of stringent controls that are applied. Not only have we never experienced a criticality accident, we have never experienced a fatality or serious injury from any nuclear related accident at Savannah River.

A hydrogen explosion is also of considerable concern. Hydrogen is formed from the reaction of metals such as plutonium or uranium with nitric acid. Hydrogen is also formed from the radiolytic decomposition of aqueous solutions. The hydrogen must be purged to keep its concentration below about 4% to protect against burning and about 15% to protect against an explosion.

Protection must be provided against the release of airborne contamination into areas occupied by personnel. This can result from a process upset accompanied by leakage through the confinement barriers. The potential for airborne contamination is assimilation into the body, usually by inhalation. Systems where the potential for airborne release exists are usually operated at a lower atmospheric pressure with respect to areas occupied by personnel. Continuous air sampling with alarms are provided, and respiratory protection in the form of filtered face masks or air supplied plastic suits may be used.

A "red oil" explosion outside of shielded confinement is another serious concern. This is the result of overheating uranyl nitrate solution that contains excessive tributyl phosphate from solvent extraction operations. Savannah River has had two such explosions. One involved an evaporator with unirradiated uranium and the other in a denitrator with decontaminated depleted uranium so that radiological consequences were negligible. There were no serious injuries from these two accidents, but the last one cost $600,000 and took six months to get back on stream. Similar hazards exist elsewhere in the chemical industry where nitric acid is frequently used to oxidize organic compounds.

The last category is process incidents. Process incidents that could have a radiological effect on an off-site population include a criticality accident, red oil explosion, leak, spill, vessel overflow, transfer error, fire, eructations, or processing of short cooled reactor fuel in which radioiodine has not had sufficient time to decay. The actual effect is quite small because, any radioactive material that is released from the primary containment is passed through from one to three layers of high efficiency air filters before being released to the environment.

One might be surprised that the highest process incident risk is the result of the common leak. Although the consequence is small, the frequency is much higher than other process incidents. In descending orders, the other risks in the primary reprocessing facility at Savannah River are: an eructation or burping of a process vessel, ruthenium volatization, waste header failure, vessel overflow, nuclear criticality, iodine release from processing short cooled fuel, dropping of a 30 ton cell cover onto a process vessel, transfer error, fire, and hydrogen explosion. The first affords about four orders of magnitude greater risk than the last.

If we sum the numerical risks for the above incidents as calculated for our F Canyon reprocessing facilities, one gets about 1 x 10^{-4} millirem per year for airborne releases of radioactivity. By itself, this value does not mean a great deal until compared with other risks. Using one example, the natural background radiation that one receives living in the vicinity of the site is 295 millirem per year, about 300,000 times the calculated value for the canyon facility.

The best comparison is in actual experience. Based on 1988 measured values, the annual contribution from the entire site operations to individuals adjacent to the site is only one-half millirem, or only about 0.1 percent of natural background radiation. As a result of this low risk, honesty in reporting the environmental impact of the site, and the obvious economic benefits, the Savannah River Site enjoys the wholehearted trust and support of its employees and neighbors.

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RISKS OF NUCLEAR FUEL REPROCESSING

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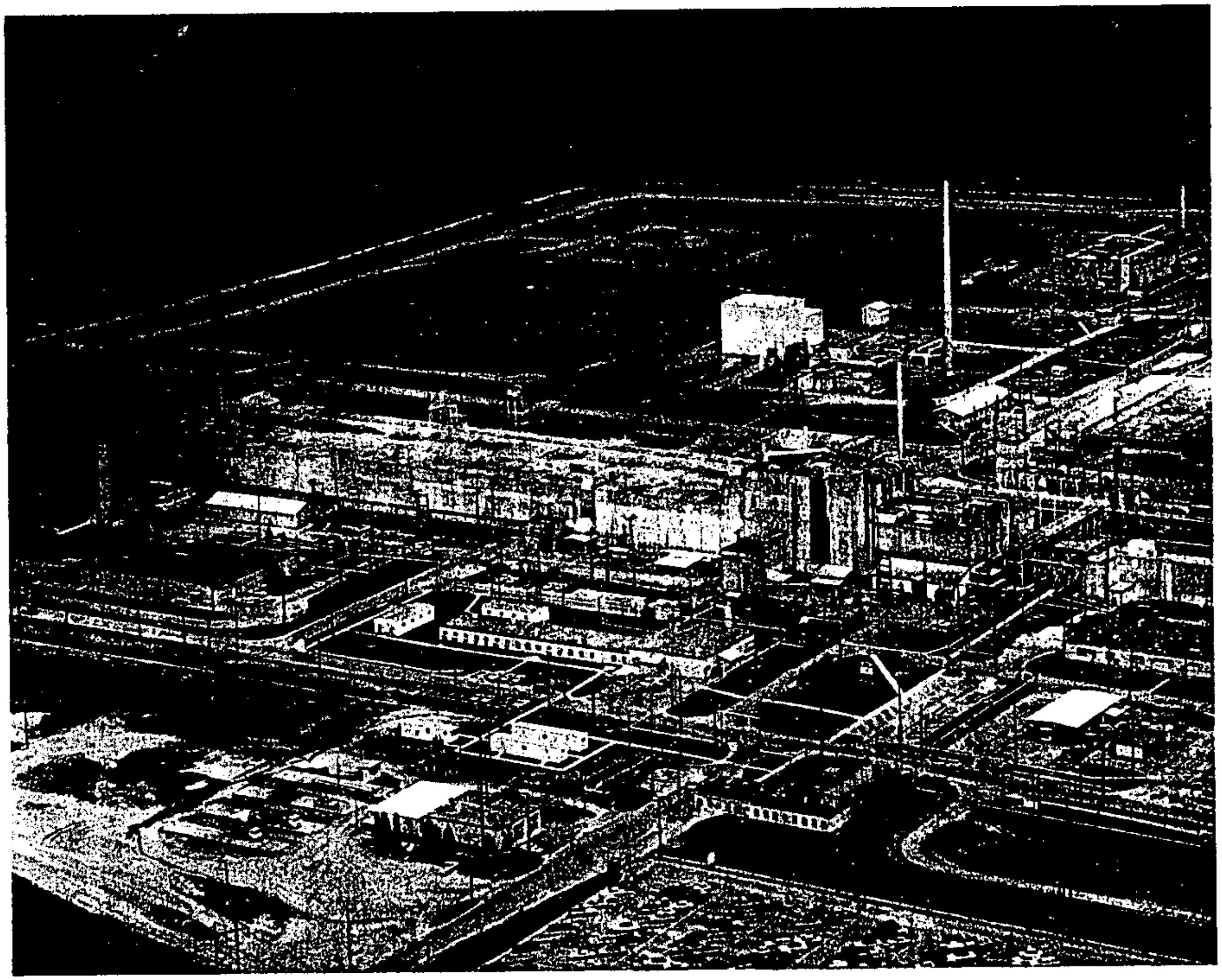
NUCLEAR PROCESSES SAFETY RESEARCH

SAVANNAH RIVER LABORATORY

HEAD END OPERATIONS IN COMMERCIAL FUEL REPROCESSING

- FUEL RECEIPT - RAIL OR TRUCK
- CASK WASHING
- PURGING
- COOLING
- DISCHARGE
- STORAGE
- CROPPING
- AIR DRYING
- SHEARING
- DISSOLVING



Building 221-F

REPROCESSING OPERATIONS AT SAVANNAH RIVER SITE

- FUEL RECEIPT - RAIL
- DISSOLVING
- CLARIFICATION
- VALENCE ADJUSTMENT
- FIRST CYCLE SOLVENT EXTRACTION
- SECOND U CYCLE SOLVENT EXTRACTION
- SECOND PU CYCLE SOLVENT EXTRACTION
- EVAPORATION
- ION EXCHANGE

BY PRODUCT PROCESSING - DEPLETED URANIUM

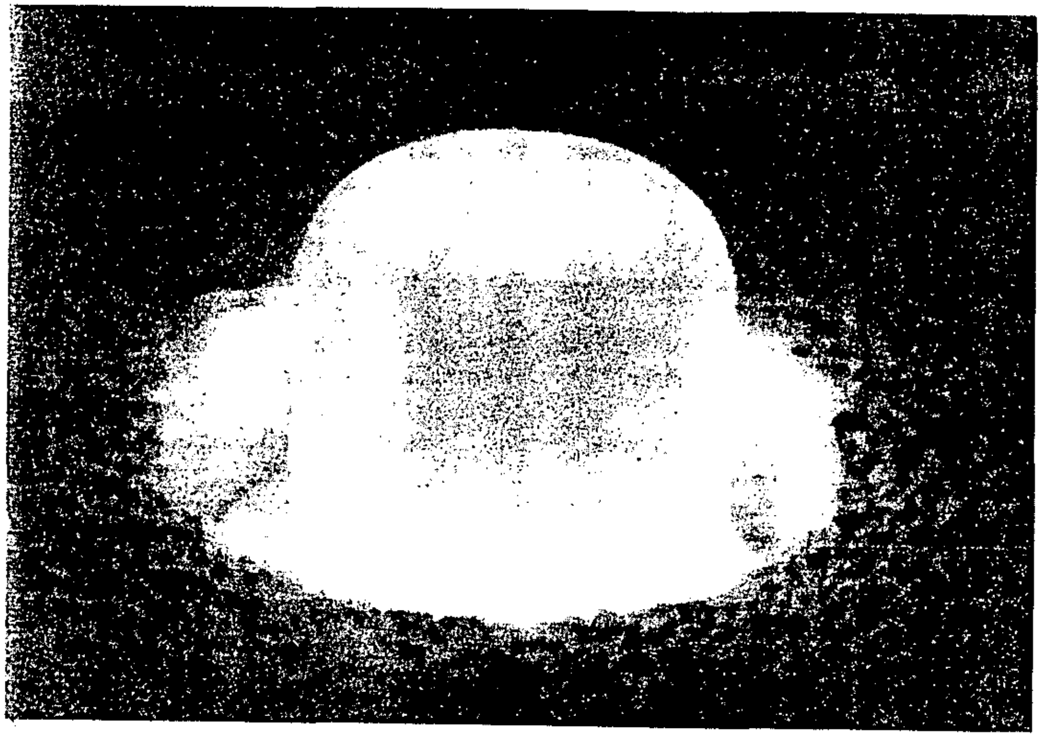
- EVAPORATION
- HYDRATE EVAPORATION
- CALCINATION

WASTE TREATMENT

- NEUTRALIZATION
- STORAGE IN TANKS
- CLASSIFICATION
- INTERIM STORAGE
- FINAL STORAGE

PRODUCT PROCESSING

- CONCENTRATION
- PRECIPITATION
- FILTRATION
- DRYING
- ROASTING
- CALCINATION



GPHS Fuel Pellet

DEFINITION OF RISK

FREQUENCY X CONSEQUENCE

FREQUENCY
- OCCURRENCES PER UNIT TIME
- OCCURRENCES PER OPPORTUNITY

CONSEQUENCES - COST PER OCCURRENCE

- Loss of Money
- Death
- Injury
- Flunking Out
- Rejection
- Fear
- Units of Radiation

NUCLEAR PROCESSES SAFETY RESEARCH
SAVANNAH RIVER LABORATORY

ASCERTAINING INITIATING EVENTS

- GENERIC INCIDENTS DATA BANK
- FAULT TREE DATA BANK

200 AREA FAULT TREE DATA BANK

- 230,000 ENTRIES
- RANGE FROM MINOR (99%) TO SIGNIFICANT (1%)
- SORTED BY SPECIFICATION CODES

FREQUENCY DETERMINATION

- FROM DATA BANK
  - STATPAC COMPUTER CODE
- FROM FAULT TREE ANALYSIS
  - LOGIC DIAGRAMS
  - BOOLEAN ALGEBRA

CONSEQUENCE DETERMINATION

- FROM DATA BANK
- COMPUTER MODELING
- METEOROLOGICAL MEASUREMENTS

CATEGORIES OF INCIDENTS

- NATURAL PHENOMENA
- INCIDENTS AFFECTING OPERATING PERSONNEL
- PROCESS INCIDENTS AFFECTING OFFSITE

NATURAL PHENOMENA

- EARTHQUAKE
- TORNADO
- HURRICANE
- FLOODS
- SNOW
- TEMPERATURE EXTREMES

INCIDENTS AFFECTING OPERATING PERSONNEL

- NUCLEAR CRITICALITY
- HYDROGEN EXPLOSION
- AIRBORNE CONTAMINATION
- RED OIL EXPLOSION

PROCESS INCIDENTS

- LEAKS
- ERUCTATION
- RUTHENIUM VOLATILIZATION
- WASTE HEADER FAILURE
- VESSEL OVERFLOW
- NUCLEAR CRITICALITY
- PROCESSING SHORT-COOLED FUEL
- DROPPING A CELL COVER
- TRANSFER ERROR
- FIRE
- HYDROGEN EXPLOSION

SUMMARY OF RISKS TO AN INDIVIDUAL AT THE PLANT BOUNDARY

-	CALCULATED RISK OF F-CANYON FROM ACCIDENTS	0.00012 MILLIREM/YR
-	MEASURED RISK OF NATURAL BACKGROUND	295 MILLIREM/YR
-	MEASURED RISK OF ENTIRE SITE FROM ALL CAUSES (1988)	0.46 MILLIREM/YR

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