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FISSION PRODUCT GAS RETENTION STUDY
FINAL REPORT

E. D. North
R. L. Booth

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ORNL-TM-4409
UC-79c — Fuel Recycle

FISSION PRODUCT GAS RETENTION STUDY

FINAL REPORT

August 1973

E. D. North
R. L. Booth

Nuclear Fuel Services, Inc.
Rockville, Maryland 20852

under

Subcontract 3607

with

Chemical Technology Division
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
Nuclear Division
for the
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FISSION PRODUCT GAS RETENTION STUDY

Summary

Various processes have been evaluated which would provide improved plant containment factors of 100 for tritium and 10,000 for iodine at a reprocessing plant for light water reactor fuels. The goals for krypton and iodine can be obtained although a factor of 1,000 for iodine appears to be more practical. The goal for tritium must await further development of the voloxidation process or the use of alternative methods.

The cost of providing improved containment for these isotopes at the West Valley Reprocessing Plant is estimated to be $16,900,000; of which $10,000,000 is primarily for recovery of tritium, $4,000,000 for recovery of krypton, and $2,900,000 is for recovery of iodine. Improved containment of iodine should be provided at existing and future reprocessing plants. Development work should be continued in processes for improved containment of krypton and tritium although the need for such processes will not develop in this decade.

INTRODUCTION

Nuclear Fuel Services, Inc. on January 25, 1972 entered into a contract numbered 3607 with Union Carbide Corporation, Nuclear Division, to study the problems associated with providing improved containment in a fuel reprocessing plant for iodine, tritium and krypton. The goal of the study is to devise means to provide a plant containment factor of about 100 for tritium and krypton and about 10,000 for iodine. The contract provides for a paper study only; no hardware is to be purchased or installed. As a part of the study, NFS is to identify problems that would probably be encountered that could adversely affect the effectiveness, operability or reliability of the system. NFS should also identify developmental or engineering data that would be required for design purposes.

A tentative flowsheet has been developed which is believed to be capable of providing the improved containment desired for the fission products of interest. It should be noted that the flowsheet requires certain operations and treatments that have not been completely developed or tested at this time, and that, accordingly, it is not possible to determine that the improved containment is in fact possible or practical.

Nuclear Fuel Services, Inc. operates a spent fuel reprocessing plant at West Valley, New York. The plant has a design capacity of one metric ton per day using the Purex process. The plant was designed and constructed in the period from 1963 to 1966 and went on stream in April, 1966. A modernization of the plant is underway at this time and with the elimination of certain bottlenecks, plant capacity will be

uprated from a nominal 300 tons per year to a nominal 750 tons per year.

The plant utilizes a batch-wise chop-leach process through the head-end, followed by continuous liquid-liquid extraction using TBP-kerosine as the extractant. Plutonium and uranium are recovered as nitrate solutions which are shipped off site for further processing before reuse.

Fuel enters the plant as whole fuel elements which are stored in the fuel pool prior to processing. Fuel elements are transferred to the Process Mechanical Cell (PMC) where the end-fittings are removed and the fuel bundle is sheared into short lengths. The sheared fuel drops from the shear into dissolver baskets which contain a consumable mild steel liner to retain fine particles.

A dissolver batch consists of 4-6 dissolver baskets containing a nominal one metric ton of uranium. The baskets are placed in a batch dissolver to which concentrated nitric acid is added to dissolve the fuel. The fuel cladding is not dissolved and is later rinsed with clean acid and removed from the plant for disposal.

During dissolution the contained krypton is released and leaves the dissolver in the dissolver off-gas system. The contained tritium is released partially as the gas, HT; however, the major fraction is converted to tritiated water (HTO) which primarily stays with the dissolver solution although some does evaporate into the dissolver off-gas stream. Iodine isotopes largely remain in the dissolver solution, however, a portion does volatilize into the dissolver off-gas stream.

The resulting dissolver solution is adjusted in acid content, sampled and analyzed for accountability purposes, and is sent to a continuous extraction system in which the fission products are removed in a codecontamination column; the plutonium and uranium are then separated, purified and recovered in solution.

The fission products leaving the bottom of the first extraction column are concentrated in several stages of evaporation and after neutralization with sodium hydroxide are stored in large underground high level waste storage tanks.

The overhead condensates from the waste evaporators are re-evaporated and fractionated for recovery of nitric acid which is routed back to the dissolver. The overhead condensate from the fractionator is then discharged to the interceptor-lagoon system and, after treatment for recovery of small amounts of strontium and cesium, is discharged to the surface waters as low level waste.

There are thus two major streams leaving the reprocessing plant that can carry off small amounts of radioactivity: the liquid stream from the interceptor-lagoon system, and the stack gases. Both streams are continuously sampled and monitored and a large body of data has been accumulated to demonstrate the levels and types of activity in each stream.

It should be noted that both streams are composites of several substreams within the plant, each of which may carry its own level of activity and each of which presents varying degrees of difficulty in collection and treatment for the removal of radioactivity.

The Appendix "I" hearings on the "as low as practicable" releases from reactors brought out quite clearly that the real problem in approaching minimum releases lies not in the streams that carry the majority of the activity and which are susceptible to treatment, but rather the difficulty in providing complete containment results from the multitude of small streams, leaks and drips which are difficult to detect and even more difficult to collect and process.

The fission products of interest in this study, iodine-129, tritium and krypton, have not been of major concern to date since the biological hazard associated with them is relatively low and the normal dilution in ambient air and water has been sufficient to keep them well below permissible levels in the environment.

When the plant was designed the iodine isotope of principal concern was iodine-131 which has an eight day half life. Since the fuels processed to date had been aged for up to a year or more prior to processing, the iodine-131 had decayed to innocuous levels in the fuel. Routine analysis of the stack effluents has shown that iodine-131 releases have consistently been less than one percent of the technical specification limit of three curies per year.

Iodine-129, due to its long half life and low activity as well as its low content in the fuels, was not considered to be troublesome; in fact Bryant has stated that even if a major portion of the iodine-129 were discharged to the environment, no health hazard would result. It has recently been estimated that as much as twenty-five percent of the input iodine-129 leaves the plant in the off-gas stream, and that about twenty percent of the input

iodine-129 is discharged in liquid wastes[1]. It has been estimated that 4.4 curies of iodine-129 were contained in the fuel processed in the period 1966-1972 and that slightly less than two curies may have been discharged to the environment in that time. Recent studies in the area surrounding the plant have shown barely detectable levels of iodine-129 in milk and surface water at near the limit of detectability of 0.3 picocuries per liter. The New York Department of Environmental Conservation Report for the third quarter of 1972 showed iodine-129 levels in milk near the NFS plant averaging 0.4 pCi/liter and ranging from <0.2 up to 1.1 pCi/L. During the same period, three milk samples taken near Albany showed <0.5, <0.9 and <0.3, for an average of 0.6 pCi/L. While these data would indicate that there is no significant difference in iodine-129 levels near the reprocessing plant as compared to elsewhere in the state, there has been concern that iodine-129, due to its exceptionally long half-life, could accumulate in the environs of a reprocessing plant to levels that would require corrective action.

Tritium, which amounts to about 700 Ci per ton of fuel, normally enters the dissolver solution as tritiated water, although a small portion leaves the plant as gaseous HT. Once the tritium enters the plant aqueous stream it is virtually impossible to separate and recover it, and the tritium follows the water stream through the acid recovery process to be discharged in the aqueous waste. The theoretical amount of tritium has not been found in the waste streams from the reprocessing plant since an indeterminate amount of tritium leaves the fuel through leaks

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(1) Iodine-129 in the Environment around a Nuclear Fuel Reprocessing Plant, Magno, Reavy and Apidianakis, EPA, Winchester, Massachusetts, Oct., 1972.

in the cladding at the reactor, and a significant fraction is combined with zirconium cladding as the hydride. These losses reduce the amount of tritium which is released from the reprocessing plant to about 60% of the theoretical amount in the fuel. Of this amount, some 80-90% is discharged in aqueous wastes where it is diluted to below the levels set by the regulatory agency before it enters the public domain. Tritium is normally found in the environment and would be there even if it were all retained at the reprocessing plant since it occurs naturally as a result of cosmic ray interaction with atmospheric nitrogen. In addition, significant quantities of tritium have been released to the atmosphere in weapons testing. Tritium, however, is an isotopic form of hydrogen and hydrogen is essential to all forms of living organisms. Some concern has been expressed as to the possibility that tritium could effect genetic mutations if it were absorbed in the nuclei of the reproductive cells.

The noble gases krypton and xenon are significant fission products. Of these krypton-85 is by far the major concern since the radioactive xenons have half-lives of the order of a few hours. By the time the fuel is processed the radioactive xenons have decayed to innocuous levels and only krypton-85 with a half life of 10.7 years remains. Krypton-85 is accompanied by about ten times its volume of stable, non-radioactive, xenon isotopes. Some 11,000 Ci per ton of krypton-85 are released, primarily in the dissolver, although a small fraction (1%-2%) is released during shearing of the fuel. Since the noble gases are quite unreactive under normal circumstances, the krypton leaves the plant in the off-gas stream where it is rapidly diluted in the atmosphere to insignificant

levels. Krypton-85 decays by emitting a β particle some 99.5% of the time and less than 0.5% of krypton emits a γ ray in decomposition. Since β particles are absorbed in about 1 meter of air or in the clothing or even the dead layers of skin, the radiation from krypton does not present any significant problem from a world wide point of view. With the advent of new and much larger reprocessing plants there may be some radiation exposure to close-in neighbors of the plant and some form of recovery of krypton may be necessary to reduce the so-called "fence post dose".

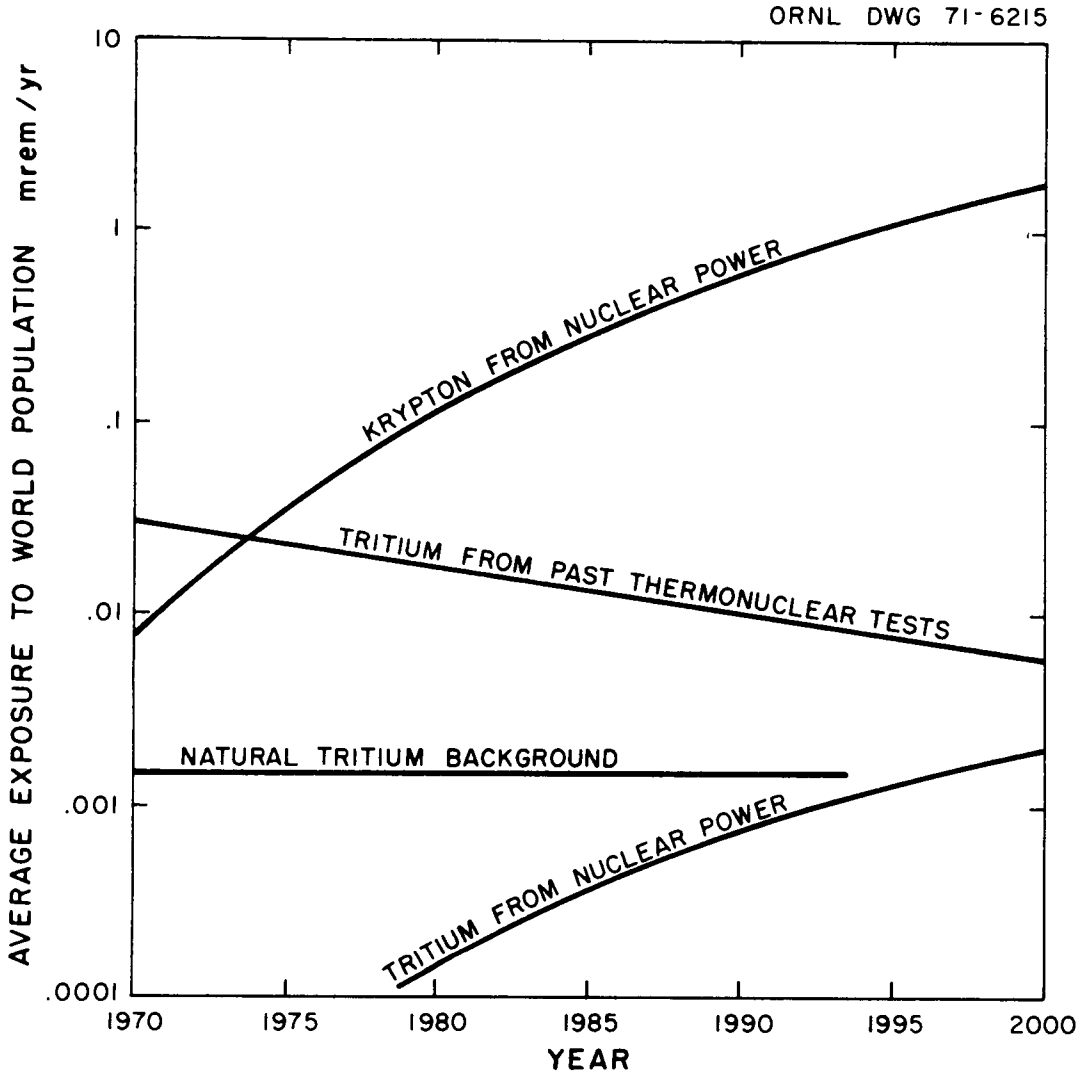
Figure 1 shows the anticipated world wide buildup of tritium and krypton in the atmosphere based upon current projections of the nuclear power industry and assuming the continued release of all of these products to the biosphere(2).

It can be seen that tritium and krypton do not constitute an immediate problem in any case since the krypton exposure even in the year 2000 will be only about 2 mR per year which is less than 2% of naturally occurring background exposure(3). The tritium exposure in the year 2000 will be less than 0.01 mR per year and is only barely above the exposure due to naturally occurring tritium. At these low levels the exposure would be difficult, if not impossible, to differentiate from the normal variation in the natural background

---

(2) Environmental Protection During Fuel Reprocessing, Yarbro, Nichols and Unger, Los Vegas ANS Meeting, 1972.

(3) Krypton-85 -- A Review of the Literature and an Analysis of Radiation Hazards, Kirk, W. P., EPA, Office of Research and Monitoring, NTIS No. PB 207079.



LONG TERM EXPOSURES TO WORLD POPULATIONS FROM KRYPTON AND TRITIUM

Fig. 1

Figure from: Yarbro, Nichols and Unger, "Environmental Protection During Fuel Reprocessing", Las Vegas ANS Meeting, 1972

exposure. Background radioactivity in the United States varies from 100-250 mR per year and there are populated areas in France that reach 350 mR per year. Certain monazite ore areas in India have a natural background of 1300 mR per year. The 2-3 mR/year from krypton and tritium would be an insignificant increment to the background and would be somewhat less than the radiation received by a passenger on a single cross-country flight in a jet plane.

Much of the LMFBR reprocessing technology under development at ORNL has potential for significantly improving LWR fuel reprocessing operations. In particular, the voloxidation step and attendant fission gas recovery steps now being developed as a part of the LMFBR head-end process, if installed in a commercial LWR fuel reprocessing plant, could substantially reduce gaseous effluents from LWR fuel reprocessing as well.

There is an obvious advantage in having commercial reprocessors conduct studies to determine the feasibility of using these process steps in their respective plants. For this reason, the present study was proposed to familiarize the potential users with the technology, assist in establishing the future role of the technology, provide an industrial assessment of the status of development and better focus future development requirements. Obviously, if LWR reprocessing plants can effectively use the advanced technology in the near future, the application of the LWR plants to LMFBR fuels would be greatly facilitated.

REVIEW OF STATUS OF TECHNOLOGY

Tritium

The calculated tritium content of one metric ton of fuel irradiated to 33,000 MWD is 692 Ci or 0.0714 grams at 150 days age. It must be remembered that a significant fraction of this amount will not be released at the reprocessing plant due to leakage at the reactor and loss by hydriding of the cladding. If it is assumed that

two-thirds of the calculated content is released, this amounts to about 460 Ci or 0.0475 grams per ton of fuel. Recovery of this small quantity of material from a ton of highly radioactive material presents a difficult challenge.

Since tritium readily exchanges with hydrogen in water, the major portion of tritium goes into the dissolver solution and flows through the plant in the water stream and is discharged with the aqueous wastes. Recovery of tritium from water, especially at these low concentrations, is completely impractical, therefore recovery of tritium will have to be effected prior to dissolution and without exposure to large volumes of water which would ultimately have to be disposed of as a radioactive waste.

Although tritium probably occurs in the fuel as elemental tritium, studies have shown that elemental tritium is not significantly released under vacuum at low temperatures. About three percent of the tritium was released from fuel in six hours at 250°C under a vacuum of better than 29.5 inches of mercury[4]. Tritium was substantially completely released (98%) only after heating under vacuum at 550°C. Gaseous releases of tritium during shearing should therefore be minimal, primarily resulting from tritium gas in the plenum of the fuel pin.

Even it it were possible to release the tritium in elemental form under reasonable conditions, there would remain the difficult problem of recovery of the material in a stable form for permanent disposal.

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(4) ORNL-TM-3698, December, 1971, Number 34.

ORNL has, therefore, been studying the release of tritium in the form of HTO by oxidizing the UO_2 fuel to U_3O_8 in a flowing stream of oxygen or air at temperatures of from 450°C to 750°C. The resulting tritiated water is then captured on a desiccant which can be safely disposed of. This process is termed "voloxidation". A "minivoloxidizer" three inches in diameter was constructed with baffles to lift and drop the clad pellets in a heated stream of air or oxygen. The UO_2 is oxidized to U_3O_8 and is gradually knocked out of the cladding. At 550°C 99.9% of the tritium and 45% of the krypton was evolved[5]. Bare pellets are completely oxidized in about one hour while about 2½ hours are required to completely oxidize stainless steel clad pellets. Increasing the rotation rate of the voloxidizer is only slightly effective in reducing the time required for complete oxidation. Increasing the rotation rate from 12 rpm to 48 rpm decreased the oxidation time from 3½ hours to 2.8 hours at 480°C.

The voloxidation step is very efficient in releasing tritium, but is only partially effective for release of krypton. This is unfortunate for if complete release of krypton were achieved, the recovery of krypton would be greatly simplified. This problem deserves further work. Some possible lines of attack are: (1) multiple oxidation-reduction steps; (2) oxidation followed by vacuum outgassing at temperature; (3) pressure-vacuum cycling after oxidation. The goal of the work would be to release 99+% of the tritium and krypton in a relatively small volume of gas.

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(5) ORNL-TM-3807, March, 1972, Number 37.

Once the tritium has been released, the problem becomes one of capturing the HTO in some disposable form for which several options are available. The classical dessicants or molecular sieves can be used or the water can be cold trapped using liquid nitrogen. In any case, some additional ordinary water should be added to the stream prior to absorption in order to obtain a workable quantity of water. The isotopic dilution afforded by this addition will greatly reduce the amount of tritium which escapes absorption thus improving the percentage of recovery. The efficiencies of some common drying agents are as follows:

EFFICIENCY OF DRYING AGENTS

Agent	Residual Water
P_2O_5	<1 mg in 40,000 liters
$Mg(ClO_4)_2$ anhy.	Unweighable in 210 liters
$CaSO_4$ anhy.	.005 mg/liter
13-X Molecular Sieve	.001 mg/liter

If completely dry air is passed over the fuel, the residual water over a 13-X molecular sieve bed will contain a significant amount of the HTO evolved from the fuel. The addition of about 30 grams of water will reduce the tritium losses to less than .05% The dilution water can easily be added to the air or oxygen used in the voloxidizer and the amount can be controlled by the humidity of the gas.

The resulting water vapor can also be recovered in a cold trap operated at dry ice or liquid nitrogen temperatures. This approach, however, presents some difficulties in disposal for it will be necessary to warm the trap to remove the water. This will increase the vapor pressure of the water to the point where tritium losses could be significant. In addition, the disposal of liquid water containing tritium would not be simple. For these reasons it is probably desirable to trap out the water on a dessicant which can then be sealed in a container for disposal.

Anhydrous calcium sulfate (Drierite) is fairly efficient and relatively inexpensive. A Drierite bed in an easily removable cartridge would provide an efficient means of trapping the water. The Drierite bed can be followed by a regenerable molecular sieve bed which would improve the decontamination factor of the system and would serve as a backup to the main water trap. The molecular sieve bed would be periodically regenerated and the wet-gas would be recycled to the Drierite bed. Another approach is to absorb the tritiated water in a molecular sieve bed which would discharge liquid water upon regneration and which would then be absorbed in a closed system on a disposable drierite cartridge. The drierite cartridge would then be sealed in a container for disposal.

Iodine

During voloxidation, which is necessary to remove tritium, some iodine in the fuel is also evolved. It would be highly desirable, from a processing standpoint, for all of the iodine to be contained in this stream. However, work at ORNL has demonstrated

that this will not be possible, as only 30% to 70% of the iodine is liberated during voloxidation. The major portion of the iodine remaining in the voloxidized fuel will be evolved, along with oxides of nitrogen, during fuel dissolution and will appear in the dissolver off-gas stream. But again, as in voloxidation, some small fraction of iodine remains, in this case in the dissolver solution.

This fraction of iodine, probably not more than 2% of the total iodine input, would then be distributed throughout various plant streams, liquid and gaseous, and presents additional processing problems. Data are not available at this time to determine the exact distribution; however, it is most probable that the retained iodine will appear in the spent solvent, carbonate scrub, high level and low level waste as well as in the VOG off-gas stream. To assure the maximum containment within the plant all of these streams must be subject to an iodine recovery system or strenuous effort must be made to drive the iodine to the dissolver off-gas stream where it can easily be recovered.

Several methods for the removal and eventual recovery of iodine in the various streams of a nuclear fuel reprocessing plant have been suggested. Most of these recovery methods have been under investigation at ORNL as part of their study on the LMFBR Fuel Cycle. Nuclear Fuel Services has reviewed recovery methods in light of their possible adaptation to the reprocessing plant at West Valley as a part of the Fission Gas Retention Study. The recovery methods considered and reviewed were:

Charcoal Beds

Charcoal beds both at ambient and at reduced temperatures have been used to purify off-gas streams containing elemental iodine as well as volatile organic iodides. Such beds have demonstrated DF's in excess of 10^4 but have very serious limitations. They are non-regenerative, are combustible, and whenever organic vapors are present, are subject to bleed-through. Hopcalite beds preceding the charcoal beds have been used to minimize bleed-through but only with limited success. Since the dissolver off-gas from a reprocessing plant contains large amounts of nitrogen oxides which are not completely absorbed in acid recovery, the gas stream to the charcoal bed can be expected to carry appreciable amounts of nitrogen oxides. The presence of these oxidizing agents in a high surface area charcoal bed would be highly undesirable and for this reason, charcoal beds are not deemed suitable for this system without serious and expensive modification of the gas stream to eliminate oxidants. This could be accomplished by adding hydrogen and passing the stream through a recombiner to produce water from the oxygen. In the absence of oxygen, the nitric oxide (NO) would be prevented from oxidizing to NO_2, and the nitric oxide would then pass harmlessly through the system. The cost of such adjustment by hydrogen is significant.

Silver Zeolite Beds

The work at ORNL and other laboratories has clearly demonstrated the effectiveness of silver zeolites to remove both methyl iodide and

elemental iodine.[6] Silver zeolite beds have removal capabilities when operated in the temperature range of 25° to 100°C equal to, and possibly better than, charcoal for most iodine forms. Furthermore, these beds have the added advantage of being non-combustible and are probably less sensitive to organic contaminants in the off-gas stream. However, they are non-regenerative and, therefore, present a problem with regard to disposal. Nevertheless, this will not be a serious a problem in that the volume is small and the iodine will be more tightly bound and consequently less subject to leaching by groundwater.

Cold Trap

Organic iodides and elemental iodine can be removed from gas streams using cold traps cooled with liquid nitrogen or perhaps dry ice slush. Such traps will also remove other condensables present in reprocessing streams, such as water and oxides of nitrogen. Therefore, if cold traps were to be used, their greatest utility will be in gas streams which are relatively dry and free of oxides of nitrogen. Aside from the problem of condensables, there is also a problem with the iodine species not being in a form which is easily contained for final disposal. Consequently, additional processing of the trapped iodine species will be necessary to convert them into less reactive, non-volatile compounds.

---

(6) Silver Zeolite: Iodine Absorption Studies, Pence, D. T., and Maeck, W. J., IN-1363, 1970.

Caustic Scrub

Caustic solutions are quite effective in retaining elemental iodine; however, such solutions do not react readily with organic iodides. Caustic reacts with elemental iodine to form iodide and hypoiodite; the latter, under some conditions, having a tendency to volatilize. To reduce volatilization to some extent sodium thiosulfate is normally added to the caustic solution.

Mercuric Nitrate Scrubber

The ORNL technique of scrubbing gas streams with a mercuric nitrate-nitric acid solution is an attractive method for the removal of elemental iodine and organic iodides. The mercuric nitrate scrubber is highly efficient for elemental iodine as well as methyl iodide which has been found in the off gases from reactors. It is apparently not as efficient in recovery of aromatic iodides; however, the presence of aromatic organics in the dissolver solution is not likely and these can be eliminated by careful choice of lubricants, etc., which might contain aromatics. The main TBP--kerosine stream should not contain significant levels of aromatic compounds. The scrubber solution is then concentrated in an evaporator which also oxidizes iodine to insoluble mercuric iodate. If this technique can be adapted to a typical reprocessing off-gas stream to routinely give DF's of 10^4, it would be Nuclear Fuel Service's choice of methods. Recovery of the iodine as the quite insoluble mercuric iodate would be desirable, particularly in view of the option of converting mercuric iodate to sodium iodate and recycling the mercury back to the recovery system.

Iodex Process (18M HNO_3)

Another attractive method for the recovery of iodine is the Iodex process, again an ORNL inovation, which is still under active investigation at pilot plant scale. Iodine will be recovered as iodic acid (HIO_3) or anhydroiodic acid (HI_3O_8); either form of which should be suitable for final disposal. The major problem with this method is the necessity to use fuming nitric acid which will present process design problems as to recovery and recycle to the system. Increased corrosion could also be expected from the use of fuming nitric acid.

Krypton

During reprocessing of spent fuel, radioactive fission-product gases krypton and xenon, are released from the fuel into the off-gas streams from the various process steps. A small quantity of these noble gases escapes from the pins during the mechanical disassembly and shearing operations with the bulk of the gas release occurring during voloxidation (if that process step is installed) or during dissolution. Any recovery system for krypton and xenon must therefore handle the combined off-gas from the shear, the voloxidizer, and the dissolver.

Typical percentages of the total krypton and xenon which would be released from each operation are 1%-2% from the shear, 40% from voloxidation, and 60% from dissolution. These percentages, of course, will vary with the individual fuel type being processed and the given operating conditions.

Retention and recovery of noble gases can be accomplished by several methods, but only two; cryogenic distillation and selective absorption by fluorocarbons, appear to be operationally feasible for a reprocessing plant. Other recovery processes to be considered include charcoal bed absorption and separation by permselective membranes.

In the cryogenic distillation process, the krypton, xenon and the air carrier stream is compressed, cooled, dried, and routed to a cryogenic distillation column cooled by liquid nitrogen. In this column the noble gases are concentrated and separated from the carrier gas.

Additional separation of the krypton from the xenon may then be accomplished in a simple batch still or fractionation tower. This separation of krypton from xenon will reduce the volume of gas to be disposed of and may produce a by-product that has potential sales value. As in most low temperature processes, the entering gas stream must be free from water, carbon dioxide and other condensables such as NO_2 which would form solids at the low operating temperatures. Both water and CO_2 may be removed with molecular sieve dryers or regenerative low temperature heat exchangers. Serious problems may result in the cryogenic process if either oxygen or nitrogen oxides are allowed to enter the system. Oxygen, at the low temperatures found in the cryogenic process, will react with relatively harmless nitrogen oxide (NO) to form NO_2, which in the solid state presents an explosion hazard. Oxygen may also undergo radiolysis to form unstable ozone which is also potentially explosive. Cryogenic systems should

therefore be free from NO_2. In order to prevent the oxidation of NO to NO_2, oxygen in the carrier gas is reacted with hydrogen in a recombiner and the water is condensed out of the system. Any unoxidized NO flows through the system without difficulty. Substantial quantitites of hydrogen are required for oxygen removal and the operating charges become substantial.

Acetylene and possibly other hydrocarbons have also been known to cause explosions in cryogenic systems such as tonnage oxygen plants. It appears that the possibility of such an explosion in a krypton/xenon removal system is remote; however, certain precautions against such an occurrence are normally taken during continuous operations.

Summarizing, the cryogenic system is mechanically simple, field-tested, and can produce separated high-purity products, krypton and xenon. It is hindered by its high cooling requirements, the added cost of oxygen removal and various explosion hazards.

The selective absorption system is based on the higher solubility of krypton and xenon in a common fluocarbon refrigerant as opposed to argon, nitrogen and oxygen.(7) The entering gas stream is compressed, cooled (only to about -30°F), and contacted in an absorber column with liquid refrigerant under moderate pressure (375 psig). The liquid stream containing the noble gases as well as some nitrogen and oxygen is subsequently fractionated to recycle the nitrogen and oxygen and then is stripped to drive off the krypton and xenon as a combined

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(7) The Recovery of Fission Product Xenon and Krypton by Absorption Processes, Steinberg, M., BNL-542 (T-140) 1959.

gaseous product. Each of the three primary processes occurs at succeedingly lower pressures with the fluorocarbon being recompressed and cooled for recycle to the absorber column. Freon-12 seems to be the optimum refrigerant since the various gases have the required difference in solubility and the vapor pressure of F-12 is not excessive at the operating temperatures.

Like the cryogenic distillation process, water must be removed from the gas stream prior to introduction to the absorber; unlike the cryogenic system, nitrogen dioxide and oxygen do not seem to pose a serious explosion hazard. It appears from preliminary experiments that the fluorocarbon system can also withstand CO_2, N_2O, NO, I_2 and CH_3I without serious effect on operations or efficiency. The effects of ozone and acetylene on the absorption system have yet to be determined.

Substantial development and pilot plant work has already been performed at the Oak Ridge Gaseous Diffusion Plant[8] on the fluorocarbon process and the process is commercially available for reactor installation at this time. The process is functionally simple and employs only basic unit operation techniques. Significant instrumentation will be required to control the various temperatures and pressures required, and conservation of input energy is desirable. Low temperature condensers will be required on off-gas streams to minimize refrigerant losses.

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(8) Experimental Investigation of the Removal of Krypton and Xenon from Contaminated Gas Streams by Selective Absorption in Fluocarbon Solvents, Stephenson, M. J., Merriman, J. R., Dunthorn, D. I., K-1780, 1970

At least two other methods have been proposed or used to retain or recover noble gases from process off-gas streams. Separation by permselective membranes involves contact of the gas with the membrane followed by gas dissolution, diffusion and evaporation. Separation efficiency for the krypton/xenon is a function of solubility and diffusivity. The process remains in the developmental stage and only limited operational data are available.[9]

Charcoal adsorption systems have been in use for a number of years and are available commercially.[10] Their principal use, however, has been in the retention of noble gases in reactor systems to allow decay of short-lived xenon and krypton isotopes, and the retained krypton/xenon is subsequently released back into the off-gas stream after the short lived isotopes have decayed. Charcoal systems can be operated at either ambient or low temperatures (increased Kr/Xe adsorption) and are usually operated in parallel to allow intermittent stripping or elution.

Operation of a charcoal system in a reprocessing plant would necessitate either disposal of the saturated charcoal bed or a secondary recovery system to capture the Kr/Xe which would be eluted from the charcoal bed. The presence of nitrogen oxides from a reprocessing plant in a charcoal system present a serious fire hazard and positive removal of such oxides would be mandatory.

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(9) ORNL-4522, Evolution of the Use of Permselective Membranes . . ., Rainey, R. H., Carter, W. L., Blumkin, S., 1971

(10) ORNL-TM-3515, Status of noble Gas Removal and Disposal, Nickols, J. O., Binford, F. T., 1971.

After a careful review of the literature and consultation with personnel at Oak Ridge National Laboratory, NFS has devised a flow sheet which, assuming the continued development of certain process steps such as voloxidation, can be expected to provide plant containment factors of 100 for tritium and krypton and 10,000 for iodine. The flow sheet could be applied to an existing reprocessing plant operating on light water reactor fuels, however, the technology could best be applied in a new reprocessing plant which would be designed with improved containment as a basic design criterion.

The flow sheet requires 99+% evolution of tritium in a voloxidation step and 98-99% evolution of iodine from the dissolver. The evolved tritium and iodine can be efficiently and effectively recovered with high decontamination factors. Iodine species that enter the dissolver solution may appear in the solvent cleanup wastes, which will be sent to storage, in the high level wastes which will also be stored, and in the low level wastes. Low level wastes will be partially recycled within the plant, and any wastes discharged will be contacted with an ion-exchange resin to remove iodine prior to discharge. It is expected that with not more than a 50% recycle of low level waste the total plant containment factor for iodine will approach or exceed 10^4.

Krypton and xenon will be recovered from the dissolver off-gas in a Freon-12 absorption system which has been shown to provide containment factors in excess of 10^2.

A detailed description of the flow sheet is presented below.

FLOW SHEETS

Block diagram flow sheets are shown in Figures 2, 3 and 4. These flow sheets show the basic operations required to provide improved containment for the isotopes of interest - krypton, iodine and tritium.

Tritium

Figure 2 shows the various operations in the head end through voloxidation, dissolution, and tritium recovery. Since a portion of the tritium will be released as elemental tritium during shearing, it will be necessary to pick up the off-gas from the shear and pass it, along with a small amount of oxygen, through a hydrogen recombiner to convert tritium to tritiated water. This stream will be combined with the off-gas from the voloxidizer and both will be sent to molecular-sieve driers for tritium recovery.

Sheared fuel, including sheared end-fittings, will be discharged to a continuous rotary kiln for voloxidation. A small stream of oxygen, saturated with water, will be provided to oxidize the fuel to U_3O_8 and to provide a manageable quantity of water to be absorbed in the driers. Better than 99% of the tritium in the fuel will thus be accumulated in the stream to the driers where it will be absorbed and disposed of and therefore further tritium recovery on other plant streams will not be required for a tritium decontamination factor of 100.

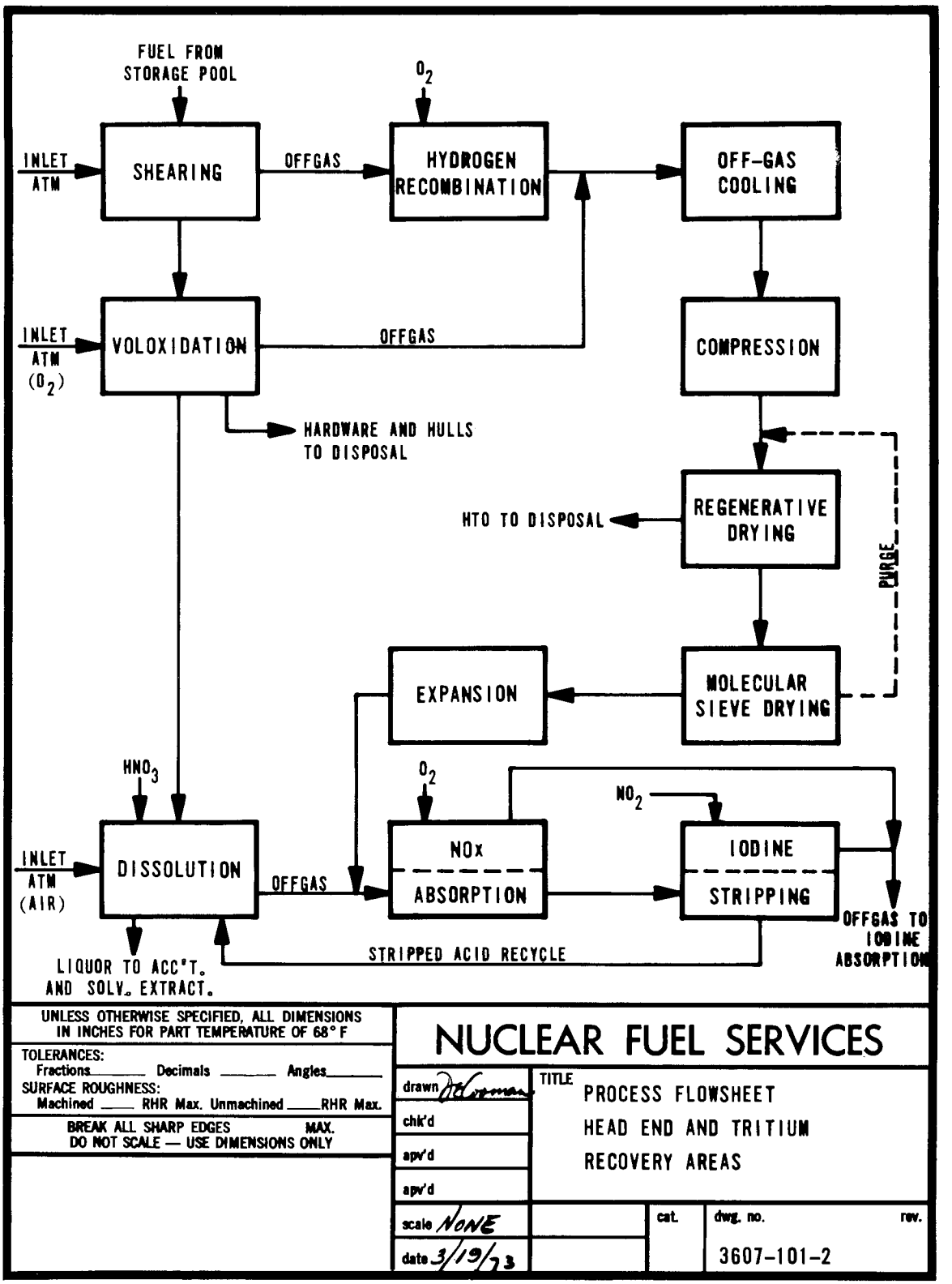

FUEL FROM STORAGE POOL
O_2
INLET ATM
SHEARING
OFFGAS
HYDROGEN RECOMBINATION
OFF-GAS COOLING
INLET ATM (O_2)
VOLOXIDATION
OFFGAS
COMPRESSION
HARDWARE AND HULLS TO DISPOSAL
HTO TO DISPOSAL
REGENERATIVE DRYING
PURGE
EXPANSION
MOLECULAR SIEVE DRYING
HNO_3
O_2
NO_2
INLET ATM (AIR)
DISSOLUTION
OFFGAS
NOx ABSORPTION
IODINE STRIPPING
OFFGAS TO IODINE ABSORPTION
STRIPPED ACID RECYCLE
LIQUOR TO ACC'T. AND SOLV. EXTRACT.
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS IN INCHES FOR PART TEMPERATURE OF 68° F
TOLERANCES:
Fractions Decimals Angles
SURFACE ROUGHNESS:
Machined RHR Max. Unmachined RHR Max.
BREAK ALL SHARP EDGES MAX.
DO NOT SCALE — USE DIMENSIONS ONLY
NUCLEAR FUEL SERVICES
drawn
chk'd
apv'd
apv'd
TITLE
PROCESS FLOWSHEET
HEAD END AND TRITIUM
RECOVERY AREAS
scale NONE
date 3/19/73
cat.
dwg. no.
rev.
3607-101-2

Fig. 2

Since it is highly probable that some ruthenium will accompany the tritium and will be deposited in and around the drier, radiation levels in the drier area will probably require at least a minimum of shielding. Considering the difficulties of semi-remotely removing a cartridge of drying agent from a radiation area, it was decided to abandon the idea of drierite cartridges for primary absorption. The primary drying operation will be performed on activated alumina at a modest pressure of about 40 psig. Drying efficiency is expected to be at least 99.9% of all water in the gas stream. Upon regeneration, a stream of liquid water will be delivered through the shielding wall into a closed container of drierite or similar agent. The drierite cartridge will then be sealed and sent to burial. A second stage molecular sieve drier will be used to pick up any inadvertant breakthrough of moisture. Any water picked up in the second stage will be purged back to the inlet side of the first stage. The detritiated off-gas will then be reduced in pressure and combined with the dissolver off-gas for further treatment.

The fuel stream from the voloxidizer will be substantially all U_3O_8 in the form of a rather dense powder. Little, if any, fuel will be retained in the cladding. This material is completely incompatible with the present batch dissolver system due to the high reactivity of U_3O_8 with nitric acid. The present batch dissolvers process a normal 1000 kg of uranium per batch, and 50-75% of the UO_2 goes into solution in 6 M nitric acid in 30-60 minutes with a rapid evolution of NO-NO_2. Controlling the rate of reaction by controlling the rate of addition of nitric acid has been considered, however, this approach is believed to be impractical due to the possibility of the formation of plutonium polymers under acid deficient conditions. Plutonium in polymeric form is difficult

to extract and excessive losses of plutonium to high level waste would result.

To prevent a runaway reaction and the consequent overpressurizing of the dissolver, it will be necessary to discharge the voloxidizer to a continuous dissolver in which the rates of feed and acid would be carefully controlled. Odom has described several successfully modeled continuous leachers that would appear to be suitable for this purpose.[11] A continuous dissolver can be controlled so as to deliver a feed solution of close to optimum extraction feed conditions, and little if any, feed adjustment would be required prior to solvent extraction. It will also be possible to provide efficient rinsing of the hulls in both fresh 6M nitric acid and water prior to discharge of the hulls to disposal. This will both reduce the losses to hull disposal and will reduce plutonium contamination of the hulls to a point where such disposal will be a greatly lessened problem.

Iodine

Dissolver off gas will contain, in addition to water and nitrogen oxides, the balance of the krypton-xenon noble gases and substantially all of the iodine contained in the fuel. Oak Ridge work has shown that dissolver off gas without reflux to the dissolver may contain up to 98% of the total iodine present and that the remainder is most difficult to volatilize into the gas stream. The chemistry of iodine in solution is quite complicated in that numerous valence states occur with varying

11 Odom, C. H., "Continuous or Semicontinuous Leacher for Leaching Core Material from Sheared Spend Nuclear Fuel Tubes", Conf. 720903, Oak Ridge, 1972.

degrees of volatility for the various species. The picture is further complicated by reaction equilibria between the species which do not go to completion in either direction.

Hydriodic acid (HI) and elemental iodine (I_2) are definitely volatile and hypoiodous acid (HOI) is also believed to be at least slightly volatile. Any of these species will probably end up in the off gas stream and will be efficiently recovered later in the process.

Iodine that is oxidized to iodic acid (HIO_3), however, probably will not volatilize and will leave the dissolver in the feed solution to extraction.

The EPA study of iodine-129 around the West Valley plant disclosed that about 25% was exhausted from the stack and about 20% was discharged in low level liquids. This leaves a balance of 55% unaccounted for.

These data also imply that 75% of the iodine remained in solution for, in the absence of iodine-131, no particular effort was made to recover iodine from the off-gas and any iodine that volatilized undoubtably went out the stack. The high percentage of solution iodine resulted from the reflux of iodine to the dissolver through the down draft condenser. At least some of the solution iodine passed through the acid recovery stream where it volatilized with the condensate and appeared in the low level waste stream as about 20% of the total. This indicates that the remainder, some 55%, went somewhere else. It is highly probable that the remainder went to the carbonate scrub solution following extraction and to high level waste. It now becomes possible to estimate the fate of the iodine in the liquid streams.

Iodine-129 in the fuel will amount to some 40,000 μCi. per ton. If it is pessimistically assumed that as much as 10%, or 4,000 μCi. per ton, remains in the dissolver solution and that the same split between streams will be seen, about 1,000 μCi. will show up in low level waste and that the ramaining 3,000 μCi. will end up in the carbonate scrub solution and in high level waste.

Oak Ridge work has shown that Amberlite XAD-4 macroreticular resin is

highly efficient in removing iodine from acid solutions.[12] If the condensate is passed through such a resin bed which can provide a decontamination factor of at least 100 (DFs of up to 2400 have been found) the amount of iodine in low level waste will be less than 10 μCi. per ton. Of course any condensate that is recycled to the head end will reduce the amount going to the waste stream. However, even if no condensate is recycled, the amount of iodine in the liquid waste will be much less than one part in 1000 of that entering the plant in the fuel.

It is highly improbable that as much as 10% of the iodine will remain in the dissolver solution providing that the down-draft condensors are removed. Such removal will not be difficult although a revision in the dissolver procedure will be required.

If, as the Oak Ridge work has shown, only 2% of the iodine remains in solution, and given the same split between liquid streams as above, an Amberlite XAD-4 treatment of low level wastes at a modest DF of 50 will provide a plant containment factor of 9000 with no recycle of low level wastes. If 50% of the low level wastes is recycled, and this is easily possible within the water balance of the plant, the same DF in the resin bed will provide a plant containment factor in excess of 10^4. By this procedure, less than 4 μCi. per ton of iodine-129 will be discharged to the environment of which about 90% will go to the low level liquid waste stream with little public exposure and in which it will be diluted with naturally occurring stable iodine-127.

The dissolver off gas will contain copious quantities of nitrogen oxides, nitric acid and water in addition to iodine and krypton. The off gas will be routed to a nitrogen oxide (NO_x) recovery tower for recovery of nitric acid. A small stream of oxygen will be added to oxidize NO to NO_2 for absorption in the NO_x tower. A stream of 6M nitric acid will be used for absorption and will be withdrawn periodically for recycle to the dissolver. Some iodine will be absorbed in the acid which will be stripped out with NO_2 to prevent recycle of iodine with the recovered acid. A major goal of the head end section is to volatilize the maximum amount of iodine into the off gas stream and to deliver it to the iodine absorption section shown in Figure 3.

12 ORNL - TM - 3614, No. 31, p. 23

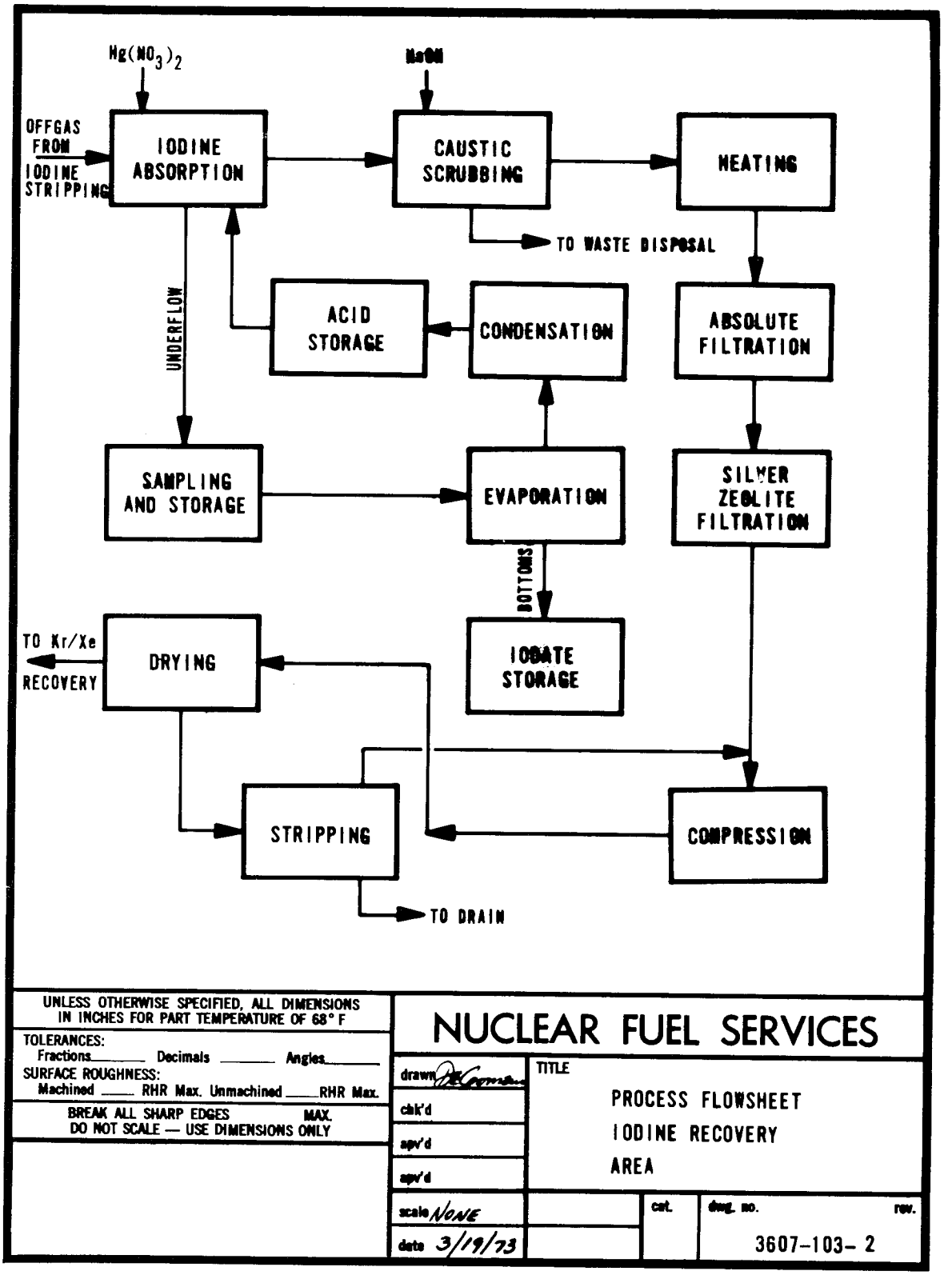

Hg(NO3)2
NaOH
OFFGAS FROM IODINE STRIPPING
IODINE ABSORPTION
CAUSTIC SCRUBBING
HEATING
TO WASTE DISPOSAL
UNDERFLOW
ACID STORAGE
CONDENSATION
ABSOLUTE FILTRATION
SAMPLING AND STORAGE
EVAPORATION
SILVER ZEOLITE FILTRATION
BOTTOMS
TO Kr/Xe RECOVERY
DRYING
IODATE STORAGE
STRIPPING
COMPRESSION
TO DRAIN
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS IN INCHES FOR PART TEMPERATURE OF 68° F
TOLERANCES:
Fractions Decimals Angles
SURFACE ROUGHNESS:
Machined RHR Max. Unmachined RHR Max.
BREAK ALL SHARP EDGES MAX.
DO NOT SCALE — USE DIMENSIONS ONLY
NUCLEAR FUEL SERVICES
drawn
chk'd
apv'd
apv'd
TITLE
PROCESS FLOWSHEET
IODINE RECOVERY
AREA
scale NONE
date 3/19/73
cat.
dwg. no.
rev.
3607-103- 2

Fig. 3

Figure 3 outlines the process steps designed to recover and convert iodine to an insoluble compound that can be economically stored pending resolution of the iodine disposal problem.

Off-gas from the dissolver combined with the off gas from the shear and voloxidizer will be scrubbed with 10M nitric acid containing 0.2-0.4 M mercuric ion. Oak Ridge work has shown this scrubber system to be highly effective for the absorption of volatile iodine species including methyl iodide. A decontamination factor of not less than 1,000 is anticipated since DF's several times this value have been seen in laboratory work.

Iodine is held in the scrubber solution as soluble mercuric iodide (HgI_2). The solution is periodically discharged to an evaporator where the concentration is increased to above 10 M. The hot, concentrated, nitric acid oxidizes mercuric iodide to the quite insoluble mercuric iodate [$Hg(IO_3)_2$] which precipitates. The mercuric iodate slurry will be dropped into a 1000 gallon stainless steel tank in a buried vault for storage. The supernatant liquor in the storage tank will be periodically decanted back to the scrubber system. The overhead condensate from the evaporator will also be recycled to the scrubber system. In this way, no iodine bearing solutions will leave the system. Water and nitric acid losses in the gas stream from the scrubber will be made up by the addition of nitric acid to which mercuric ion will be added to replace that lost to mercuric iodate storage tank.

The off-gas from the scrubber will contain nitric acid and some carbon dioxide, both of which are undesirable in the later krypton recovery system; therefore the mercuric scrubber will be followed by a caustic scrubber using 10 M sodium hydroxide. Bottoms from the caustic scrubber will go to the intermediate level waste evaporator for eventual storage in the intermediate level waste tank.

The off gas from the caustic scrubber will be reheated and passed through an absolute filter and a silver zeolite bed to pickup any slight trace of iodine that may have escaped absorption in the mercuric nitrate scrubber. Silver zeolite beds have been shown to be extremely effective in absorbing organic iodides and all species of inorganic iodine. The DF across the silver zeolite bed is conservatively estimated at not less than 1,000; thus, the off gas stream at this point will contain less than

1 μCi. iodine-129 per ton of fuel processed. Even if the DF's across the mercuric ion scrubber and the silver zeolite bed are as low as 300, the off gas will still contain less than 1 μCi. iodine-129.

Of the 40,000 μCi. iodine-129 in one ton of fuel, it is estimated that 39,000 μCi. will be recovered as mercuric iodate and stored in the waste tank; about 300 μCi. will be diverted and stored as iodic acid in the high level waste. Less than 1 μCi. will leave the plant via the stack and less than 4 μCi. will leave the plant in low level liquids, thus, the overall iodine decontamination factor across the plant is expected to be well over 10,000.

Krypton

The off gas stream at this point is free of iodine and tritium and, with the exception of its water content, is ready for krypton recovery. The off gas will be compressed to about 40 psig, and dried over activated alumina or 13-X molecular sieve to a dew point below -40°F. Water from the drier will be discharged to a strip tank where any dissolved krypton will be stripped by moderate heating. The krypton will be recycled to the suction side of the compressor and the water will be discharged to waste. Drying is accompanied at this point to avoid recycling freon through the drier which would be required if the drier were located behind the main compressor of the krypton recovery unit.

The krypton-xenon recovery system is shown in Figure 4. The system chosen is the freon absorption system as developed at Oak Ridge. Dried off gas is compressed to 375 psig and sent to an absorption tower where it is contacted with Freon-12 at -25°F. The F-12 dissolves nitrogen, oxygen, argon, krypton and xenon whose solubilities increase in the order presented. Henry's Law Constants for the various components in Freon-12 are shown in Figure 5. Henry's Law states that for gases that do not react with the solvent, the mole fraction of gas in the solvent is proportional to the partial pressure of the component in the gas stream as in equation [1].

$$y = Hx \qquad [1]$$

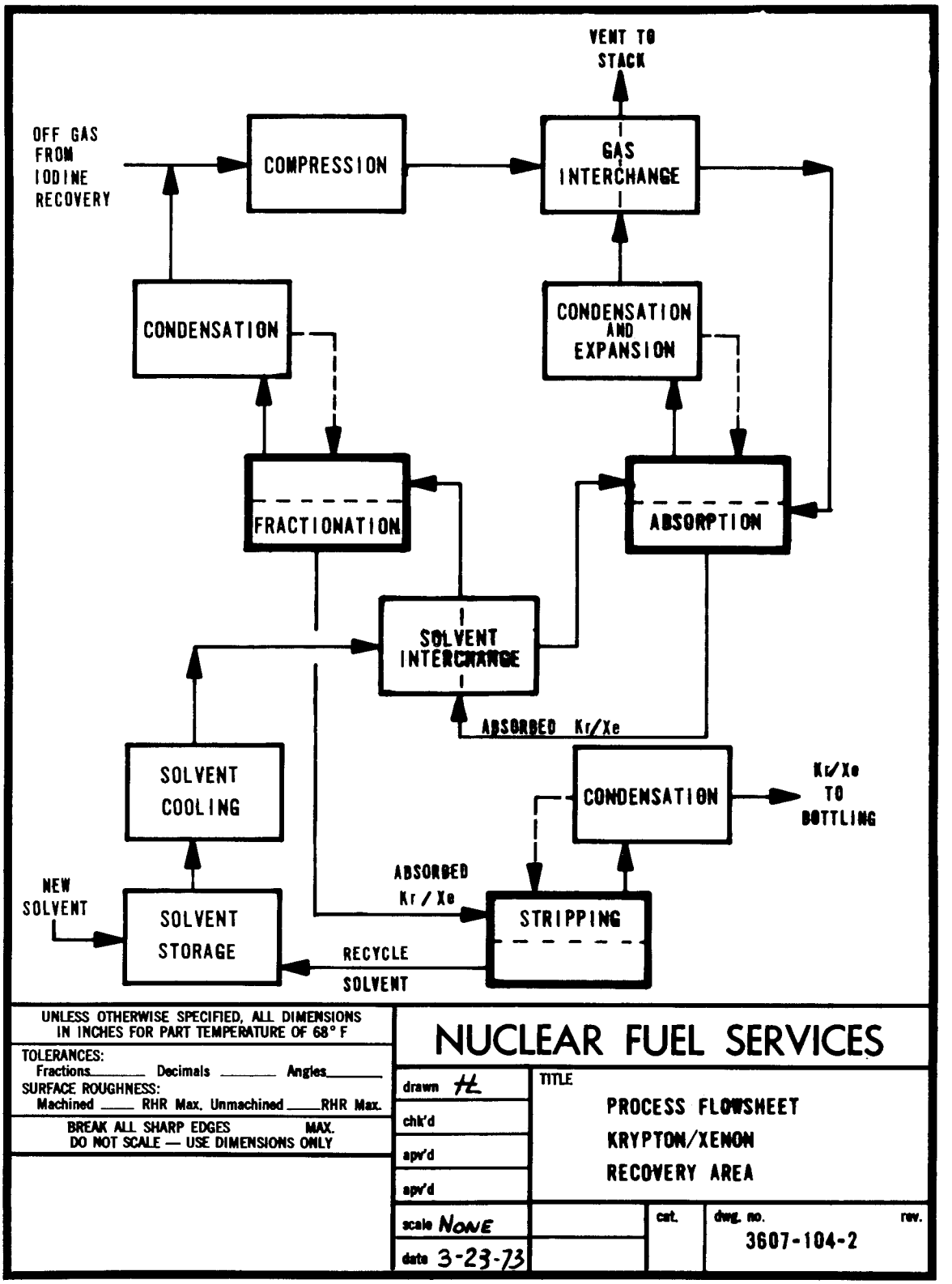
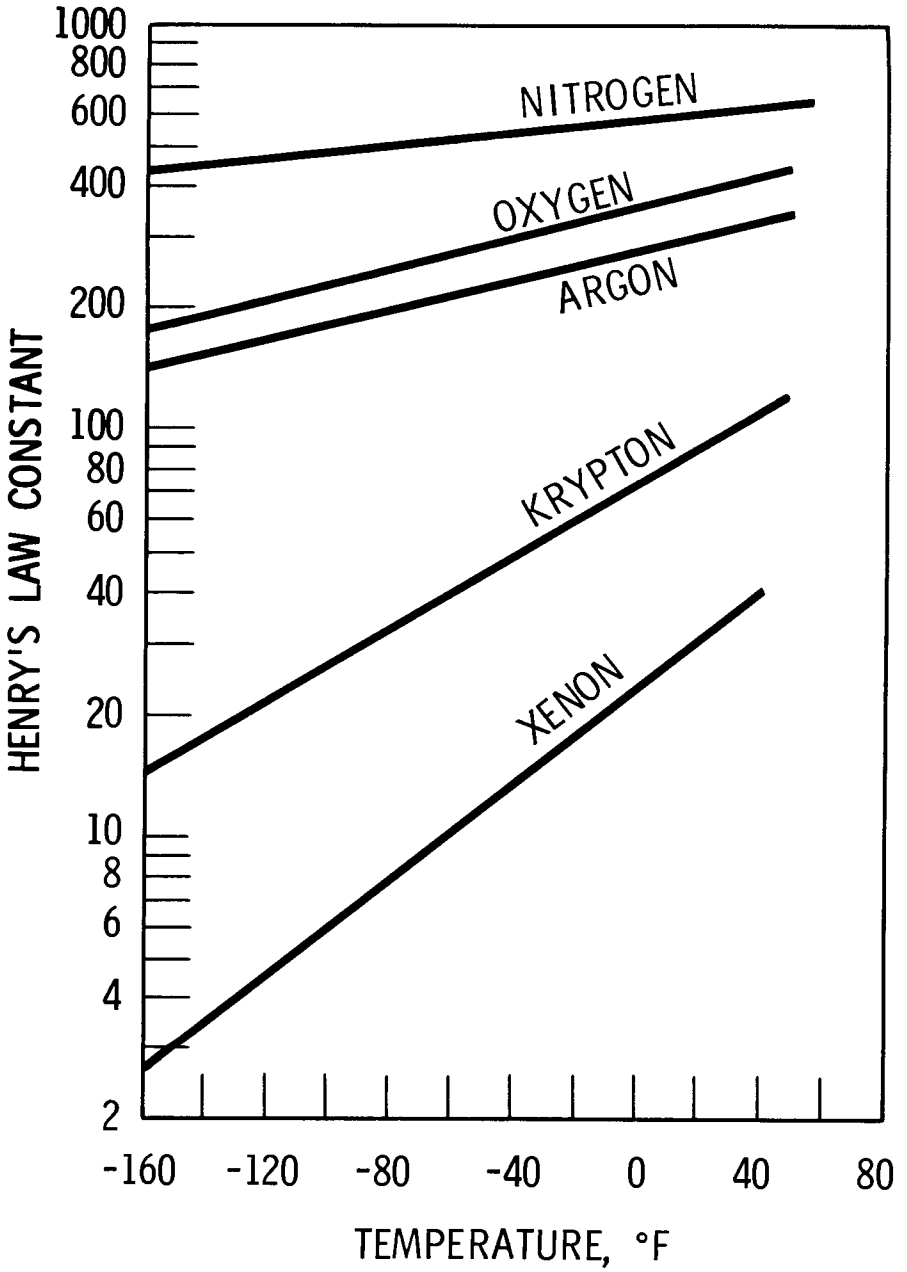

VENT TO STACK
OFF GAS FROM IODINE RECOVERY
COMPRESSION
GAS INTERCHANGE
CONDENSATION
CONDENSATION AND EXPANSION
FRACTIONATION
ABSORPTION
SOLVENT INTERCHANGE
ABSORBED Kr/Xe
SOLVENT COOLING
CONDENSATION
Kr/Xe TO BOTTLING
NEW SOLVENT
SOLVENT STORAGE
ABSORBED Kr / Xe
STRIPPING
RECYCLE SOLVENT
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS IN INCHES FOR PART TEMPERATURE OF 68° F
TOLERANCES:
Fractions Decimals Angles
SURFACE ROUGHNESS:
Machined RHR Max. Unmachined RHR Max.
BREAK ALL SHARP EDGES MAX.
DO NOT SCALE — USE DIMENSIONS ONLY
NUCLEAR FUEL SERVICES
drawn
chk'd
apv'd
apv'd
TITLE
PROCESS FLOWSHEET
KRYPTON/XENON
RECOVERY AREA
scale NONE
date 3-23-73
cat.
dwg. no.
3607-104-2
rev.

Fig. 4



RELATIVE SOLUBILITIES OF GASES
IN REFRIGERANT-12

Fig. 5

Figure from: Merriman, Stephenson, Pashley and Dunthorn, "Removal of Radioactive Krypton and Xenon from Contaminated Off-Gas Streams", K-L-6257

Henry's Law holds quite well at low concentrations and at constant temperature. Figure 8 shows the variation in the constant over a temperature range from -160°F to 80°F. The absorber column temperature of -25°F was chosen to give reasonably good relative volatilities between krypton-xenon and air at a temperature that can be easily reached with a single cycle refrigeration apparatus. At this temperature, the Henry's Law constant are:

Component	H @ -25°F in F-12
Nitrogen	570 atm.
Oxygen	325
Argon	255
Krypton	61
Xenon	18

The feed gas will be substantially air with some residual oxygen that was added in the NO_x column, plus krypton and xenon in the part per million range. Assuming an off-gas stream of 120 CFM and krypton-xenon evolution over a four hour period, the feed gas will contain about 500 ppm krypton and 7300 ppm xenon. Considering that Oak Ridge has demonstrated the efficiency of krypton absorption in the part per billion range, this is a relatively rich feed and is moreover in a range where much experimental data is available. Table 1 presents experimental performance data from the Oak Ridge work that is pertinent to the design conditions. These data indicate the high efficiency of the freon absorption process in the concentration range anticipated as well as the critical nature of the L/G ratio in the absorber column. The Freon-12 system using Goodloe packing at an L/G ratio of from 3.5 to 4.25 is easily capable of providing a DF of much better than 100 under the design conditions of temperature and pressure.

The Freon absorption system is composed of three columns; the absorber, the fractionator, and the stripping column.

TABLE I

ABSORPTION SYSTEM PERFORMANCE DATA

	Run Number						
	1	2	3	4	5	6	7
Average Absorber Temperature, °F	-24°	-25°	-30°	-32°	-31°	-26°	-26°
Absorber Pressure, psia	416	416	416	416	416	416	416
Solvent Flow Rate, gpm	0.75	0.75	0.75	0.75	0.75	1.0	1.0
Absorber Feed Gas:							
Flow Rate, scfm	9.5	9.6	15.1	15.0	20.6	15.2	15.5
Krypton Concentration, ppm.	990	1670	125	305	60	1130	1070
Average L/G Ratio, mole basis	4.52	4.25	2.81	3.04	1.92	3.58	3.70
Krypton Removal in Absorber, %	99.71	99.81	97.51	98.51	75.02	98.70	99.17
Absorber Column Krypton Decontamination Factor	345	526	40	67	4	77	120

Table from: Merriman and Pashley, "Engineering Development of an Absorption Process for the Concentration and Collection of Krypton and Xenon", K-1786, 1970.

The krypton rich liquid stream leaving the bottom of the absorber is delivered to the top of the fractionator which operates at about 45 psig and 32°F. Heat is supplied to the bottom of the column to fractionate out the more volatile components, nitrogen, oxygen and argon while retaining a significant portion of the krypton and xenon in solution. The off-gas from the fractionator is contaminated with krypton and is therefore recycled to the suction side of the main compressor. The purpose of the fractionator is to reduce the nitrogen and oxygen content of the krypton-xenon stream to a low value in order to reduce the total volume of gas which eventually will be sent to storage. The volatile gases fed to the fractionator are better than 90% nitrogen and oxygen while the volatile gases leaving the fractionator in solution are better than 80% krypton-xenon. Twelve transfer units will effect this separation and the column has been designed to provide not less than 15 transfer units.

Krypton bearing solvent from the fractionator is taken to the stripping column which operates at a pressure of about 25 psia and a temperature of 2°F. The remaining volatile gases are stripped from the Freon solvent and are compressed and stored in standard hydrogen cylinders. It is important that essentially all the krypton be stripped from the Freon at this point so as to maximize the effectiveness of the absorber to which the Freon is recycled. It can be seen from the Colburn equation [2] that the presence of krypton in the liquid feed to the absorber will substantially increase the number of transfer units for a given separation since the term Kx_2 is subtracted from the gas outlet concentration, y_2, which must be very low in order to achieve the desired decontamination.

$$N_{OG} = \frac{2.3}{(1-\frac{kG}{L})} \log \left[\left(\frac{y_1 - kx_2}{y_2 - kx_2} \right) \left(1 - \frac{kG}{L} \right) + \frac{kG}{L} \right] \qquad [2]$$

where: N_{OG} = number of transfer units

k = gas-liquid equilibrium coefficient

L = liquid flow rate, moles/min

G = gas flow rate, moles/min

y = gas phase mole fraction, absorbent

x = liquid phase mole fraction, absorbent

1 = gas inlet end of column

2 = gas outlet end of column.

If x_2 is low enough to be considered zero, then the term becomes $\frac{y_1}{y_2}$ which is the desired decontamination factor. This assumption is particularly helpful in preliminary scoping calculations.

The gas streams leaving the top of the various columns will, of course, be saturated in Freon-12 which must be condensed and refluxed back to the columns. This is particularly important on the absorber column since the flow through the column is substantial, and any freon in this stream will be lost from the system. The Freon losses in a 125 cfm air stream at 375 psia and various temperatures are as follows:

Temp.	Lbs/hr	$/hr*
-20°F.	102	$25.50
-60°F.	36	$ 9.00
-100°F.	9.6	$ 2.40

*at 25¢/lb. F - 12

Losses from a lower pressure stream at the same temperatures would be significantly greater. It can be concluded that the exit gas stream from the absorber must be cooled to the area of -100°F while at the absorber pressure in order to keep the F-12 losses to a practical level. This will be accomplished by passing the exit gases through a cryogenic heat exchanger

at 375 psia and -100°F. The condensed F-12 will be refluxed to the absorber. The cooled gas will then be expanded through a turbo-expander such as those manufactured by Rotoflow Corporation.[13] Such equipment is extensively used in gas liquifaction and in the recovery of liquified natural gas (LNG). The turbo-expander cools the working fluid by adiabatic expansion while performing work external to the system. A modern liquid oxygen plant is an excellent example of this process.

The temperature of a gas expanded adiabatically is given by equation (3):

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} \qquad (3)$$

where: T_1 = gas inlet temperature ^oR
T_2 = gas outlet temperature ^oR
P_1 = inlet pressure
P_2 = outlet pressure
K = Cp/Cv (K air = 1.40)

Alternatively, a temperature-entropy diagram may be used if available. Calculations were performed by both techniques using air as the working fluid, and the results correlated within the limits of engineering accuracy.

The application of a turbo-expander to the system is shown in Figure [6].

The gas stream leaving the absorber column at -25°F is, of course, saturated with F-12 at 375 psia. The exit gas stream is passed through a reflux condenser in which it is cooled to - 100°F at 375 psia to condense out F-12 to about one weight percent F-12 in the exit air. The cooled gas stream then goes to the turbo-expander where it is expanded down to atmospheric pressure and a temperature of -235°F which is still above the freezing point of F-12 of -252°F. The turbo-expander at 60% efficiency will deliver about 10 H.P. which will be absorbed in a hydraulic fluid and the heat will be discharged in a water cooler. The expanded gas then is used on the cold side of the reflux condenser in which it is heated to about -110°F. The -110°F stream then goes to the cold side of the economizer heat exchanger to cool the incoming inlet air stream from the compressor. The gas stream leaves the economizer at about 40° F and is exhausted to the plant stack.

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13 Engineer's Guide to Turbo-Expanders, Swearingen, J. S., Hydrocarbon Processing, April, 1970.

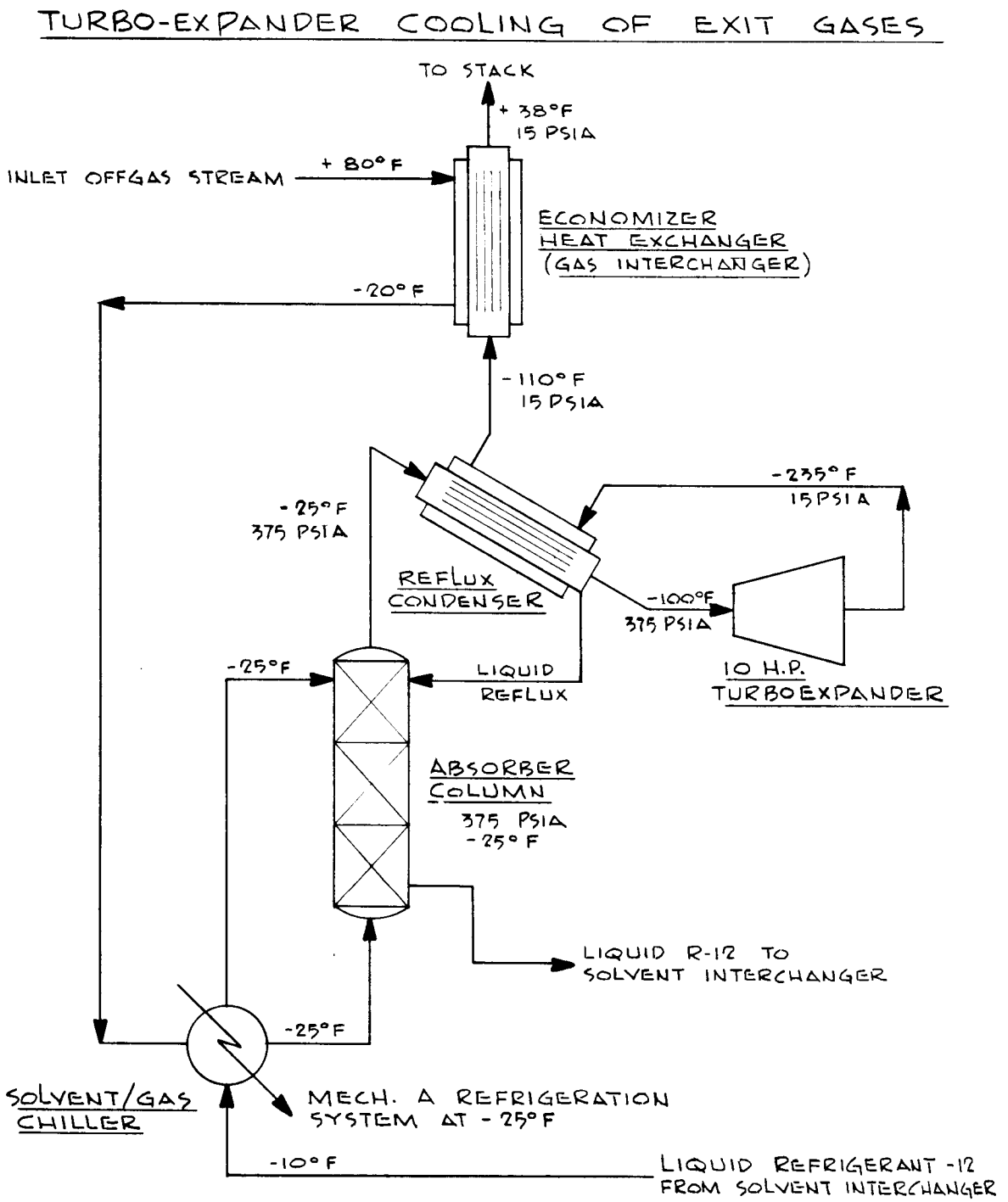
TURBO-EXPANDER COOLING OF EXIT GASES
TO STACK
+ 38°F
15 PSIA
INLET OFFGAS STREAM
+ 80° F
ECONOMIZER
HEAT EXCHANGER
(GAS INTERCHANGER)
-20° F
-110° F
15 PSIA
-235° F
15 PSIA
-25° F
375 PSIA
REFLUX
CONDENSER
-100°F
375 PSIA
10 H.P.
TURBOEXPANDER
-25°F
LIQUID
REFLUX
ABSORBER
COLUMN
375 PSIA
-25° F
LIQUID R-12 TO
SOLVENT INTERCHANGER
-25°F
SOLVENT/GAS
CHILLER
MECH. A REFRIGERATION
SYSTEM AT - 25° F
-10° F
LIQUID REFRIGERANT -12
FROM SOLVENT INTERCHANGER

Fig. 6

The inlet air stream from the compressor, which has previously been cooled to about 80°F in a water cooler, leaves the economizer at about - 20°F thus significantly reducing the load on the mechanical "A" refrigeration system used to cool to -25°F both the inlet air and the inlet liquid F-12 to the absorber column.

It will, of course, be desirable to provide low temperature condensing for the off-gas from the fractionator and the stripper. Cooling the stripper off-gas is particularly important to minimize the volume of gas to storage. These two streams will be cooled to -80°F using a two-stage refrigeration system. It would be desirable to cool the stripper gas to even lower temperatures to minimize the F-12 content in the stored gases.

Two refrigeration systems will thus be required; Mechanical "A", operating between -25°F and cooling water temperature, and Mechanical "B", operating between -80°F or lower and -25°F. The Mechanical "A" system is rated at 750,000 BTU/hr, and the Mechanical "B" system is rated at 40,000 BTU/hr. The total refrigeration load is about 65 tons for process requirements. Some slight additional capacity will be required to offset heat losses from the apparatus.

The primary load on the Mechanical "A" system is absorbing the heat supplied to the reboilers on the fractionator and the stripper and during startup of the system.

Krypton Storage

Thus far the primary technical problem has been the separation and concentration of the krypton in the off-gas stream. Since the freon absorption system concentrates xenon along with krypton, the resulting product, assuming the substantial elimination of nitrogen, oxygen and argon in the fractionator, will be a mixture of krypton and xenon plus any F-12 that is not condensed out in the stripper gas condenser. If the stripper gas condenser operates at 25 psia, the F-12 content of the gas cooled to -80°F will be 11 mole %. This is of little concern from a loss point of view, however, it does increase the gas volume to be stored by some 13%. In the final design of the facility, effort should be made to cool the stripper gas to even lower temperatures to reduce the F-12 content. The most economical source for further cooling is undoubtably the cold gas from the turbo-expander.

The krypton content is made up of a number of stable isotopes in addition to Kr-85. The fission gas from one ton of 33,000 MWD fuel at 150 days age will contain 28.7 grams of Kr-85 out of a total of 372 grams of krypton, the balance being made up of stable isotopes. The xenon content at 150 days will be 5423 grams of various stable isotopes. The total volume of krypton and xenon from one ton of fuel will be about 35 cubic feet, and allowing for nitrogen, oxygen and F-12 it is expected that 50 cubic feet of gas per ton of fuel will go to storage. Since about two thirds of the stripper gas is expected to be xenon, and three quarters will be xenon and F-12, a P-V curve for xenon was calculated using Van der Wall's constants for xenon. Using the xenon P-V data and a volume of 1.55 cubic feet in a standard hydrogen cylinder, it is estimated that 380 standard

cubic feet can be stored in one hydrogen cylinder at 1700 psia; thus one cylinder will contain the stripper gas from about seven tons of fuel. Standard hydrogen cylinders are normally filled to 2000-2200 psi and are hydrostatically tested at 3750 psi. A working pressure of 1700 psi thus is less than fifty percent of the test pressure and is well below the normal working pressure for these cylinders. The P-V curve begins to rise rather sharply above 1700 psi and no great advantage in stored volume would be obtained in going to higher pressures.

Using the above working pressure, the cylinder will contain nearly 80,000 Ci. of Kr-85 and will radiate about 120 watts which can easily be accommodated with a modest skin temperature rise of 30°-50°F above ambient temperatures. A more serious problem will be the radiation field near the cylinder.

ORNL-3576 provides shielding and radiation data for krypton isotopic power sources.[14] At a power rating of 120 watts, the gamma plus bremsstrahlung radiation can be expected to be about 150 R/hour at one meter. Significant shielding will obviously be required at both the loading station and in the storage area for the filled cylinders. The gamma and bremsstrahlung energies, however, are relatively weak, 0.52 Mev maximum, and three inches of lead will bring the radiation levels down to 1 mR/hour. About fifteen inches of concrete will provide equivalent shielding.

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(14) "Handbook of Shielding Requirements and Radiation Characteristics of Isotopic Power Sources for Terrestial, Marine and Space Applications", E. D. Arnold, ORNL-3576, April, 1964.

Since the working inventory in the krypton recovery system will be less than 10,000 Ci., radiation levels in the process area will not be excessive, however, it is anticipated that modest shielding will be required around the columns and auxilliary equipment.

The cylinder loading station will consist of a standard hydrogen cylinder within a three inch thick lead cask weighing about 2600 pounds. A lead or uranium collar will be fitted around the cylinder valve to reduce extremity exposure to personnel during change out of loaded cylinders. After the cylinder is filled to the desired pressure, the cylinder valve, as well as the valve in the charging line, will be closed. The pressure in the pig-tail will be bled off to the head end of the system to recycle most of the contained Kr-85 before disconnecting the pig-tail. The pig-tail will be disconnected and the valve will then be capped and covered. If the pressure is bled down to 40-50 psi prior to opening the line, the resulting release of Kr-85 will be less than 5 Ci. or less than .05% of the Kr-85 content in one ton of fuel. If the disconnection is performed once per seven tons of fuel processed, the loss from the pig-tail will be less than .01% of the Kr-85 recovered.

The loading station will be enclosed in a glove box like hood. The primary purpose of the enclosure is to protect the operator from a high pressure jet directed at his face and to collect off-gas leakage during disconnection which will be discharged to the stack. The effect of such losses on the overall DF will be negligible.

After the cylinder is disconnected, the lead sleeve will be covered with a lead plate and the cylinder will either be taken to a storage area or shipped off site for disposal.

At some future time a market for xenon might develop. Krypton is now being used as an inert gas in high intensity lamps and xenon probably would be superior to krypton for this purpose. If such a need should develop, it would be a simple matter to recycle the cylinders for xenon recovery by cryogenic distillation. One thousand tons of fuel will produce about 32,000 cubic feet of xenon so that after a few years of storage, an inventory of potentially saleable gas will be accumulated. The decision on xenon recovery can be delayed until the supply warrants the recovery.

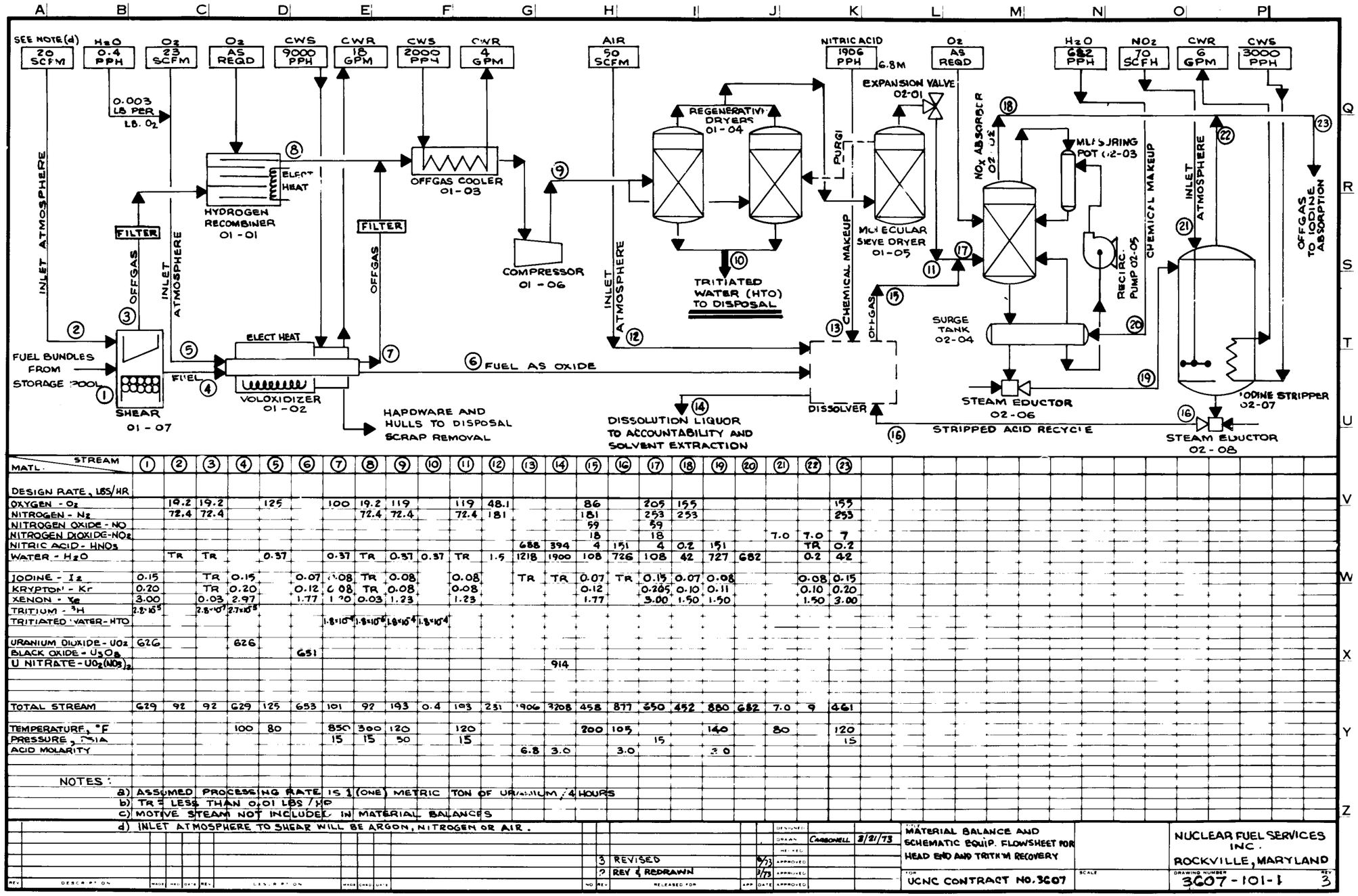
Material Balances

Typical material balance flowsheets for the tritium, iodine, and krypton recovery systems are shown in Figure 7 (Dwg. No. 3607-101-1), Figure 8 (Dwg. No. 3607-103-1), and Figure 9 (Dwg. No. 3607-104-1). These drawings also present a schematic representation of the process equipment proposed for each unit operation; this equipment will be discussed in the next section of the report.

The basis for the material balances is an assumed processing rate of one metric tonne of uranium per four hour period. While this rate is not meant to imply a plant capacity of six tonnes/day, it was necessary to select this instantaneous rate in order to size the equipment for the expected maximum flow rates in any given hour.

Each figure lists the average component flow rate for all major streams as well as the temperature, pressure, and concentration of critical streams; the material balances have been calculated and shown

in pounds per hour. The streams have been numbered consecutively through the flowsheets for ease of identification. Introduction of water to the system via the steam used in eductors has been neglected. Certain other minor constituents have also been omitted such as argon and carbon dioxide.



MATL. \ STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DESIGN RATE, LBS/HR																							
OXYGEN - O_2		19.2	19.2		125		100	19.2	119		119	48.1			86		205	155					155
NITROGEN - N_2		72.4	72.4					72.4	72.4		72.4	181			181		253	253					253
NITROGEN OXIDE - NO															59		59						
NITROGEN DIOXIDE - NO_2															18		18				7.0	7.0	7
NITRIC ACID - HNO_3													688	394	4	151	4	0.2	151			TR	0.2
WATER - H_2O		TR	TR		0.37		0.37	TR	0.37	0.37	TR	1.5	1218	1900	108	726	108	42	727	682		0.2	42
IODINE - I_2	0.15		TR	0.15		0.07	0.08	TR	0.08		0.08		TR	TR	0.07	TR	0.15	0.07	0.08			0.08	0.15
KRYPTON - Kr	0.20		TR	0.20		0.12	0.08	TR	0.08		0.08				0.12		0.205	0.10	0.11			0.10	0.20
XENON - Xe	3.00		0.03	2.97		1.77	1.20	0.03	1.23		1.23				1.77		3.00	1.50	1.50			1.50	3.00
TRITIUM - ^3H	2.8×10^{5}		2.8×10^{7}	2.7×10^{5}																			
TRITIATED WATER - HTO							1.8×10^{-4}	1.8×10^{-4}	1.8×10^{-4}	1.8×10^{-4}													
URANIUM DIOXIDE - UO_2	626			626																			
BLACK OXIDE - U_3O_8						651																	
U NITRATE - $UO_2(NO_3)_2$														914									
TOTAL STREAM	629	92	92	629	125	653	101	92	193	0.4	193	231	1906	3208	458	877	650	452	880	682	7.0	9	461
TEMPERATURE, °F				100	80		850	300	120		120				200	105			140		80		120
PRESSURE, PSIA							15	15	50		15						15						15
ACID MOLARITY													6.8	3.0		3.0			3.0				

NOTES:

a) ASSUMED PROCESSING RATE IS 1 (ONE) METRIC TON OF URANIUM / 4 HOURS

b) TR = LESS THAN 0.01 LBS / HR

c) MOTIVE STEAM NOT INCLUDED IN MATERIAL BALANCES

d) INLET ATMOSPHERE TO SHEAR WILL BE ARGON, NITROGEN OR AIR.

REV.	DESCRIPTION	MADE	CHKD	DATE	REV.	DESCRIPTION	MADE	CHKD	DATE

NO.	REV.	RELEASED FOR	APP.	DATE
3		REVISED		8/73
2		REV & REDRAWN		3/73

DESIGNED:
DRAWN: CARSONELL 3/21/73
REVISED:
APPROVED:
APPROVED:
APPROVED:

TITLE: MATERIAL BALANCE AND SCHEMATIC EQUIP. FLOWSHEET FOR HEAD END AND TRITIUM RECOVERY

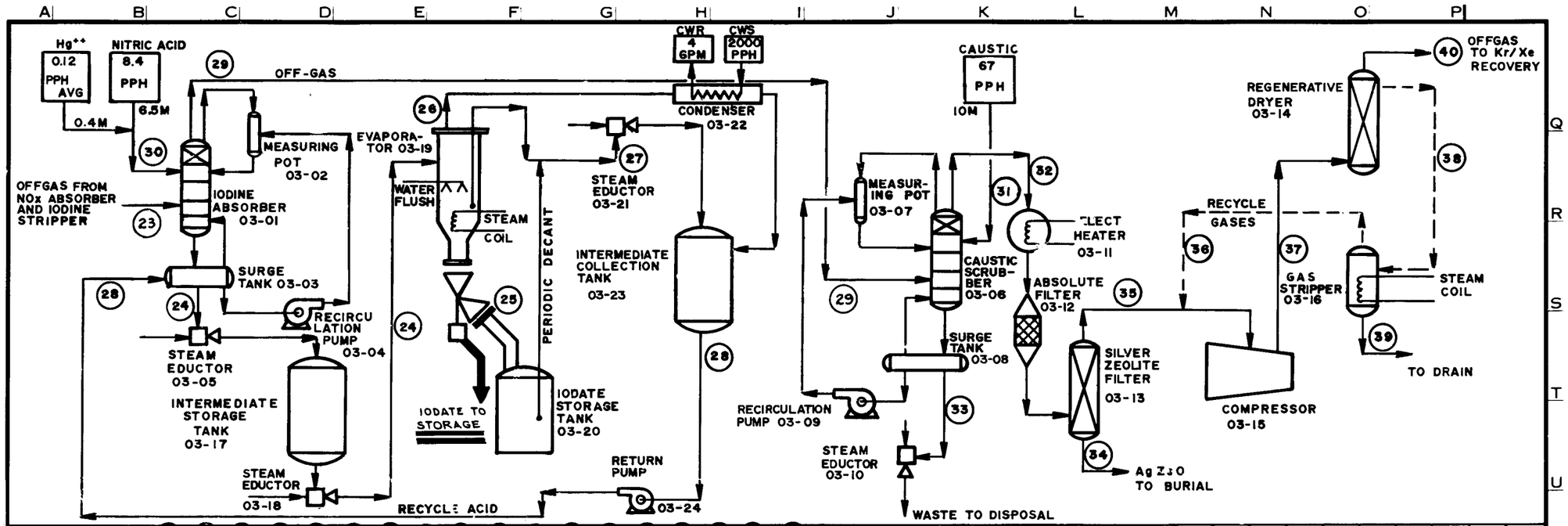
FOR: UCNC CONTRACT NO. 3607

SCALE:

NUCLEAR FUEL SERVICES INC.
ROCKVILLE, MARYLAND

DRAWING NUMBER: 3607-101-1 REV. 3

Fig. 7



MAT'L \ STREAM	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
DESIGN RATE, LBS/HR																		
OXYGEN - O_2	155						155			155			155	TR	155	TR		155
NITROGEN - N_2	253						253			253			253	TR	253	TR		253
NITROGEN DIOXIDE - NO_2	7						7.3											
NITRIC ACID - HNO_3	0.2	8.4	TR	2.4	6.0	8.4	3.2	3.0										
WATER - H_2O	42	12.6	TR	7.6	5.0	12.6	47.4	5.4	47	9.4	87.3		9.4		9.4	9.4	9.4	
IODINE - I_2 OR $2I^-$	0.15	0.15					TR			TR		TR						
KRYPTON - Kr	0.20						0.20			0.20			0.20	TR	0.20	TR		0.20
XENON - Xe	3.00						3.00			3.00			3.00	TR	3.00	TR		3.00
MERCURY, Hg^{++}		1.3			1.2	1.2		0.1										
MERCURIC IODATE - $Hg(IO_3)_2$			0.33															
SODIUM HYDROXIDE - NaOH									20		11.7							
MISC. SODIUM SALTS											16.5							
TOTAL STREAM	461	22.4	0.3	10.0	12.2	22.2	469	8.5	68	421	116	–	421	–	421	9.4	9.4	411
TEMPERATURE °F	120			200		100	140		80	100			140	140		120		140
PRESSURE, PSIA	15												15	15	44			44
ACID/BASE MOLARITY		8.0		4.2	11.5	8.0		6.5	10.0		3.4							

NOTES:
a) ASSUMED PROCESSING RATE IS 1 METRIC TON OF URANIUM / 4 HOURS
b) TR = LESS THAN 0.01 LBS/HR
c) MOTIVE STEAM NOT INCLUDED IN MATERIAL BALANCE

2 REV & REDRAWN 4/13

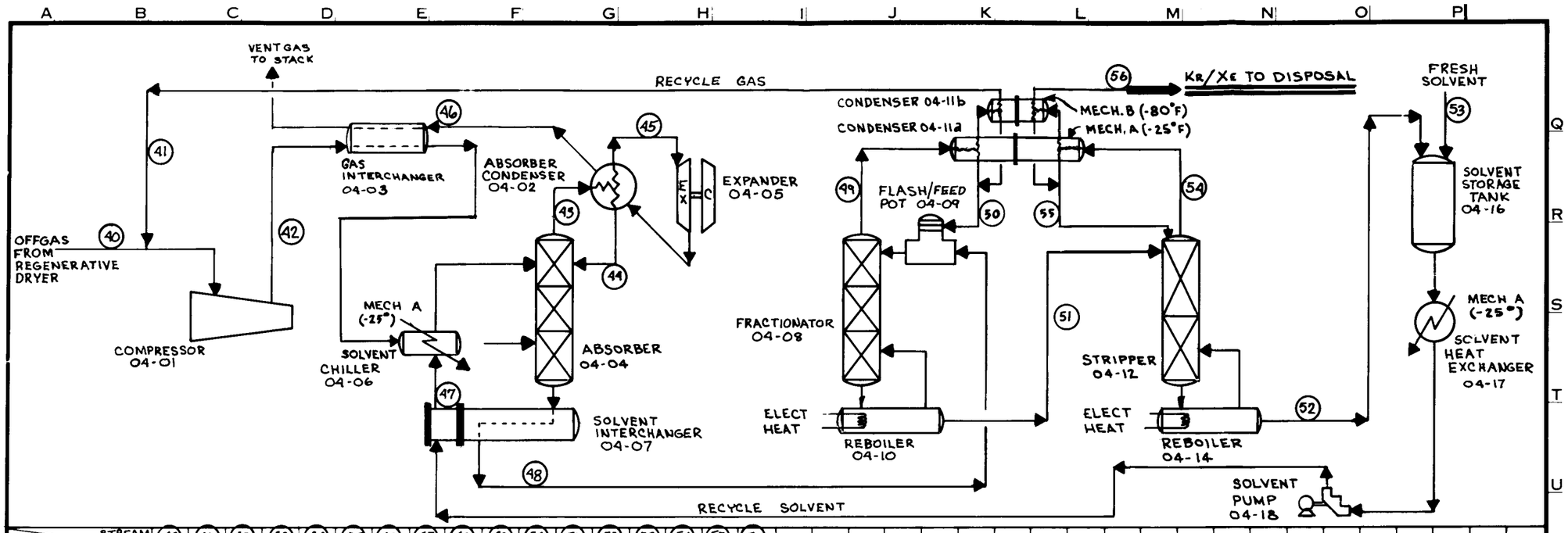
TITLE MATERIAL BALANCE & SCHEMATIC EQUIPMENT FLOWSHEET FOR IODINE RECOVERY

FOR UCNC CONTRACT #3607

NUCLEAR FUEL SERVICES INC.
ROCKVILLE, MARYLAND

DRAWING NUMBER 3607-103-1 REV 2

Fig. 8



MAT'L \ STREAM	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
DESIGN RATE, LBS/HR																	
OXYGEN - O_2	155	76	231	153		153	153		78	76		2			2		2
NITROGEN - N_2	253	65	318	252		252	252		66	65		1			1		1
KRYPTON - Kr	0.205	0.14	0.34	0.001		0.001	0.001	TR	0.344	0.14		0.204			0.204		0.204
XENON - Xe	3.00	2.74	5.74	0.02		0.02	0.02	TR	5.72	2.74		2.98			2.98		2.98
FREON 12 - $CClF_2$		39.5	39.5	59.9	54	6.2	6.2	5632	5666	1488	1448	5626	5629	8	7208	7206	2.1
TOTAL STREAM	411	184	595	465	54	411	411	5632	5816	1632	1448	5632	5629	8	7214	7206	8
TEMPERATURE, °F	140	-80	80	-25	-100	-100	-110	-10	-15	32	-34	32	2	—	2	-26	-80
PRESSURE, PSIA	44	44	375	375	375	375	15	375	375	44	44	44	24	—	24	24	24

NOTE: a) ASSUMED PROCESSING RATE IS 1 METRIC TON OF URANIUM/4 HOURS
b) TR = LESS THAN 0.01 LBS/HR
c) ANY ARGON PRESENT NOT INCLUDED IN MATERIAL BALANCE - WILL EXIT IN STREAMS 46 AND 56

REV	DESCRIPTION	MADE / APP DATE
3	REVISED	6/73
2	REV & REDRAW	4/13

DESIGNED / DRAWN / CHECKED / APPROVED / APPROVED / APPROVED

TITLE: MATERIAL BALANCE AND SCHEMATIC EQUIPMENT FLOWSHEET FOR KRYPTON/XENON RECOVERY
FOR: UCNC CONTRACT No. 3607

NUCLEAR FUEL SERVICES INC.
ROCKVILLE, MARYLAND
DRAWING NUMBER 3607-104-1 REV 3

Fig. 9

EQUIPMENT DESCRIPTION AND SYSTEM LAYOUT

Major Process Equipment

The unit operations and basic processing methods required to recover tritium, iodine, and krypton have been discussed at some length in the previous section of this report. The specific process equipment necessary for this recovery was shown schematically in Figures 7, 8, and 9 and is described in Table 2.

Materials of construction for the equipment and piping will be primarily 18-8 low carbon stainless steel except in certain cases such as the voloxidizer or shear which might require special alloys for temperature and strength considerations. Table 2 lists other features of the process equipment such as services required, approximate size, capacity, internals (if any), and the floor space envelope.

Liquid movements in the tritium and iodine removal systems are accomplished by gravity flow, steam jet ejectors, or submersible centrifugal pumps--methods which are consistent with current practices at the West Valley Plant. The liquid (F-12) in the krypton system is transferred by a pressure differential established by the solvent pump and suceeding lower operating pressures in the three primary columns. Gas and vapor streams throughout the new process are motivated by pressure differentials created by the three compressors in the system.

Where possible, equipment similar to equipment already in use at the plant has been specified. This would include pumps, columns, tankage, eductors, filters, and condensers. Units such as the hydrogen recombiner,

TABLE 2

PROCESS EQUIPMENT LISTING AND COST ESTIMATE -- FISSION PRODUCT GAS RETENTION STUDY

Area	Item	Number	Approximate Size	Materials	Features	Est. Floor Envelope, Foot	Estimated Cost
-0-	Hydrogen Recombiner	01-01	4" Dia. x 2' Lg.	Stainless steel	Handle 150 PPH (30 SCFM) Air w/trace H_2, Elect. Heat (3KW), 300°F	2 x 3	$ 3,000
Head-End And Tritium Recovery	Voloxidizer (two required)	01-02a 01-02b	18" Dia. Tube x 20' Lg.	Cast 25-12 (HH) Alloy or Inconel Tube; MS Shell	Convert 650 PPH UO_2, Elect. Heat Ea. (20KW), CW. Ea. (12 GPM), 850°F	4 x 30 x 12'H (EA)	450,000
	Off-Gas Cooler	01-03	10 $Ft.^2$	Stainless	Cool 250 PPH (50 SCFM) Air to 100°F, CW (4 GPM)	1 x 4	1,000
	Regenerative Dryers (two required)	01-04a 01-04b	--- ---	Stainless wetted--Dryer, Cond. System, & Filters; MS Shell	Dry 250 PPH (50 SCFM) Air w/0.4 PPH H_2O, 50 psia, CW (2 GPM), Elect. Heat (8KW), Act. Alumina Des.	6 x 6 x 7'H (EA)	47,000
	Molecular Sieve Dryer	01-05	---	Stainless wetted--Dryer & Filters	Backup to 01-04 above, Heat reactivated, Elect., Linde 13-X Mol. Sieves	2 x 3 x 5'H	12,000
	Compressor	01-06	25 HP Single Stage	Stainless wetted	Compress 250 PPH (50 SCFM) Air, 15 to 50 Psia, Triple Diaphragm, After-cooler	3 x 5 x 5'H	18,200
	Shear	01-07	150 HP Motor	Stainless or Alloyed Contact Parts	Chop 1/4 ton Fuel/Hr.--Est. Price Includes Table And Req'd. Fixtures	4 x 5 (in cell) 6 x 12 (aisle)	700,000
	Expansion Valve	02-01	4" Outlet Connection	Stainless	Drop Line Press. 50 to 15 Psia, Press Indicated and Controlled	Negligible	1,500
	NO_x Absorber	02-02	2.5' Dia. x 36' High	Stainless Column and Rings	Handle 700 PPH (140 SCFM) Gas Incl. NO_x Raschig Ring Pack, O_2 & H_2O Addition.	3 x 3 x 40' H	27,800
	Measuring Pot	02-03	1' Dia. x 6' High, 35 Gal.	Stainless	Dished Heads	1 x 1 x 6'H	1,500
	Surge Tank	02-04	3' Dia. x 9' Lg, 475 Gal.	Stainless	Set Horizontally, Dished Heads	3 x 9	4,300

Area	Item	Number	Approximate Size	Materials	Features	Est. Floor Envelope, Foot	Estimated Cost
	Recirculation Pump	02-05	5 HP, 3450 RPM	Stainless	Pump~50 GPM @ 80' TDH, Submerged	2 x 3	$ 5,500
	Steam Eductor	02-06	1/2"	Stainless	Move 1000 PPH (2 GPM) Water, 20' Head,~50 PPH Steam @ 140 Psia	Negligible	400
	Iodine Stripper	02-07	3 1/2' Dia. x 7' High, 500 Gal.	Stainless	Strip 1000 PPH Water w/NO_2, CW (6 GPM) Dished Heads	4 x 4 x 8'H	6,100
	Steam Eductor	02-08	3/4"	Stainless	Move 1000 PPH (2 GPM) Water, 50' Head ~90 PPH Steam	Negligible	400
						TRITIUM SUB-TOTAL:	$1,278,700
-03-	Iodine Absorber	03-01	1' Dia. x 20' High	Stainless Column and Plates	Handle 600 PPH (120 SCFM) Air w/0.15 PPH I_2, Sieve Plates, HNO_3/Hg^{++} Addition, Demister	1 x 1 x 24'H	7,800
Iodine Recovery	Measuring Pot	03-02	6" Dia. x 4' High 6 Gal.	Stainless	Dished Heads	1/2 x 1/2 x 4'H	800
	Surge Tank	03-03	2' Dia. x 6' Lg., 140 Gal.	Stainless	Set Horizontally, Dished Heads	1 x 6	3,000
	Recirculation Pump	03-04	3 HP, 3450 RPM	Stainless	Pump~50 GPM @ 50' TDH, Submerged	2 x 3	5,000
	Steam Eductor	03-05	1/2"	Stainless	Move 50 PPH (5GPM) HNO_3, 10' Head, ~10 PPH Steam	Negligible	400
	Caustic Scrubber	03-06	1' Dia. x 20' High	Stainless Column and Plates	Handle 600 PPH (170 SCFM) Air w/3 PPH HNO_3 Sieve Plates, Demister, NaOH & $Na_2S_2O_3$ Addition	1 x 1 x 24'H	7,800
	Measuring Pot	03-07	6" Dia. x 4' High, 6 Gal.	Stainless	Dished Heads	1/2 x 1/2 x 4'H	800
	Surge Tank	03-08	2' Dia. x 6' Lg., 140 Gal.	Stainless	Set Horizontally, Dished Heads	1 x 6	3,000

Area	Item	Number	Approximate Size	Materials	Features	Est. Floor Envelope, Foot	Estimated Cost
-03- (cont.)	Recirculation Pump	03-09	3 HP, 3450 RPM	Stainless	Pump ~50 GOM @ 50' TDH, Submerged	2 x 3	$ 5,000
	Steam Eductor	03-10	1/2"	Stainless	Move 150 PPH (15 GPM) Dilute NaOH, 50' Head, ~30 PPH Steam	Negligible	400
	Heater	03-11	---	Stainless	Heat 500 PPH (100 SCFM) Air From 100°F to 150°F, Elect (3KW) or Steam	1 x 4	1,200
	Absolute Filter (two required)	03-12a 03-12b	24" x 24" x 12"	Stainless Housing; W.P. Glass Media	Filter 500 PPH (100 SCFM) Air, Parallel Units	3 x 6 (Both)	4,000
	Silver Zeolite Filter	03-13a 03-13b	4" Deep	Stainless Housing	Filter 500 PPH (100 SCFM) Air w/trace Iodine, Contact Chageout, 2 req'd.	3 x 4 (Both)	7,000
	Regenerative Dryer	03-14	---	Stainless Wetted-- Dryers and Filters	Dry 500 PPH (100 SCFM) Air w/10 PPH H_2O, 44 Psia, Min. Elect., Ht. React. Act. Alumina Des.	2 x 3 x 7'H	15,000
	Compressor	03-15	25 HP Duplex	Stainless Wetted	Compress 500 PPH (100 SCFM) Air, 15 to 44 Psia, Triple Metal Diaphragm Aftercooler	5 x 6 x 4'H	31,300
	Gas Stripper	03-16	1.5' Dia. x 4'H, 50 Gal.	Stainless	Dished Heads, Steam Coil, Min. Heating	2 x 2 x 4'H	2,500
	Intermediate Storage Tank	03-17	4' Dia. x 6'H, 550 Gal	Stainless	Dished Heads, Sample Line	4 x 4 x 6'H	5,000
	Steam Eductor	03-18	1/2"	Stainless	Move 2 GPM HNO_3 to Evap., Intermittent, 20' Head, ~50 PPH Steam	Negligible	400
	Evaporator	03-19	2' Dia. x 6' H	Stainless	Handle 150 Gal Batch, Steam (50 PPH) Coil, Water Flush, Drain Valve, Spg. Control	3 x 4 x 8'H	15,000
	Iodate Storage Tank	03-20	4' Dia. x 10'H, 1000 Gal.	Stainless	Holds 20^+ years of Iodate Ppt., Decant Line, Underground, Dished Heads	N/A	8,500

Area	Item	Number	Approximate Size	Materials	Features	Est. Floor Envelope, Foot	Estimated Cost
-03- (cont.)	Steam Eductor	03-21	3/4"	Stainless	Move 2 GPM Acid to Collect. Tank, Intermittent, 20' Suct. & Head, ~75 PPH Steam	Negligible	$ 400
	Condenser	03-22	20 Ft.^{2}	Stainless	Cool 50 PPH HNO_3 Vapor to 100°F, CW (4 GPM)	1 x 6	1,400
	Intermediate Collect. Tank	03-23	3' Dia. x 6'H, 300 Gal.	Stainlessq	Holds HNO_3 For Return to System, Dished Heads	3 x 3 x 6'H	3,500
	Return Pump	03-24	1 HP, 1750 RPM	Stainless	Pump 20 GPM @ 25' TDH	2 x 3	3,000
						IODINE SUB-TOTAL:	$ 132,200
-04-	Compressor	04-01	60 HP Duplex	Stainless Wetted	Compress 700 PPH (140 SCFM) Air, 44 to 375 Psia, Triple Metal Diaphragm, After-cooler	4 x 11 x 5'H	37,300
Krypton/ Xenon Recovery	Absorber Condensor	04-02	24 Ft.^{2}	Stainless	Condense 50 PPH F_{12} & cool 500 PPH Air to -100°F with -233°F Air FM Expander	1 x 6	1,900
	Gas Interchanger	04-03	40 Ft.^{2}	Stainless	Cool 700 PPH (140 SCFM) Incoming Air FM Amb. to -25°F with -110°F Air FM Expander	1 x 8	2,500
	Absorber	04-04	10" Dia. x 16'H	Stainless Column & Packing	Handle 700 PPH (140 SCFM) Air Cont. Kr & Xe, 3 Sect. of Mesh Packing	1 x 1 x 20'H	8,600
	Expander	04-05	---	Stainless	Expand 500 PPH (100 SCFM) Air FM 375 Psia to 15 Psia Producing Temp. of -233°F, ~10 HP Work	4 x 6	20,000
	Solvent Chiller	04-06	20,000 BTU/Hr - "A", 35 Ft.^{2}	Stainless	Cool 7000 PPH F_{12} to Abs. FM -10°F to -25°F with Mech. "A" System.	1 x 6	2,300

Area	Item	Number	Approximate Size	Materials	Features	Est. Floor Envelope, Foot	Estimated Cost
-04- (cont.)	Solvent Inter-Changer	04-07	35 $Ft.^2$	Stainless	Cool 7000 PPH F_{12} to Abs. FM 0°F to -10°F with 7000 PPH F_{12} FM Abs.	1 x 6	$ 2,300
	Fractionator	04-08	10" Dia. x 16' H	Stainless Column & Packing	Handle 7000 PPH F_{12} Cont. Kr & Xe, 3 Sect. of Mesh Packing	1 x 1 x 20'H	8,600
	Flash/Feed Pot	04-09	14" Dia. x 3'H, 24 Gal.	Stainless	Enlarged Sect. of Fract. w/2-3 Plates For Flashing	2 x 2 x 4'H	1,500
	Reboiler	04-10	1.5' Dia. x 3' L., 40 Gal.	Stainless	Bottom Sect. of Fract. Elect. Heat (35 KW), Vaporize 1600 PPH F_{12} @ 32°F	2 x 2	4,000
	Condenser (Fract. & Stripper)	04-11	700,000 BTU/Hr. -- "A" - 120 $Ft.^2$ 30,000 BTU/Hr. -- "B" - 10 $Ft.^2$	Stainless	Condense Tot. of 8000 PPH of F_{12} and cool 250 PPH (50 SCFM) Air to -80°F Mech. A & B Systems	2 x 6 1 x 4	4,100 1,000
	Stripper	04-12	20" Dia. x 16' H	Stainless	Handle 7000 PPH F_{12} Cont. Kr & Xe, 2 Sect of Mesh Packing	2 x 2 x 20'H	17,600
	Reboiler	04-14	2' Dia. x 4'L., 95 Gal.	Stainless	Bottom Sect. of Stripper, Elect. Heat (160 KW), Vaporize 7500 PPH F_{12} @ 2°F	2 x 2	6,500
	Solvent Storage Tank	04-16	3 1/2' Dia. x 6 1/2'H, 450 Gal.	Stainless	Hold Approx. 5500 Lbs. of F_{12}, Dished Heads, Insulated, Cooled by 04-17	4 x 4 x 7'H	6,500
	Solvent Heat Exchanger	04-17	15,000 BTU/Hr. -- "A", 15 $Ft.^2$	Stainless	Cool Solvent Hourly Inventory (6000 Less) FM 10°F to 0°F (Syst. Heat Losses), Mech. "A" System	1 x 4	1,300

Area	Item	Number	Approximate Size	Materials	Features	Est. Floor Envelope, Foot	Estimated Cost
-04- (cont.)	Solvent Pump	04-18	7.5 HP	Stainless Wetted	Pump and Meter 7000 PPH F_{12} to Abs., Pressurize 24 Psia to 375 Psia, Triple Diaphragm.	3 x 4 x 4'H	$ 7,500
					KRYPTON/XENON SUB-TOTAL:		$ 133,500
					TOTAL PURCHASED PRICE:		$1,544,400
					FREIGHT AND TAXES @ 5%:		$ 77,220
					GRAND TOTAL OF PROCESS EQUIPMENT:		$1,620,000

compressors, and driers which are not duplicated in the present plant, were sized, specified, and costed based on data from the manufacturers of commercially available items. The voloxidation furnace was defined in its present state based on discussions with a major rotary-furnace manufacturer as well as input from individuals specializing in criticality and heat transfer.

In addition to the numbered process equipment listed, there are certain items of un-numbered process equipment which could not conveniently be included in the flowsheets. These include the bottled gas supply stations, the cold chemical makeup systems, the macroreticular resin filter for iodine removal from liquid streams, and the tritium and krypton loadout facilities. These are all described in somewhat more detail in the Cost Estimate Section under "Auxiliary Equipment."

Utilities

The major utility and service loads for the system have been estimated as follows:

Utility and Service Requirements

Electrical	850 KW
Cooling Water	200 GPM
Steam (excluding bldg. heating)	200 LBS/HR
Compressed Air	150 CFM

It should be noted that these requirements are instantaneous rates or demands and should not be extrapolated to represent the "average" utility usage for the facility. In order to accommodate the foregoing requirements

new cooling water and primary electrical systems will be required and are included in this study under "Auxiliary Equipment." It appears that existing plant systems can handle the steam and compressed air demands of the F.P.G.R. facility.

Instrumentation

The basic instrumentation required to complement the equipment flow-sheets is shown in single-line, single-entity fashion on the following drawings:

Figure 10 (Dwg. No. 3607-601-1) Head End and Tritium Recovery

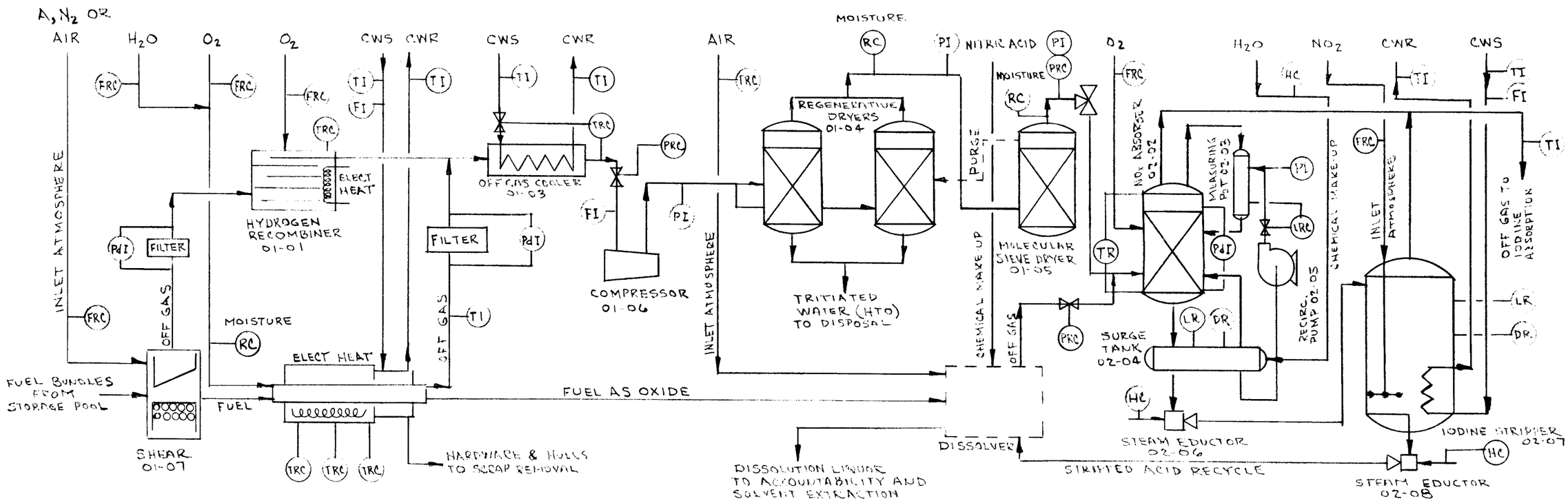
Figure 11 (Dwg. No. 3607-603-1) Iodine Recovery

Figure 12 (Dwg. No. 3607-604-1) Krypton/Xenon Recovery

The single-entity approach does not show any required elements, transmitters, multi-point recorders, etc., but these are included in the instrument listing that is presented in the Cost Estimate Section of the report. Control valves are shown where appropriate in the drawings but they are not labeled. It should be noted that most instruments will be panel mounted and critical readouts will be wired into the existing control room at the plant.

Plant Layout

The equipment required for the recovery of tritium poses major problems in the design, layout, and location of building facilities. Unlike iodine and krypton, which can be isolated and recovered with minimal changes to existing processes, tritium evolution and recovery requires extensive modifications to the existing head-end of the reprocessing plant. In fact, the

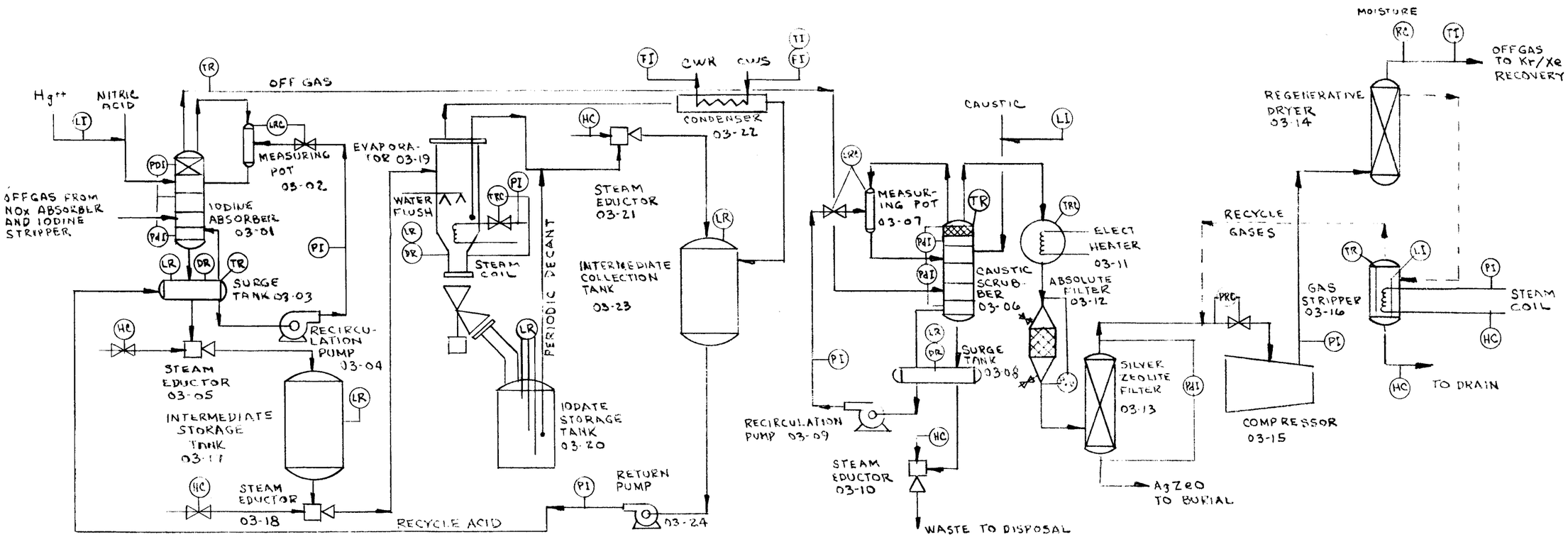


NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK

INSTRUMENTATION FOR HEAD END AND TRITIUM RECOVERY

DATE 6/20/73 BY DWG. NO. 3607-601-1

Fig. 10



NUCLEAR FUEL SERVICES, INC. WEST VALLEY, NEW YORK
INSTRUMENTATION FOR IODINE RECOVERY
DATE 6/21/73 BY JRH DWG. NO. 3607-603-1

Fig. 11

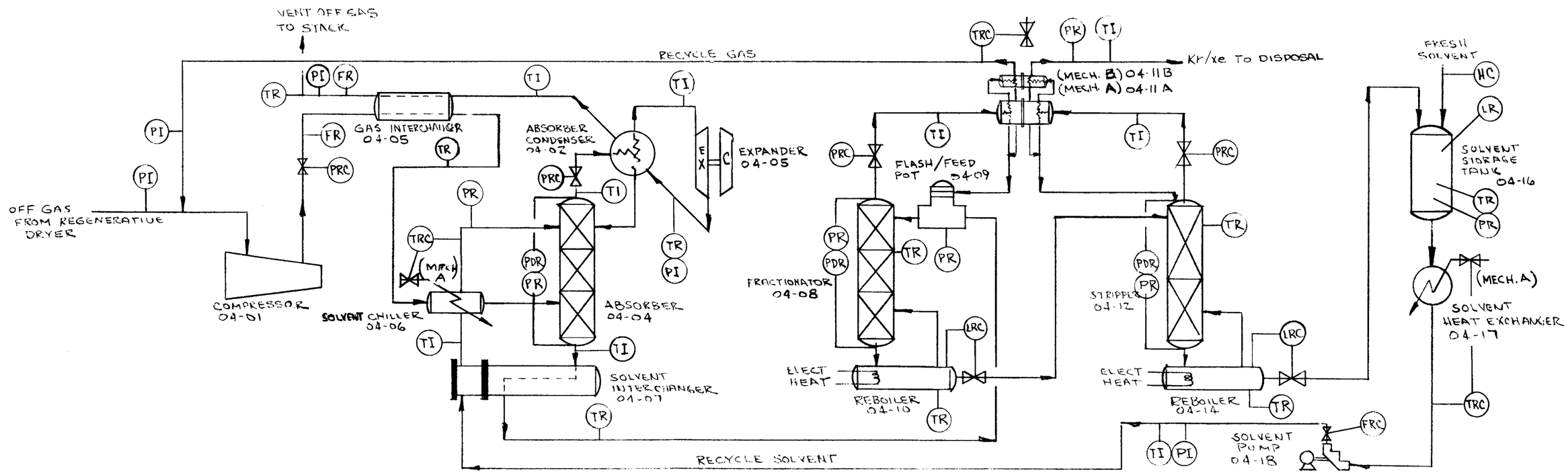

VENT OFF GAS TO STACK
RECYCLE GAS
Kr/Xe TO DISPOSAL
(MECH. B) 04-11B
(MECH. A) 04-11A
FRESH SOLVENT
OFF GAS FROM REGENERATIVE DRYER
COMPRESSOR 04-01
GAS INTERCHANGER 04-05
ABSORBER CONDENSER 04-02
EXPANDER 04-05
FLASH/FEED POT 04-09
SOLVENT STORAGE TANK 04-16
SOLVENT CHILLER 04-06
ABSORBER 04-04
FRACTIONATOR 04-08
STRIPPER 04-12
SOLVENT HEAT EXCHANGER 04-17
SOLVENT INTERCHANGER 04-07
ELECT HEAT
REBOILER 04-10
REBOILER 04-14
SOLVENT PUMP 04-18
RECYCLE SOLVENT
NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK
INSTRUMENTATION FOR KRYPTON/XENON RECOVERY
DATE 6/17/73
DWG. NO. 3607-004.1

Fig. 12

requirement for voloxidation, in order to release tritium from the pelletized fuel, necessitates major processing changes, a new head-end cell, and design changes in existing operating equipment.

The voloxidizer, located process-wise in front of the dissolver, discharges U_3O_8 powder mixed with cladding hulls as its product. The existing West Valley dissolvers are designed to operate on a batch basis with sheared fuel rods containing UO_2 pellets as the feed material. Introduction of U_3O_8 powder to these dissolvers is not compatible with either their mode of operation or their physical design; it would be impossible to control the rate of reaction and the subsequent pressure buildup. Because of this incompatibility, the use of a continuous dissolver will be a necessity. Such a dissolver has not been specified or costed as a part of this contract but it will constitute an integral part of the facility. Floor area and utility/service provisions for the continuous unit have been made.

Initially, the possibility of installing the voloxidizer in the General Purpose Cell (GPC) and the continuous dissolver in the Chemical Process Cell (CPC) was examined. The voloxidizer because of its length could not be situated in the GPC as it presently exists, but space could be made available by utilizing the adjacent minature cell area. Major modifications and alterations would be necessary under this scheme including decontamination of the extremely "hot" GPC, removal and disposition of existing equipment, and demolition of a three foot thick high density concrete cell wall. Location of a continuous dissolver in the CPC would require a major design and installation effort but few structural changes would be required. This work in the GPC and CPC plus the installation of

other new equipment in adjacent areas would necessarily shut down reprocessing plant operations for a time conservatively estimated at two years.

There are material handling problems associated with locating the voloxidizer in the GPC and the continuous dissolver in the CPC. Chopped fuel from the existing shear (which would have to be modified) in the Process Mechanical Cell (PMC) must drop downward through two interlocking seal mechanisms into the voloxidizer in the GPC below. U_3O_8 powder, and hulls if not separated for washing at this point, must exit the volox unit into some type of dual seal conveying device to be lifted into the CPC area above for dissolution. The design of these units and installation of them into a highly radioactive cell area would be extremely difficult.

In order to prevent a two-year loss of revenue from the reprocessing plant, the concept of a new head-end cell including voloxidation and dissolution was investigated. The construction of a new cell to house the required head-end equipment and the fission gas product retention systems could be accomplished without an extensive plant shutdown. Total plant down time might be held to three months during which time the various tie-ins and interconnections between the new and existing systems could be made.

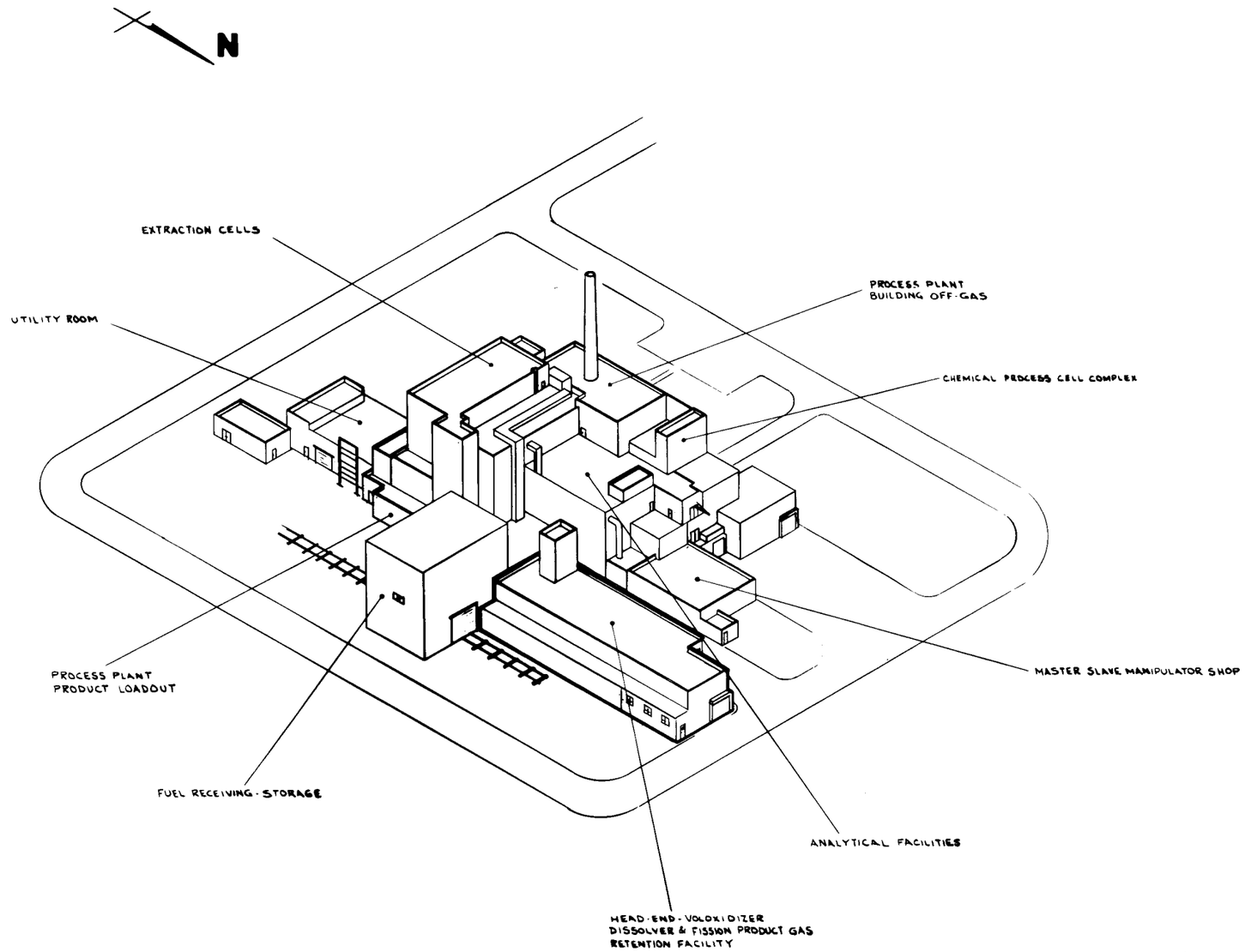
An estimated cost comparison was made between the two alternatives in order to determine which alternate would form the basis of the plant layout proposed by this study. Certain items of cost such as the tritium and krypton recovery equipment were equal under either of the alternatives. Otherwise, the cost evaluation became a fairly straightforward comparison of new cell cost versus the loss of revenue and modification costs associated with putting the equipment in the existing plant. Utilizing this approach it appeared

that construction of a new cell would be the cheaper route by several million dollars. Consequently, the new cell approach was adopted and forms the basis of the layouts and cost estimates to follow.

Physical location of the new facility relative to the existing plant was heavily influenced by the location of the existing Fuel Receiving and Storage (FRS) pool. The pool is used for storage of fuel assemblies, and the new head-end cell must be located such that those assemblies can be physically transferred into it from the FRS. Other considerations in locating the new cell included ease of removal of processed hulls and recovered fission gases, proximity to existing utilities and services, ability to inter-connect process lines, and minimal disturbance to existing auxiliary facilities.

The new cell was sited on the northeast corner of the plant adjoining the north side of the FRS as shown in perspective on Figure 13 (Dwg. No. 3607-200-1). Fuel assemblies can be transferred into the new cell from the FRS using an underground channel and mechanical extension device almost identical to the system now used to move fuel into the PMC. Installation of this unit in the FRS will require the rearrangement of fuel storage racks and the erection of a cofferdam where the north wall of the pool is breached (assuming the pool cannot be emptied because of fuel inventory).

From the designated cell location liquid waste lines can be piped to treatment facilities without undue hardship, ventilation and service lines can be inter-connected, dissolver solution can be routed to feed adjustment in the CPC, and the recovered tritium and krypton can be conveniently



NOTE:
CERTAIN AUXILIARY FACILITIES NOT SHOWN.

NO.	DATE	REVISIONS	BY	CH'K	APPR.	APPR.	APPR.
SCALE		DESIGNED		DRAWN			

NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK

PERSPECTIVE VIEW OF FISSION PRODUCT GAS RETENTION FACILITY

DRAWING NO. 3607-200-1 REV. NO.

PROJECT NO. SHEET 1 OF 1

Fig. 13

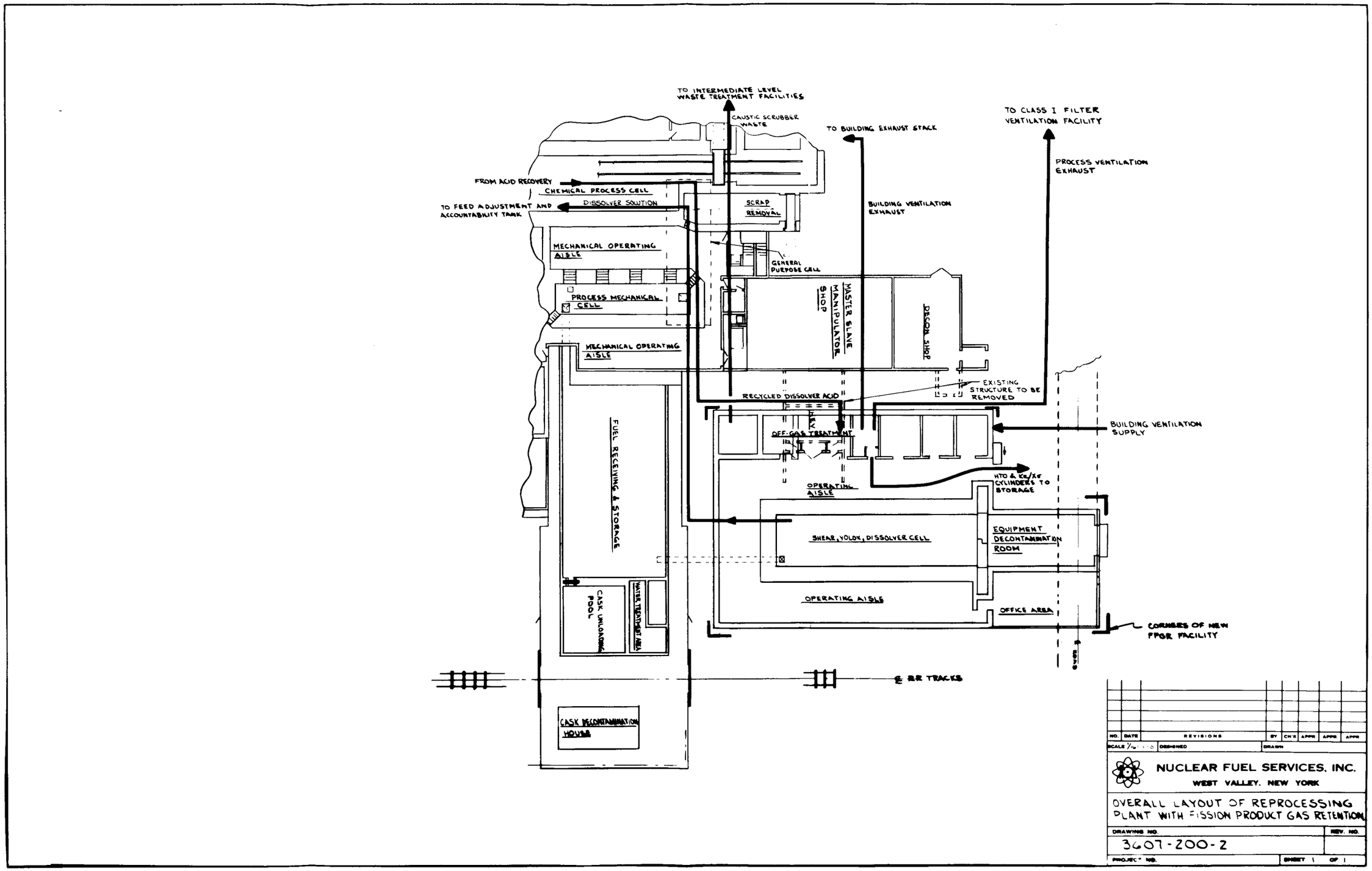
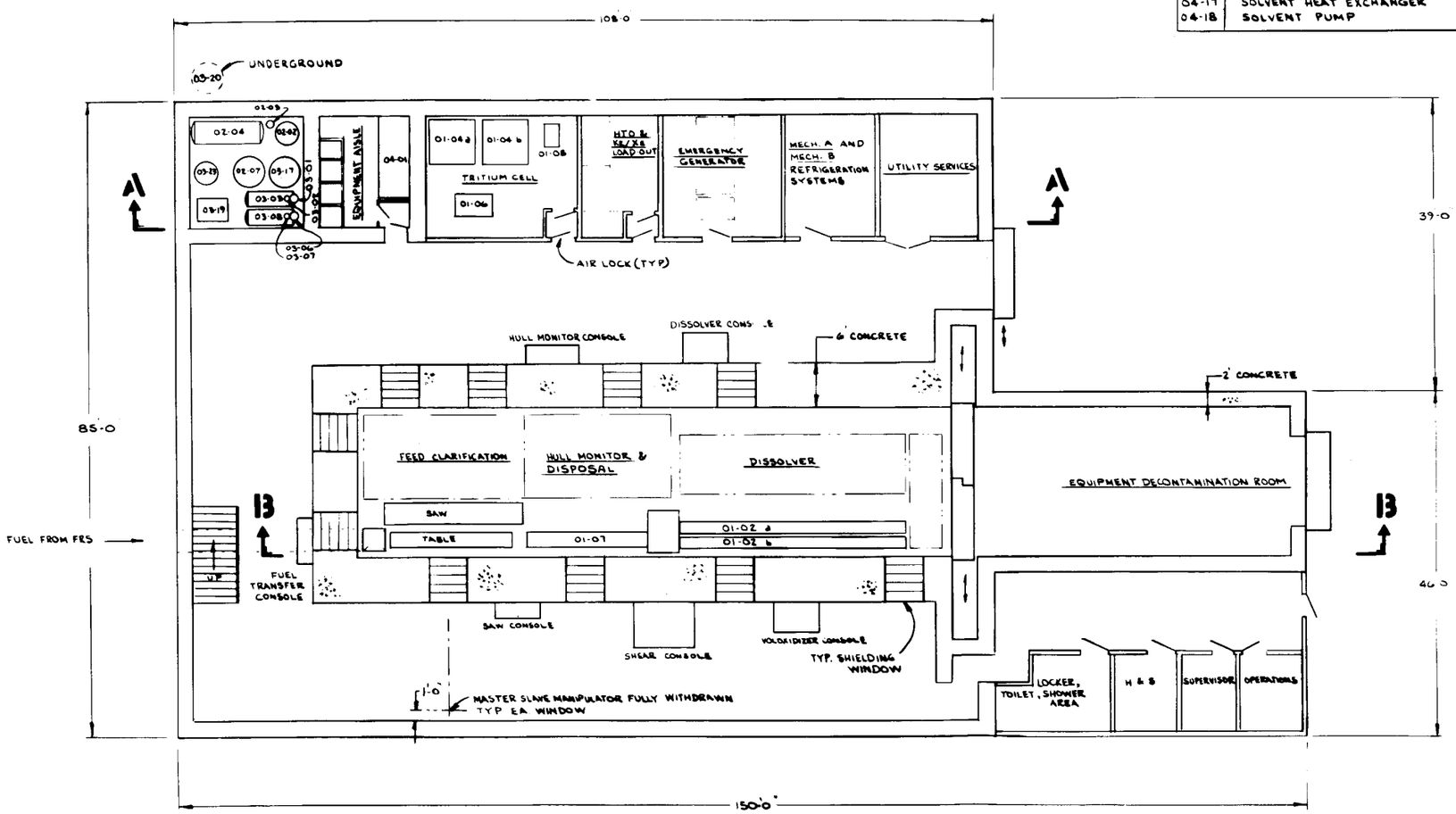

TO INTERMEDIATE LEVEL WASTE TREATMENT FACILITIES
CAUSTIC SCRUBBER WASTE
TO BUILDING EXHAUST STACK
TO CLASS I FILTER VENTILATION FACILITY
PROCESS VENTILATION EXHAUST
FROM ACID RECOVERY
CHEMICAL PROCESS CELL
TO FEED ADJUSTMENT AND ACCOUNTABILITY TANK
DISSOLVER SOLUTION
SCRAP REMOVAL
BUILDING VENTILATION EXHAUST
MECHANICAL OPERATING AISLE
GENERAL PURPOSE CELL
PROCESS MECHANICAL CELL
MASTER SLAVE MANIPULATOR SHOP
DESIGN SHOP
MECHANICAL OPERATING AISLE
EXISTING STRUCTURE TO BE REMOVED
RECYCLED DISSOLVER ACID
OFF-GAS TREATMENT
BUILDING VENTILATION SUPPLY
HTO & Kr/Xe CYLINDERS TO STORAGE
OPERATING AISLE
FUEL RECEIVING & STORAGE
SHEAR, VOLOX, DISSOLVER CELL
EQUIPMENT DECONTAMINATION ROOM
CASK UNLOADING POOL
WASTE TREATMENT AREA
OPERATING AISLE
OFFICE AREA
CORNERS OF NEW FPOR FACILITY
℄ RR TRACKS
CASK DECONTAMINATION HOUSE
NO. DATE REVISIONS BY CH'K APPR APPR APPR
SCALE DESIGNED DRAWN
NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK
OVERALL LAYOUT OF REPROCESSING PLANT WITH FISSION PRODUCT GAS RETENTION
DRAWING NO. REV. NO.
3607-200-2
PROJECT NO. SHEET 1 OF 1

Fig. 14

EQUIPMENT LISTING

ITEM NO.	DESCRIPTION
04-01	COMPRESSOR
04-02	ABSORBER CONDENSER
04-03	GAS INTERCHANGER
04-04	ABSORBER
04-05	EXPANDER
04-06	SOLVENT CHILLER
04-07	SOLVENT INTERCHANGER
04-08	FRACTIONATOR
04-09	FLASH/FEED POT
04-10	REBOILER
04-11	CONDENSER
04-12	STRIPPER
04-14	REBOILER
04-16	SOLVENT STORAGE TANK
04-17	SOLVENT HEAT EXCHANGER
04-18	SOLVENT PUMP

ITEM NO.	DESCRIPTION
01-01	HYDROGEN RECOMBINER
01-02	VOLOXIDIZER
01-03	OFF GAS COOLER
01-04a	REGENERATIVE DRYER
01-04b	REGENERATIVE DRYER
01-05	MOLECULAR SIEVE DRYER
01-06	COMPRESSOR
01-07	SHEAR
02-01	EXPANSION VALVE
02-02	NO_x ABSORBER
02-03	MEASURING POT
02-04	SURGE TANK
02-05	RECIRCULATION PUMP
02-06	STEAM EDUCTOR
02-07	IODINE STRIPPER
02-08	STEAM EDUCTOR
03-01	IODINE ABSORBER
03-02	MEASURING POT
03-03	SURGE TANK
03-04	RECIRCULATION PUMP
03-05	STEAM EDUCTOR
03-06	CAUSTIC SCRUBBER
03-07	MEASURING POT
03-08	SURGE TANK
03-09	RECIRCULATION PUMP
03-10	STEAM EDUCTOR
03-11	HEATER
03-12a	ABSOLUTE FILTER
03-12b	ABSOLUTE FILTER
03-13	ZEOLITE FILTER
03-14	REGENERATIVE DRYER
03-15	COMPRESSOR
03-16	GAS STRIPPER
03-17	INTERMEDIATE STORAGE TANK
03-18	STEAM EDUCTOR
03-19	EVAPORATOR
03-20	IODATE STORAGE TANK
03-21	STEAM EDUCTOR
03-22	CONDENSER
03-23	INTERMEDIATE COLLECTION TANK
03-24	RETURN PUMP



FIRST FLOOR PLAN
ELEVATION 100'-0"

NO.	DATE	REVISIONS	BY	CH'K	APPR.	APPR.	APPR.

SCALE 1/8" = 1'-0 | DESIGNED | DRAWN

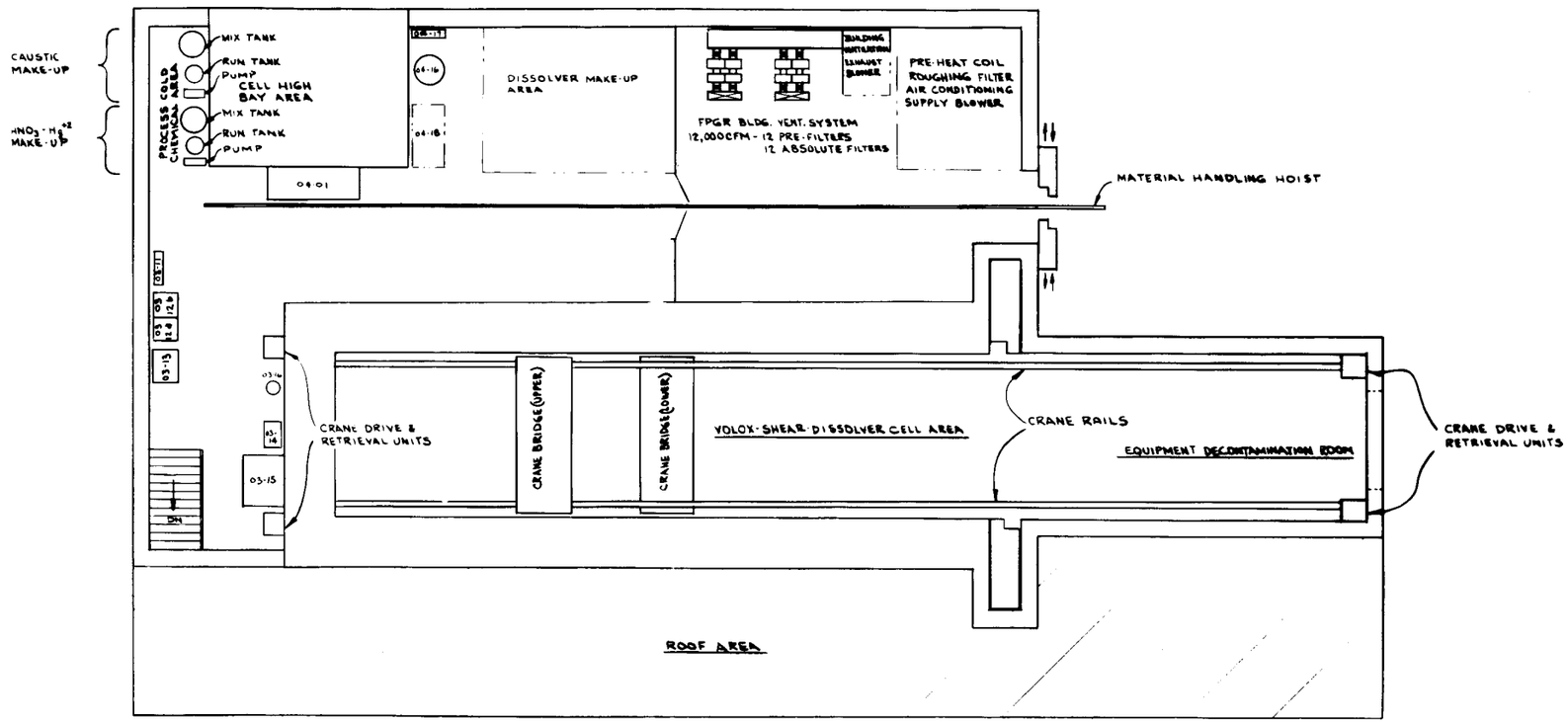
NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK

BUILDING LAYOUT FISSION PRODUCT GAS RETENTION FACILITY (FIRST FLOOR PLAN VIEW)

DRAWING NO. 3607-200-3 | REV. NO.

PROJECT NO. | SHEET 1 OF 3

Fig. 15



2ND FLOOR PLAN
EL. 112'-0"

NOTE:
SEE DRAWING 3607-200-3 SHEET 1 FOR EQUIPMENT DESIGNATIONS.

NO.	DATE	REVISIONS	BY	CH'K	APPR.	APPR.	APPR.

SCALE 1/8"=1'-0" DESIGNED DRAWN

NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK

BUILDING LAYOUT FISSION PRODUCT GAS RETENTION FACILITY (SECOND FLOOR PLAN VIEW)

DRAWING NO. 3607-200-3 REV. NO.

PROJECT NO. SHEET 2 OF 3

Fig. 16

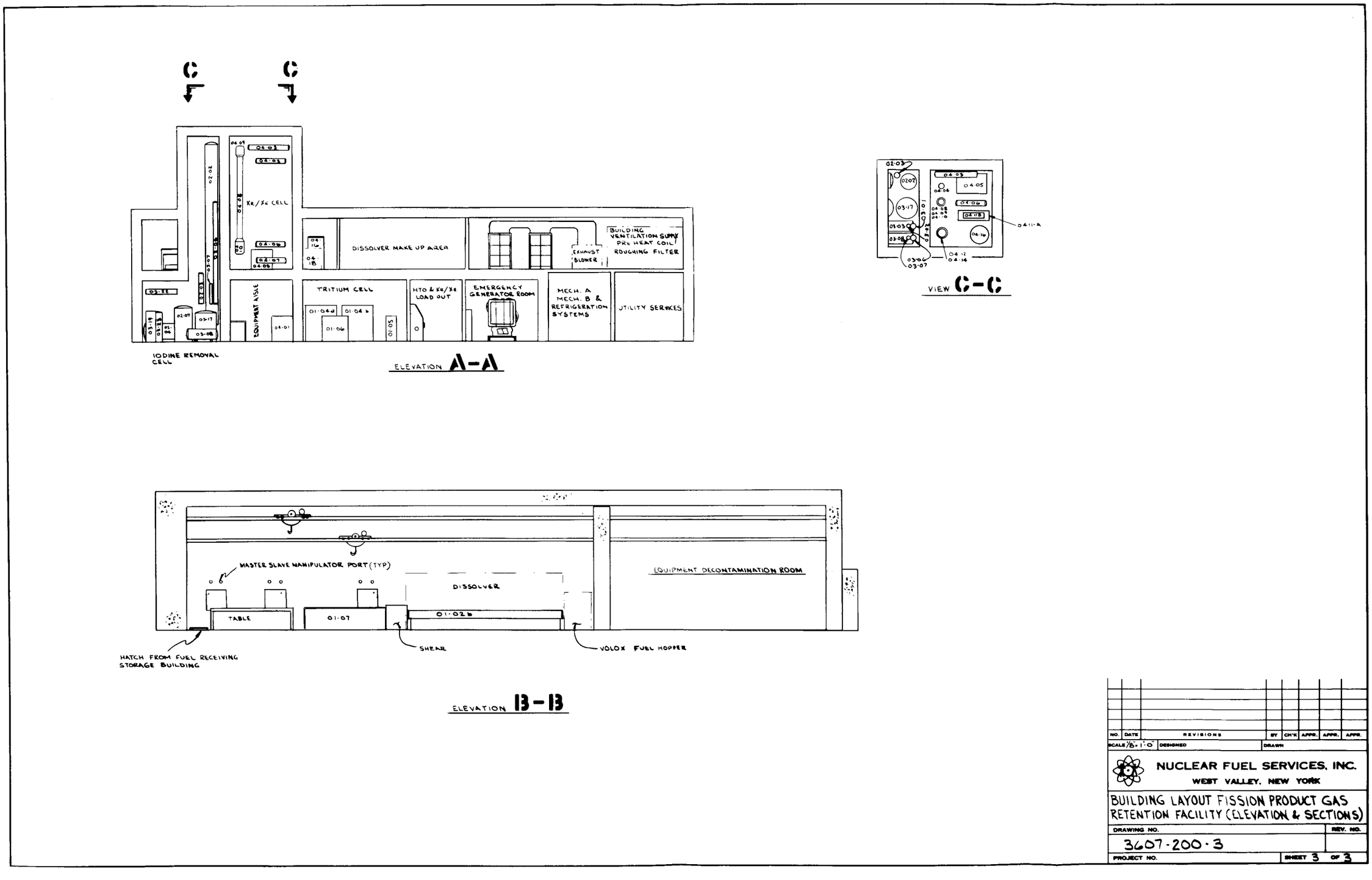

C
C
Kr/Xe CELL
DISSOLVER MAKE UP AREA
BUILDING VENTILATION SUPPLY PRE HEAT COIL
ROUGHING FILTER
EXHAUST BLOWER
TRITIUM CELL
HTO & Kr/Xe LOAD OUT
EMERGENCY GENERATOR ROOM
MECH. A MECH. B & REFRIGERATION SYSTEMS
UTILITY SERVICES
EQUIPMENT AISLE
IODINE REMOVAL CELL
ELEVATION A-A
VIEW C-C
MASTER SLAVE MANIPULATOR PORT (TYP)
DISSOLVER
EQUIPMENT DECONTAMINATION ROOM
TABLE
SHEAR
VOLOX FUEL HOPPER
HATCH FROM FUEL RECEIVING STORAGE BUILDING
ELEVATION B-B
NO. DATE REVISIONS BY CH'K APPR. APPR. APPR.
SCALE 1/8" = 1'-0" DESIGNED DRAWN
NUCLEAR FUEL SERVICES, INC.
WEST VALLEY, NEW YORK
BUILDING LAYOUT FISSION PRODUCT GAS RETENTION FACILITY (ELEVATION & SECTIONS)
DRAWING NO. REV. NO.
3607-200-3
PROJECT NO. SHEET 3 OF 3

Fig. 17

removed. The schematic routings of these various streams can be seen in Figure 14 (Dwg. No. 3607-200-2). This drawing also shows in some detail the relationship of the new facility to the north end of the reprocessing plant.

Internal partitioning and equipment arrangement were made consistent with proven operational concepts at the West Valley plant. Floor plan layouts of the two-story building showing the numbered process equipment and most of the auxiliary equipment are included as Figures 15 and 16 (Dwg. No. 3607-200-3, Sheets 1 and 2). Selected building elevations and sections are shown in Figure 17 (Dwg. No. 3607-200-3, Sheet 3). Virtually the entire processing area has been placed inside Class I containment; only certain office and service areas do not share this two foot thick concrete protection. The head-end cell is surrounded by six feet of concrete for radiation protection.

Major equipment located inside the head-end cell includes the shear, voloxidizer, and an optional saw which could be necessary depending on exact voloxidizer feed requirements. A new shear has been included since it is impractical to relocate the one now in the PMC (it would still require modification). Some of the control and drive components of the existing shear would be usable, however, as a part of the console located in the operating aisle. Space has been included for the dissolver, hull monitoring and disposal equipment, and feed clarification equipment; none of which were studied as a part of this contract. The cell is equipped with the required support elements such as viewing windows, manipulators, and cranes.

A 2'-3' sliding and interlocking concrete door separates the cell from the Equipment Decontamination/Crane Room (EDR). This area will be used for crane and processing equipment repair and maintenance. It will house a decontamination station for use on equipment prior to maintenance or removal.

Aisles in the facility are adequate to allow personnel movement around the equipment control consoles as well as to allow retraction of the slave manipulators. A small office and service area is planned alongside the EDR but outside of the Class I structure.

The tritium, iodine, and krypton removal areas are grouped in the southwest corner of the building and separated from the head-end cell; where necessary, radiation shielding has been provided. The columns for all three systems are housed in a compact high-bay area shown in views "A-A" and "C-C" on Figure 17. Process pumps are grouped in a common "pump niche" arrangement. A process cold chemical area sets above the first floor tritium and iodine recovery equipment. The underground iodate storage tank is located off the southwest corner of the building. Tritium (as HTO) and compressed krypton/xenon gas are loaded out in a partitioned room close to the collection equipment.

Utility and service equipment occupies the northwest corner of the building. These include the emergency diesel generator, the two refrigeration systems for krypton/xenon recovery, and the building ventilation supply and exhaust systems.

COST ESTIMATE

The total cost of the Fission Product Gas Retention Facility is estimated at $16,900,000 including engineering, indirect charges, and contingency. The figure does not include, however, the cost of items considered to be outside the scope of this contract in terms of concept and cost estimation; ie., a continuous dissolver, hull removal and handling equipment, post-dissolution feed clarification equipment, and tritium/krypton storage facilities. Physical space for all but the latter is included in the proposed building. The facility cost estimate summary is shown in Table 3.

The estimating method used is a variation of the "Type M" described originally by Chilton[15] and Lang[16] and more recently summarized by Nichols[17] and Vilbrandt[18]. As described, the method has an average accuracy of +15 to -30 percent and would normally carry a contingency of 30 to 35 percent. It is believed that the following estimate may be somewhat more accurate than that due to the use of calculated building, instrumentation, auxiliary equipment, and engineering costs rather than estimation of these costs via a percentage multiplier. Consequently, a 20 percent contingency figure has been used in this estimate.

---

[15] C. H. Chilton, Chemical Engineering, 56(6): 97 (1949)

[16] H. J. Lang, Chemical Engineering, 54(10): 118 (1947)

[17] W. T. Nichols, Chemical Engineering, 58(6): 248 (1951)

[18] F. C. Vilbrandt and C. E. Dryden, Chemical Engineering Plant Design, 4th Ed., pp 192-194 (1959)

TABLE 3

COST ESTIMATE SUMMARY--FISSION PRODUCT
GAS RETENTION FACILITY

I	Delivered Equipment (Table 2):	$ 1,620,000
II	Installation (43% of I):	700,000
III	Process Piping (60% of I + II):	1,390,000
IV	Instrumentation (Table 4):	330,000
V	Buildings and Support Equipment (Table 5):	4,015,000
VI	Existing Plant Modifications (Table 6):	415,000
VII	Auxiliary Equipment and Services (Table 7):	900,000
VIII	Total Physical Plant Cost:	$ 9,370,000
IX	Indirect Costs (31% of VIII):	2,900,000
X	Engineering Services (Table 8):	1,050,000
	Sub-Total:	$13,320,000
XI	Contractor's Fee (3% of Sub-Total):	400,000
XII	NFS Engineering (Table 8):	360,000
	Total:	$14,080,000
XIII	Contingency (20% of Total):	2,820,000
	GRAND TOTAL:	$16,900,000

Estimated cost figures have been derived both from vendor-quoted prices and from engineering estimates based to a large degree on NFS' experience at the West Valley reprocessing plant. The following paragraphs describe the individual cost elements and the way in which the costs were estimated.

The delivered equipment cost of $1,620,000 is itemized in Table 2 in the previous section of this report. This figure is the estimated delivered cost, including freight and taxes, of all numbered process equipment. It does not include certain items of un-numbered process equipment listed elsewhere, and it does not include building support or auxiliary equipment which are also listed in their respective accounts. The account is further broken down to show the estimated purchase price of the head end and tritium recovery equipment to be $1,280,000; the iodine recovery equipment to be $130,000; and the krypton recovery equipment to be $130,000.

Direct equipment installation charges of $700,000 were calculated as 43 percent of the delivered equipment cost. Piping costs, in turn, were figured at 60 percent of the installed equipment cost (delivered equipment plus installation). The percentage multipliers above are consistent with the "Type M" method and with NFS' construction experience.

The total installed direct instrumentation cost is shown in Table 4 as $330,000. This figure represents instruments, installation materials, and labor costs for a nominally instrumented facility. Unit costs for instruments were based on published 1972 prices by a major instrumentation manufacturer; labor costs were estimated at $12 per man-hour. The

TABLE 4

PROCESS INSTRUMENT LISTING AND COST ESTIMATE

FISSION PRODUCT GAS RETENTION STUDY

AREA	TEMPERATURE					PRESSURE						FLOW				LEVEL					DENSITY		MOISTURE		HAND CONTROL	CONTROL VALVE
	TE	TT	TI	TR	TRC	PT	DPT	PI	DPI	PR	PRC	FT	FI	FR	FRC	LS	LE	LI	LR	LRC	DE	DR	XE	XRC	HC	CV
Head End and Tritium Recovery	16	16	8 (2)	3 (1)	5	7	3	4 (1)	3 (1)	- (-)	3	10	3 (1)	- (-)	7	-	3	- (-)	2 (1)	1	2	2 (1)	3	3	3	12
Iodine Recovery	9	9	3 (1)	4 (1)	2	8	5	6 (2)	5 (2)	1 (1)	1	1	1 (1)	- (-)	-	3	8	3 (1)	6 (2)	2	3	3 (1)	1	1	6	10
Krypton & Xenon Recovery	22	22	9 (3)	10 (3)	3	16	3	5 (2)	- (-)	10 (3)	4	3	- (-)	2 (1)	1	-	3	- (-)	1 (1)	2	-	- (-)	-	-	1	11
Total Number	47	47	(6)	(5)	10	31	11	(5)	(3)	(4)	8	14	(2)	(1)	8	3	14	(1)	(4)	5	5	(2)	4	4	10	33
Unit Cost, $: Instrument	30	250	850	1600	1500	500	650	850	850	1600	1500	775	850	1600	1500	200	1200	850	1600	1500	200	1600	1500	1500	400	300
Materials	47 loops @ 100					42 loops @ 100						14 loops @ 100				17 loops @ 100					5 loops @ 100		4 loops @ 150		150	50
Install. Labor	47 loops @ 600					42 loops @ 600						14 loops @ 720				17 loops @ 720					5 loops @ 720		4 loops @ 960		480	480
Panel Board	11 feet @ 800					10 feet @ 800						6 feet @ 800				5 feet @ 800					1 foot @ 800		2 feet @ 800		400	-
Total Cost:	$82,960					$85,250						$42,430				$50,090					$9,100		$18,040		$14,300	$27,390

GRAND TOTAL INSTRUMENTATION COST: $330,000

Notes: (a) Numbers in parentheses denote multi-point instruments.
(b) Labor costs calculated at $12 per hour.
(c) Panel Board costs @ $800 per linear foot - 2 instruments/foot.
(d) Above estimates are direct installed costs.

summary has been taken from Figures 10, 11, and 12 in Section V and shows primary elements or switches, transmitters, indicators, recorders, controllers, hand controls, and control valves. All instruments will be panel mounted either in the new facility, or, for some of the critical parameters, in the main reprocessing plant control room.

Building construction and building support equipment have been combined into a single cost element and are presented in Table 5. Recent experience at West Valley has shown that the total in-place building cost (including foundation, structural steel, roof, etc.) for Class I concrete structures is approximately $500 per cubic yard of concrete poured. Non Class I structures were estimated at $25 per square foot of floor space. The support equipment cost was estimated on an individual unit basis and includes installation costs.

Prior to the start of construction of the new facility, certain existing plant structures or features must be demolished, removed, or relocated. During and after construction there are numerous tie-ins and inter-connections to be made between the new and old facilities. All of these existing plant modifications are listed and costed in Table 6. Again, the estimated costs shown are the total direct charges; they include both materials and labor.

The auxiliary equipment and services required to operate the new facility are listed separately in Table 7. At least two service requirements, compressed air and steam, can probably be fulfilled using existing capabilities. The others have been estimated on an individual basis as total direct installed costs. Table 7 also includes nine items of

TABLE 5

BUILDING AND SUPPORT EQUIPMENT LISTING AND COST ESTIMATE

I	Building Construction	
	Class I Section and Cell Area Including Foundation, Structural Steel, Roof, and Wall Penetrations - Direct Cost Calculated on Basis of 5500 cubic yards of Concrete at $500/Yd.^{3}:	$2,750,000
	Offices, Utility Space, and Other Non-Class I Areas - Direct Cost Calculated on Basis of 3500 square feet of Floor Area at $25/Ft.^{2}:	87,500
	Building Cost Sub-Total:	$2,837,500
II	Building Support Equipment	
	Materials Handling -	
	Hot Cell/Cranes, Two Required:	$ 150,000
	Maintenance/Decon Area Crane:	50,000
	Hoist to Second Floor:	5,000
	Hoist on Second Floor:	5,000
	Fuel Assembly Transfer Mechanism (From FRS):	20,000
	Transport Vehicle for Casks and Discarded Equipment:	10,500
	Cell Manipulators -	
	Power Assist Manipulator for Hot Cell:	100,000
	Manual Manipulators, 20 Required:	300,000
	Hardware -	
	Hot Cell Windows, 10 Required:	300,000
	Hot Cell Door Mechanism:	90,000
	Transfer Hatch for Fuel Assemblies into Hot Cell:	50,000

II (Continued)

Miscellaneous -

Decontamination Facility in Maintenance/Decon Area:	$ 80,000
Stack Sampler and Monitor:	15,000
Support Equipment Cost Sub-Total:	$1,175,500

GRAND TOTAL OF BUILDING AND SUPPORT EQUIPMENTS COSTS:	$4,015,000

TABLE 6

EXISTING PLANT MODIFICATION LISTING AND COST ESTIMATE

I	Relocations and/or Demolition	
	Relocate Waste Lines, North End of FRS:	$ 20,000
	Relocate Fire Lines:	15,000
	Relocate Roadway:	10,000
	Relocate Underground Electrical Cables:	10,000
	Demolish Old Head-End Vent Building:	10,000
	Relocation and/or Demolition Sub-Total:	$ 65,000
II	Tie-Ins Between Existing and New Facilities	
	Broaching of North Wall of FRS Basin to Accommodate Fuel Transfer Device and Removal of Fuel Racks in FRS:	$ 50,000
	Extension of Utility Lines (Steam, Compressed Air, Water, Etc.) to New Area:	15,000
	Connection of Instrumentation and Alarms to Existing Control Room as Required:	30,000
	Dissolution Liquor to Accountability and Feed Adjustment Tank:	30,000
	Recycle Acid from 01/14 Area to New Acid Mix Tank Area:	20,000
	Connection to Existing HNO_3 and NaOH Systems:	15,000
	Connection of Sample Transport System to Existing Hot Lab:	40,000
	Connect Vessels to Existing VOG System:	20,000
	Final Off-Gas from F.P.G.R. Area to Existing Stack:	30,000

II (Continued)

Building and Cell Ventilation Class I Tie-In To Existing Vent System and Stack:	$ 75,000
Tie-In of Floor Drains and Low Level Waste Lines:	10,000
Tie-In of Intermediate Level Waste Lines:	15,000
Tie-Ins Sub-Total:	$350,000
GRAND TOTAL OF EXISTING PLANT MODIFICATION COST:	$415,000

Table 7

AUXILIARY EQUIPMENT AND SERVICES LISTING AND COST ESTIMATE

I	Un-numbered Process Equipment	
	Bottled Gas Stations (Oxygen, Nitrogen, Argon, NO_2 and Refrigerant-12):	$ 10,000
	Nitric Acid Feed System to Dissolver (includes Makeup and Feed Tanks):	45,000
	Recycle (Hot) Nitric Acid Feed Pump:	5,000
	Mercuric Nitrate and Sodium Hydroxide Makup Systems (Tanks and Pumps):	20,000
	Macroreticular Resin Filter (Trace Iodine Removal From Condensate and Liquid Stream):	15,000
	Tritiated Water Loadout Station:	12,000
	Krypton/Xenon Bottling Compressor and Storage Tank:	20,000
	Krypton/Xenon Loadout Station and Transfer Mechanism:	15,000
	Process Sample Room and Transport System:	30,000
	Un-numbered Process Equipment Cost Sub-Total:	$172,000
II	Utility and Service Equipment	
	Electrical	
	Transformer (1000 KVA; 13.8 KV/480V) Including substation installation:	$ 33,500
	Modifications to Existing Switchgear and Feeder Station Including Disconnect, Fuses, etc.:	36,500
	Distribution to New Facility:	16,000
	Motor Control Center:	5,000
	Lighting Breakers and Controls:	2,000
	Emergency Diesel Generator and Switchgear (150KW):	40,000
	Interior Distribution, Connections, and Local Disconnects:	100,000

II (Continued)

Heating and Ventilating -	
Steam Boiler (For Building Heating and Minimal Process Requirements):	Existing
Ventilation Supply System Including Filters, Heaters, Etc.:	$ 20,000
Building Exhaust System Including Fans, HEPA Filters, Dampers, Etc.:	100,000
Building Ventilation System Including Ducting, Louvers, Pressure Differential Controls	80,000
Cooling -	
Evaporative Cooling Tower, Class I Construction, About 150 GPM:	45,000
Refrigeration System - Mech. "A" (-40°F), Dual 40-Ton Units:	160,000
Refrigeration System - Mech. "B" (-100°F), Single 3-Ton Unit:	40,000
Insulation, Kr/Xe Recovery	20,000
Compressed Air -	
Compressor (For Process, Instrument, and Breathing Air):	Existing
Instrument Air Supply, Class I Construction:	5,000
Hydraulic -	
Central System for Shear, Rams, Motors, Etc.:	20,000
Fire Control -	
Dry Chemical System:	10,000
Utility and Service Equipment Cost Sub-Total:	$733,000
GRAND TOTAL OF AUXILIARY EQUIPMENT AND SERVICES COST:	$900,000

NOTE: Above estimates are direct installed costs.

"un-numbered" process equipment necessary for operation of the Fission Product Gas Retention facility. These items, while integral and important to the process, did not lend themselves to inclusion in the numbered equipment flowsheets so they are herein listed, described, and costed (direct installed) separately.

Indirect charges are estimated at 31 percent of the total physical plant cost of $9,370,000. This percentage has been derived from a recently completed major construction project at West Valley.

Required engineering services have been divided into two categories: those acquired on a sub-contract basis and those supplied by NFS personnel. Table 8 shows a breakdown of each major engineering task into these categories. Man years of work have been estimated and dollar extensions made based on $30,000/man year for outside engineering services and $21,000/man year for NFS in-house engineering.

A three percent contractor's fee has been added onto the physical plant, indirect, and outside engineering service costs to represent the minimum typical fee charged by an Architect/Engineer/Contractor.

The total estimated cost then becomes $14,080,000 to which a 20 percent contingency is added for the grand total of $16,900,000. Of this total, approximately 55% ($9,370,000) are direct charges and 45% ($7,530,000) are indirects, engineering, and contingency.

Costs presented in this estimate should be considered as 1972 unescalated dollars and no attempt has been made to compensate for escalation. In no case should the contingency dollars be considered as an escalation fund.

TABLE 8

ENGINEERING REQUIREMENTS AND COST ESTIMATE

PHASE	ENGINEERING SERVICES MAN-YEARS	ENGINEERING SERVICES $	NFS ENGINEERING MAN-YEARS	NFS ENGINEERING $
Process and Equipment Design and Development	2.0	60,000	2.0	42,000
Preparation of Licensing and Regulatory Requirements	1.0	30,000	2.0	42,000
Architect/Engineer/Contractor Engineering Services	24.0	720,000	6.0	126,000
Specification and Procurement	2.5	75,000	1.5	31,500
Field Construction	5.0	150,000	2.5	52,500
Pre-Operational Check-Out	0.5	15,000	3.0	63,000
GRAND TOTAL ENGINEERING REQUIREMENTS:	31.0	$1,050,000	17.0	$360,000

Note: Above estimates based on $30,000/man-year for A&E engineering and $21,000/man-year for NFS engineering. A&E figures include overhead and fee.

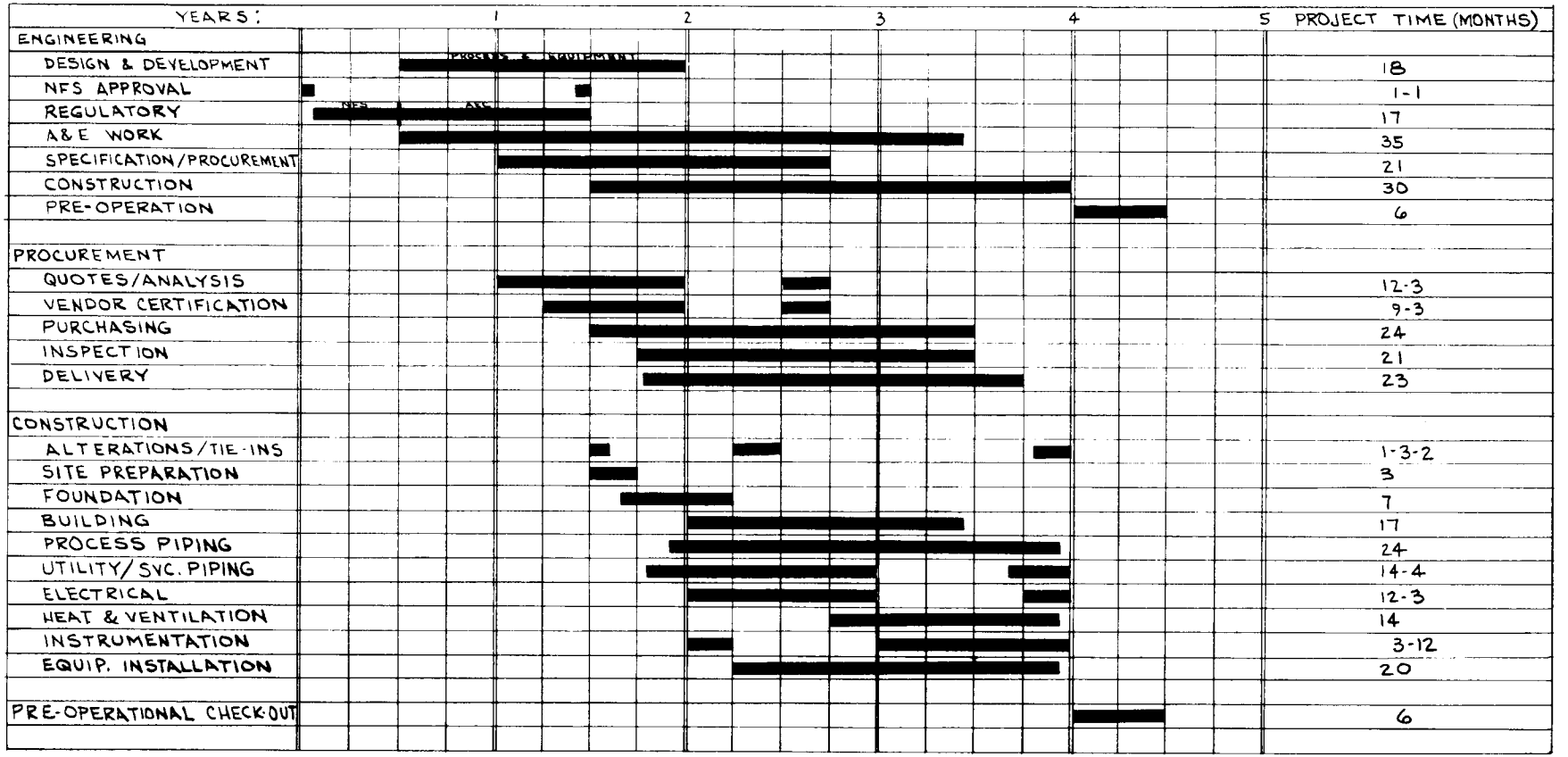
OVERALL SCHEDULE

The overall project schedule presented in Figure 18 shows the total time interval required for an operational facility to be 4.5 years. Even so, the schedule starting point would be preceded by NFS project approval and certain work required to meet the licensing requirements under Federal Code Title 10, Chapter 50. Assuming that an amendment of the existing operating license and the issuance of a construction permit as defined in Section 50.91 would be required, a one-half year schedule period was allowed for the preparation of the necessary regulatory documentation. The submission of the required paper work to the USAEC would be followed by an 18 month design and development period undertaken by NFS and the selected Architect/Engineer (A&E). Concurrent liaison work with the Commission would be necessary to assure a reasonable date for issuance of the construction permit. Also concurrently, engineering effort on specifications and construction, bid solicitation, and vendor certification could be accomplished.

Upon receipt of the construction permit, physical construction requiring some 2.5 years would be undertaken. This 30-month period encompasses building construction, equipment installation, and the required modifications and physical tie-ins to the existing reprocessing plant. The final schedule period of six months is allocated to pre-operational checkout and cold start up of the facility.

OVERALL PROJECT SCHEDULE

FISSION PRODUCT GAS RETENTION - U.C.C 3607



NOTE:
NFS PROJECT APPROVAL AND NFS PREPARATION OF S.A.R. AND ENVIRONMENTAL REPORT REQUIRED PRIOR TO START OF THIS SCHEDULE.

FIGURE 18

NUCLEAR FUEL SERVICES INC.
WEST VALLEY N.Y.
JUNE 21, 1973 JRH

Fig. 18

SAFETY ANALYSIS

There are two pertinent sections of the Federal Code Title 10, Chapter 50 that apply to the licensing of the new facilities required by this study: Sections 50.59 and 50.91.

Section 50.59 concerns authorizations of changes, tests and experiments. This section authorizes changes in a licensed facility which do not constitute a major alteration of the facility, provided that any changes involving a change in technical specifications, or an unreviewed safety question, are authorized by the Commission. The Commission has taken the position that where approval is required, construction or modification of a facility may not be begun prior to receipt of the necessary approval, and that such approval will be given only after the cafeful review of a Safety Analysis Report. When the Commission determines that the proposed change presents hazard considerations not described in the original safety analysis report for the facility, it may refer the request for a change to the Advisory Committee on Reactor Safeguards. Since voloxidation and krypton recovery have not been previously described nor reviewed, the latter route would appear to be required under Section 50.59

The possibility exists however, that the Commission might hold that the addition of voloxidation and krypton recovery constitutes a material alteration of the facility and thus require the amendment of the license and the issuance of a construction permit as set forth in Section 50.91.

Under either procedure, however, the licensing of these facilities will be a lengthy proceeding and must entirely precede the start of construction. Thus a long lead time for the installation of tritium and krypton recovery must be included in any realistic schedule.

The modifications required to improve the containment factor for iodine do not appear to involve new and/or unreviewed safety questions, and as such can probably be licensed under Section 50.59 without ACRS review.

The following discussion of safety related questions is not intended to meet the requirements of Sections 50.33 and 50.34, Content of Applications, but rather is intended to call attention to the major problem areas where significant safety questions may be expected.

Normal Operation

Under normal operating conditions the principal safety questions concern the avoidance of criticality, minimizing radiation exposure to the public and to operating personnel, the adequate performance of effluent control systems, and resisting the effects of natural phenomena.

Natural Phenomena -- The requirement for withstanding the effects of natural phenomena are set forth in Criterion 2 of Appendix A, 10CFR50. The two phenomena of major concern at West Valley are earthquakes and tornadoes since the plant is located far above the nearest stream and flooding, hurricanes and seiches will have little, if any, effect on the plant.

West Valley lies in an area where a modest number of rather minor earthquakes have been experienced, most of them centered near Attica,

some 30 miles northeast of the site. Detailed studies of the geology of the area have resulted in the selection of 6% of gravity for the ground acceleration of an earthquake that might be experienced within the useful life of the plant, and 12% of gravity for the ground acceleration of the maximum earthquake that might be experienced at the site. Appropriate response spectra for the two accelerations have been derived and are the starting point for the aseismic design of the structures, systems and components important to safety. Safety Guide 29 lists those portions of a nuclear reactor that must be designed to remain functional in order to permit the safe shut down of the facility following the maximum earthquake. These structures, systems and components are termed Class I.

Virtually all of the structures and systems required for this study are highly safety related and therefore must be designed to Class I standards.

In addition to the earthquake, Class I structures and systems must also remain functional after a direct strike by a design basis tornado. The criteria for a design basis tornado have not been clearly defined at this time although the Commission has used a combination of 300 mph rotational velocity and 60 mph translational velocity in evaluating some reactions. Studies by competent meteorologists at Hanford and at Idaho have resulted in lower recommended design velocities for those sites.

NFS commissioned a study by Dames and Moore that resulted in a recommendation of 170 mph rotational and 30 mph translational velocities for West Valley. These velocities have been submitted for approval, however, at this time no action has been taken by the Commission.

Various studies of the effects on structures of earthquakes and tornadoes have shown that of the two, the tornado wind pressure and missile penetration is usually controlling in the design of facilities. These studies have shown that 24 inches of concrete will not be penetrated by the maximum velocity missile in a 300 mph tornado--the missile being a 4"x12"x10 foot plank weighing about 90 lbs. A lesser thickness of about 16 inches can be used if the lower velocities are approved.

The design of the cell structure for the facility is shown in Figure [15] showing the plan view. It will be noted that all safety related equipment is located behind a 2-foot thick concrete wall. This wall is primarily to provide missile protection, however, in the equipment area it also provides shielding from radiation. There are no window openings in the outer barrier and the doors are designed to either withstand the missile or are set behind offset walls which will prevent the entry of a missile into the operating aisles. The reinforcing steel and footings will be designed to withstand the earthquake and the overturning movement resulting from the tornado wind pressure. The only major piece of equipment outside barrier will be a cooling tower or an evaporative cooler which can take a strike by a missile and remain at least partially functional to permit a safe shut down. Repair of the cooling tower can be expected in a relatively short time in order to bring the unit back on stream. The central cell is surrounded by 6-feet of concrete for biological shielding.

Criticality -- There are only three areas in the new system where criticality could occur: The shear, the voloxidizer, and the dissolver.

None of the remaining areas contain significant amounts of fissile material.

The shear presents only a minor criticality problem since only a single fuel element is handled at a time. Sheared fuel will be discharged to the voloxidizer through a chute and seal arrangement that will be designed to be safe because of geometry. This requires that the diameter of the chute and seal arrangement be within safe limits for the maximum unirradiated fuel enrichment to be processed. It is expected that a 10-inch diameter can be used and that criticality cannot occur under conditions of full reflection and moderation. Unsheared fuel, of course, will retain the geometry of the fuel element which will have previously been shown to be sub-critical.

The voloxidizer will also be designed to avoid criticality by safe geometry. Since the voloxidizer will be a rotating kiln operating at about 450°C, it will be relatively simple to show that the system is unmoderated and only nominally reflected. Under these conditions, an 18-inch diameter tube should present no criticality problems. It will be necessary, of course, to demonstrate that the voloxidizer will remain unmoderated under any credible conditions.

The criticality problem becomes more complex, however, when two rotating kilns are used in order to provide redundancy in equipment and to reduce the total length of the apparatus in order to conserve cell length. In this case, interaction between the two systems must be considered. The lack of moderation, however, greatly simplifies the criticality problem and two side by side voloxidizers do not appear unreasonable.

Since the voloxidizers must discharge through a seal arrangement to the dissolver, the voloxidizers must necessarily be at a higher elevation than the dissolver. It will not be difficult to positively prevent a backup of dissolver solution into the voloxidozer. In addition, the higher elevation of the voloxidizer will assure that it can not be moderated by flooding in the cell.

Criticality considerations in the dissolver have not been evaluated since this piece of equipment is outside the scope of the present study, and since no design for the dissolver has been chosen. While Odom, in his paper cited above, does not address the criticality problem any further than noting that it exists, it appears that the criticality problem can readily be resolved by using safe geometry.

Poisoning the dissolver solution with boron or cadmium is another method of controlling criticality. This approach, however, creates two additional problems. Some means must be provided to positively assure the continuous presence of the poison, and the addition of the poison to the dissolver solution will increase the volume of solids in the high level waste which will eventually have to be solidified and shipped off site for disposal.

The use of borated stainless steel or tubes of boron carbide in the construction of the dissolver are two possibilities that should be investigated.

Radiation Protection

The handling and processing of fuel and dissolver solution will all be conducted within the main cell constructed for this purpose. The cell wall thickness will be sufficient to reduce radiation levels to 1 mR/hr or less at the exposed surface of the cell in normally occupied areas.

The other equipment processing the effluent streams will not receive large quantities of highly radioactive materials. For the most part, the auxiliary equipment will see a few hundred to a few thousand curies of tritium, iodine and krypton which are primarily low energy beta emitters. Modest shielding will be supplied around this equipment with a wall thickness sufficient to bring radiation levels to 1 mR/hr in normally occupied areas.

Two potential areas of radiation exposure to personnel are the filters in the shear off-gas and the voloxidizer off-gas lines. Both of these streams will undoubtably carry small amounts of highly radioactive dust which will create high radiation levels wherever it deposits. This problem will be accentuated in the off-gas stream from the voloxidizer since the relatively dense UO_2 fuel particles will be converted to a dense but relatively fine powder. The rotation of the voloxidizer will, and is designed to, lift the powder and expose it to the gas stream thus increasing the probability of dusting in the off-gas.

Small, duplicate, sintered metal filters with about 20 micron porosity will be installed on each of these streams as close to the shear and voloxidizer as possible with provision for automatic blowback and cycling between filters. The location of the filters will have to be carefully chosen to facilitate change out should a filter unit fail.

A potentially serious radiation problem may be encountered in the voloxidizer off-gas due to the volatility of ruthenium tetroxide. It has been stated that a small percentage of ruthenium will volatilize during voloxidation and that it will deposit down stream on the cool surfaces of the off-gas line. The rhodium daughter products of ruthenium have short half lives and are fairly strong gamma emitters. The line from the voloxidizer will thus require significant shielding to and through the off-gas cooler.

Tritium Disposal

The milligram quantities of tritium, only a portion of which will be released as elemental tritium, does not present a hydrogen explosion problem in the recombiner or voloxidizer since it will be diluted to far below the lower explosive limit of 4% in air by the air streams through these units.

The tritiated water absorbed in the regenerative driers does present a tritium exposure problem, however during regeneration and load out of the driers. Tritiated water from the primary driers will be delivered to the load-out station as a liquid containing about 500-600 Ci. per liter. The product will be discharged to a container of anhydrous calcium sulfate for disposal. This operation and the sealing of the container will be performed in a glove box to eliminate tritium exposure to operating personnel. The glove-box atmosphere will be recycled back to the regenerative driers to recover any tritium that might escape into the glove-box atmosphere.

A backup molecular sieve drier will be installed downstream from the primary drier to recover any tritium that might break through the primary drier. Tritium absorbed in the backup will be recycled to the primary drier during regeneration.

The off-gas from the shear and voloxidizer will be combined with the dissolver off-gas and routed to a shielded nitrogen oxide (NOx) absorber for the recovery of nitric acid. The product from the NOx absorber will be about 6M nitric acid which will be recycled to the dissolver after being stripped of iodine. The operation of these units is straight forward and there do not appear to be any unusual safety questions involved other than shielding to a 1 mR/hr level at the surface of the cell in occupied areas.

Iodine Storage

The off-gas will next be passed through to an iodine absorber column where it will be contacted with 10M nitric acid containing some 0.2-0.4M mercuric nitrate for recovery of iodine as mercuric iodide. Periodically the mercuric iodide solution will be concentrated to azeotropic concentration in the evaporator. The hot, concentrated, nitric acid will oxidize the iodide to iodate which precipitates as insoluble mercuric iodate. The slurry is then dropped into a 1000 gallon stainless steel tank located in a burried concrete vault outside the cell. In the absence of definitive criteria for the long term disposal of radioactive iodine, this method of retrievable storage has been adopted pending resolution of the problem.

After repeated discharges of slurry to the storage tank, the tank will fill with slurry and supernatent liquid. The slurry will be allowed to settle out and the supernate will be decanted back to the absorber system.

Since both mercury and iodine-129 are objectionable contaminants in the environment, and are highly undesirable in other parts of the reprocessing plant as well, the system has been designed to be completely self contained. No mercury or iodine is discharged from this system to other parts of the plant. Makeup water, acid,and mercury will be periodically added as required. Water and a small amount of acid will be lost in the off-gas stream and will be absorbed in the caustic scrub column down stream. Additional acid will be consumed in the oxidation of the iodine. Mercury will, of course, be consumed in the formation of the mercuric iodate and this will be discharged to the storage tank. At some future time the mercury can be recovered and the iodine can be shipped off-site for disposal.

The storage of iodine as the insoluble salt in a buried tank in a vault is safe for a number of reasons. The material is protected from the effects of natural phenomena--tornadoes and earthquakes. The vault will be equipped with a sump and a level alarm to detect a leak in the tank or seepage of ground water into the valut. The nitric acid-mercuric nitrate system is no more corrosive than nitric acid and an adequate corrosion allowance for a 30 year life will be added to the wall thickness.

The off-gases are next routed to a caustic scrubber for the removal of nitric acid, any residual NO_x, and carbon dioxide. The off-gases are then reheated and passed through a silver zeolite bed where the last

traces of elemental iodine or organic iodides will be trapped. The life of the silver zeolite bed is calculated to be in excess of six months. When the bed becomes loaded, as determined by periodic samples taken downstream, the bed will be replaced and the loaded bed will be sent to disposal.

At this point the iodine-129 content of the off-gas has been reduced to less than 1 μCi/ton of fuel assuming minimum DF's of 300 across each of the mercuric-ion scrubber and the silver zeolite. DF's of 1000 or better have been demonstrated across each of these absorbers. Gaseous effluents of iodine have been reduced to the lowest practicable level, and when these are diluted by the annual average X/Q at the site boundary of 7×10^{-8} sec/m^3, the effect in the environment will be undetectable.

Krypton Recovery

The off-gas stream at this point has been cleaned of iodine, particulates, NO_x and carbon dioxide. The gas is compressed and dried to a dew point of -40°F. in a regenerative drier and sent to the krypton recovery unit. The gas stream is compressed to 375 psia and scrubbed in the Freon absorption column. After fractionation and stripping the recovered krypton and xenon are compressed to 1700 psia in standard hydrogen bottles and are sent off-site for disposal.

In normal operation the columns operate at 375, 45 and 25 psia and at temperatures of from -25°F to +32°F. These temperatures and pressures are modest compared to the conventional tonnage oxygen plants and no safety questions are apparent.

The main compressor is a two-stage diaphragm compressor designed for nuclear service and rated for 400 psia. The use of a diaphragm compressor

eliminates the possibility of a leak around the shaft of a conventional piston compressor. Diaphragm life is reported to be better than 8000 hours which is just about one year of continuous operation. The diaphragms will have to be changed on an annual basis to assure continued operation. The changing of the diaphragms will be accomplished by contact maintenance during the annual turn-around after the system has been purged of krypton.

The inventory of krypton in the system has been calculated to be about 13,000 Ci. and shielding equivalent to 3 inches of lead will reduce the gamma and bremsstrahlung radiation levels to 1 mR/hr. The krypton unit will thus require 10-12 inches of concrete around the unit. No moving parts need be in the krypton cell other than a few motor operated control valves. The main compressor, the turbo-expander, and the liquid freon pump may be located in pump niches for access for maintenance without a purge of the entire system.

The krypton bottling station must also be shielded by the equivalent of three inches of lead since the bottles will contain up to 80,000 Ci. of krypton. The principal potential radiation exposure will be a dose to the extremities (hands and forearms) of the operator changing out the cylinders. A collar of 1-1/4 inch thick uranium will be fitted around the neck of the cylinder during this operation to reduce the radiation levels to about 10 mR/hr. It is estimated that the pig-tail can be disconnected in less than 5 minutes per cylinder for a dose to the extremities of about 1 mR. The total annual dose for this operation will be about 100 mR compared to an allowable dose to the hands and forearms of 18-3/4 rems per calendar quarter.

The krypton bottle will be surrounded during loading by a 3-inch thick lead cask which will reduce the radiation to less than 1 mR/hr at the surface. The top of the cylinder will be enclosed in a hood to protect the face of the operator from a puff of high pressure krypton bearing gas should the pig-tail be inadvertently loosened while under pressure.

As stated above, the pig-tail will be bled down to less than 50 psi before the coupling is loosened and the release of krypton from the pig-tail will be about 3-1/2 Ci. which will be vented to the stack. This release amounts to 0.004% of the krypton in the cylinder and over a period of a year the krypton release will be about 350 Ci.

The main absorbtion column will have a DF of not less than 100 under the postulated operating conditions which represents a release of not more than 112 Ci. per ton for a total release of 115 Ci. per ton. This release when diluted by the annual average site boundary X/Q of 7×10^{-8} sec/m^3, will deliver the following doses:

Table No. 9

Potential Annual Doses from
Exposure to 1% of Maximum Kr-85 Releases

Recipient	Whole Body	Skin
Nearly resident	1.4×10^{-6} rem	1.1×10^{-4} rem
Typical resident within 50 miles	2.3×10^{-8} rem	1.8×10^{-6} rem
Total Population within 50 miles	.043 man-rem	3.3 man-rem

The above doses have been calculated on the very conservative assumption of 99% recovery of krypton. The Oak Ridge work has shown efficiencies of up

to 99.9% and it is reasonable to assume that DF's during actual operations will fall somewhere within the range of 100-1000. A conservative estimate of a DF of 300 would reduce the total krypton releases to 40 Ci. per ton and the delivered doses would be one-third the values given in Table No. 9.

Abnormal Operation

The condition of abnormal operation most frequently encountered will probably be a power outage. Power is suppled to West Valley by Niagra Mohawk Corp. stations at North Angola and Machias by a 34,500 volt loop system that can supply power from either station. Niagra Mohawk records for the period 1965 through 1970 indicate that the frequency of outages can be expected to be 10 to 20 per year, the great majority of which will last no more than 30-60 seconds while automatic switching of the load occurs. There has been only a single outage of appreciable length of time since 1966 and that was a 90 minute outage at the time of the blackout of the whole Northeast in 1967.

A 150 KW diesel-electric generator will be installed in the new facility with automatic switchgear which will, in the event of an outage, disconnect from the utility supply, shed non-critical loads, and start the emergency generator. The individual power loads in the system will be designed to drop out automatically on power failure and will be manually restarted by the operating force in compliance with an emergency procedure designed to restart critical equipment such as ventilation blowers and compressors first, followed by less critical loads so as to avoid overloading the emergency power supply with heavy starting loads.

Non-essential operations will be suspended until normal utility power is restored.

Table 10 presents the listing and estimated power demand of critical items which will be fed from the emergency power system.

TABLE 10

Emergency Power Requirements

Equipment	Operating Load - kw
Emergency lighting	5
Instruments	2
Main Ventilation Blower	25
Off-gas Compressor 01-06	25
NO_x Absorber Recirculation pump 02-05	6
Iodine Absorber Recirculation pump 03-04	4
Caustic Scrubber Recirculation pump 03-09	4
Off-gas Compressor 03-15	25
Cooling Water Circulation	10
	106 kw

The normal, short term, excursion will not affect plant operation since the utility power will be back on line in 30-60 seconds, and equipment will be restarted on normal power even though the emergency power supply has been activated and is available.

It is expected that in any lengthy outage that fuel shearing and dissolution as well as krypton absorbtion would be suspended. The heavy

power load of the main krypton compressor, 04-01, and the mechanical "A" and "B" refrigeration systems will be difficult and costly to pick up on emergency power. Under these conditions the off-gas from compressor 03-15 will be vented to the stack, bypassing the krypton absorbtion system. The krypton release under power outage conditions will be limited to that in the system at the time of power failure. With about one ton of fuel in the system, and assuming that 50% of the fuel had previously released its krypton, the krypton release would be about 5000 Ci. which would be released over a period of from 10-30 minutes. The dose delivered down plume as a result of such a release would be about 7-10% of the values shown in Table 9. A nearby resident would receive a dose of about 1×10^{-7} rem, whole body, and 1×10^{-5} rem to the skin.

A far more serious problem that may be encountered is a zirconium fire in the voloxidizer. The voloxidizer normally operates at 450°C (842°F) and oxidizes UO_2 to U_3O_8, an exothermic reaction releasing 24.9 K cal. per gram mole. This is equivalent to 415,500 BTU per ton of fuel. In addition to the heat of reaction, decay heat of 65,900 BTU/hr/ton of fuel will also be evolved. For design purposes it has been assumed that the feed rate to the voloxidizer would be 1/4 ton per hour and with a residence time of two

hours, the fuel inventory is 1/2 ton. The normal heat release rate in the voloxidizer then is:

Heat of reaction	103,900 BTU/hour
Decay Heat	32,950
	136,850 BTU/hour

This heat plus any heat input to bring the voloxidizer to the operating temperature will be released to the cell atmosphere and carried off in the cell ventilation. About 700 CFM will be required for this purpose assuming a 20°F temperature rise. The control of such an operation will be difficult for the UO_2 must be brought to ignition temperature and then cooling must be effected to prevent sintering the fuel which will restrict the release of tritium. The problem of heat removal becomes extremely difficult if the zirconium cladding ignites, as well it might, since Sax gives an auto-ignition temperature of 500°F for zirconium.[19] The heat of formation of zirconium oxide is 262,900 cal/gram mole. With an average of 103 kg of zirconium in the voloxidizer the heat released on oxidation of the total charge would be 1,180,000 BTU. This amount of heat delivered in a period of a few minutes would cause severe damage to the apparatus and the volatization and release of fission products to the cell atmosphere. If the zirconium ignites and burns smoothly, the heat removal problem can probably be handled, however the resulting zirconium oxide will not dissolve in the dissolver and a difficult feed clarification and disposal problem will result.

19 Sax, N. I., "Dangerous Properties of Industrial Materials." Van Nostrand Reinhold, New York 1968

These questions can only be resolved by actual operation of a pilot scale voloxidizer using sheared commercial fuel in the continuous mode of operation. Pilot plant work of this type is absolutely necessary prior to the design and construction of a full scale unit.

In the event that a runaway reaction occurs, it will not be possible to use water for quenching because of the criticality problem. Water is also highly undesirable in metal fires because of the possible formation of hydrogen with far more damaging consequences than the zirconium fire itself. It is also not practical to inject the usual solid fire control materials such as "Metal-X," etc., into the tube. Therefore, it will be necessary to detect the fire by the rapid increase in temperature followed by inerting the atmosphere in the tube. This can be accomplished by shutting off the air supply and purging the tube with helium or argon. This will permit the cooling of the voloxidizer which can then be discharged to the dissolver at the expense of adding the tritium content of the bypassed material to the plant liquid stream. The addition of 300-400 Ci. of tritium to the liquid stream will have no effect on plant personnel and little effect on the public since the tritium will be diluted in the surface waters to below allowable limits.

The loss of any one of the three compressors in the system will have the effect of shutting off the flow of off-gases from the voloxidizer and/or the dissolver. The continued flow of these off-gases is required to prevent leakage of contamination from the equipment into cell ventilation and from the cell to the environment, therefore, it is essential that this flow be maintained at all times. Since all mechanical equipment is subject to failure, and even though the probability of failure is remote, there must be provision for maintaining this essential flow.

The first two compressors not only provide the operating pressure in the driers, they also provide suction to the voloxidizer, shear, and the dissolver. The redundancy provided by the multiple compressors provides the assurance that the flow can be maintained with the loss of any single compressor. However, the suction side of the compressor will not be capable of overcoming the pressure drop in a drier with any meaningful flow and it will be necessary to bypass the drier served by the failed compressor.

Thus, if the first (01-06) compressor fails for any reason, it will be necessary to bypass the tritium driers and divert the volox off-gas to the inlet side of the iodine absorber (03-01). (It will not be necessary to take this stream through the NO_X column [02-02].) The net effect will probably be the absorption of the majority of the tritiated water in the liquid side of the iodine or caustic scrubbers. On a temporary basis this can be accepted pending repair of the compressor.

If the second compressor (03-15) fails, the off-gas will be bypassed around the pre-krypton drier and the suction of the main krypton compressor

will maintain the flow. The effect here will be to add a small amount of water to the krypton recovery system. There is reason to believe that the water may solidify as minute or colloidal particles in the krypton recovery system and thereby pass through the various columns in the system. This has not been demonstrated at this time although there are plans to attempt this in the near future at the ORGDP pilot plant. If this provides unsuccessful, it will be necessary to bypass the off-gas to the stack at the expense of a krypton release while the compressor is repaired.

The loss of the main krypton compressor will, of course, shut down the krypton recovery apparatus with the same krypton release pending repair of the compressor. Thus, the effect of the loss of any single compressor is:

Compressor	Effect
Tritium(01-06)	Will lose tritium recovery
Krypton drier(03-15)	May lose krypton recovery
Krypton unit(04-01)	Will lose krypton recovery

In all cases iodine recovery is maintained and in no case is more than one isotope recovery system lost--either tritium or krypton but not both.

The occasional short term release of these materials as a result of equipment failure will not create an undue risk or hazard to the public.

In a system as complex as this, there are many opportunities for failure of single pieces of equipment with varying consequences ranging from a shift to spare equipment to a complete plant shutdown. The effect of various equipment failures or maloperation is shown in Table 11.

TABLE 11

EFFECT OF MALOPERATION

Maloperation	Indication	Result	Corrective Action
1. Loss of voloxidizer drive equipment	1. Voloxidizer stops	1. Loss of capability Line shuts down	1. Repair drive
2. Loss of volox heater element	2. Decrease in volox temperature	2. Reduced H-3 evolution. H-3 to dissolver	2. Shift to installed spare heater
3. Volox overheat	3. High temperature alarm	3. Potential loss of volox unit	3. Stop feed Shut off air supply. Inert gas into tube.
4. Volox discharge plug or seal failure	4. No feed to dissolver	4. Loss of capability Line shuts down	4. Cool volox Remove obstruction
5. Diaphragm failure in 01-06 compressor	5. Loss of pressure in 01-04 drier	5. Loss of volox ventilation	5. Open bypass around compressor and drier to maintain flow. Replace diaphragm
6. Loss of circulation pump on any scrub column	6. Loss of flow in scrubber	7. Loss of scrubber capability	6. Switch to installed spare pump. Repair defective pump.

TABLE 11 (Continued)

Maloperation	Indication	Result	Corrective Action
7. Leak in steam coil in 03-19 evaporator	7. Increase in level in evaporator	7. Loss of evaporator	7. Dump evaporator to iodate tank. Replace coil.
8. A. Filter failure 03-12; or B. Filter plug	8. A. Loss of Δp across filter; B. High Δp across filter	8. A. Loss of filtration B. Loss of flow	8. Shift to installed spare. Replace filter
9. Loss of diaphragm compressor 03-15	9. Loss of pressure in 03-14 drier	9. Loss of DOG and volox ventilation	9. Open bypass around compressor to suction side of main krypton compressor. Repair compressor
10. Loss of main krypton compressor 04-01	10. Loss of pressure in absorber column	10. Loss of krypton unit	10. Vent off-gas to stack from 03-15 compressor Repair compressor
11. Turbo-expander failure	11. Increase in inlet air temperature to absorber	11. Increased load on Mech. A system. Increased freon loss to stack.	11. Bypass turbo expander and repair unit.
12. Loss of Mechanical A of B refrigeration	12. Increase in temperature in condensers	12. Loss of krypton recovery	12. Bypass krypton recovery unit. Vent to stack. Repair equipment.
13. Loss of solvent pump	13. Loss of flow to absorber column	13. Loss of krypton recovery	13. Same as 12.
14. Loss of heater in reboiler on fractionator or stripper column	14. Decrease in temperature and pressure in column	14. Loss of krypton recovery	14. Same as 12.

TABLE 11 (Continued)

Maloperation	Indication	Result	Corrective Action
15. Plug in column	15. Low level in reboiler	15. Loss of krypton recovery	15. Same as 12.
16. Leak in krypton line at loading station	16. Krypton in air in loadout area	16. Release of krypton; contamination of load out area	16. Close valve on line from stripper. Repair leak or replace pigtail
17. Loss of building ventilation blower	17. Loss of air flow or Δp across filters	17. Loss of building ventilation	17. Shift to installed spare blower
18. Power outage	18. Loss of power	18. Line shutdown	18. Start emergency power supply. Maintain essential services until power is restored
19. Loss of cooling water	19. Increased temperature in various units	19. Loss of cooling	19. Shift to installed spare cooling water pump

One abnormal occurrence that merits close study does not involve the operation of the system: the loss of a bottle of krypton at storage pressure. This is primarily a handling and transportation problem since it is inconceivable that the bottle would be lost while in the loading station. A leak could develop, which would be vented to the stack, but a sudden loss of the entire contents could only result from loss of the cylinder valve. The probability of such an occurrence is very low, based on experience with normal bottled gases, however, the possibility does exist. The study of such an occurrence, is not within the scope of this study and it is mentioned merely to call attention to the problem.

AREAS REQUIRING FURTHER DEVELOPMENT

The most pressing problems requiring further development work are all concerned with the voloxidizer. This unit is essential for the recovery of tritium, for without this unit, tritium will enter the plant liquid stream from which separation and recovery is prohibitively expensive.

The problem of zirconium fires in the voloxidizer has been discussed previously and it has been pointed out that it is essential that a pilot scale voloxidizer be constructed and operated using sheared fuel. The present work indicates that carefully cut pellets in zirconium cladding can be successfully voloxidized. The volox feed in an operating plant, however, will be far different from that studied in the laboratory. Sheared fuel can be expected to have torn and ragged metal from grid spacers and wires, and some clipped tubes may develop ragged edges. These wires and torn edges may well initiate combustion of the zirconium which could extend through the full length of the tube and which would drastically increase the heat load on the system. Even if the increased heat load can be accomodated, there will remain the problem of the separation and disposal of the resulting zirconium oxide. It is possible to dissolve the zirconium oxide, however, this would require the use of hydrofluoric acid in the dissolver with increased corrosion throughout the plant. The HF can probably be complexed with aluminum to reduce corrosion; this, however, will introduce both aluminum and fluoride into high level wastes and will increase the volume of calcined wastes to be disposed of.

If the zirconium dioxide is not dissolved, the feed to solvent extraction will require clarification, not a simple problem in the high radiation levels in the cell. The resulting sludge would require washing both to reduce uranium and plutonium losses, and to reduce plutonium to an accepted level for economic disposal.

If the voloxidizer is to be used, three major pieces of equipment must be operated in series and the off-gas from each must be isolated from the others. Some form of seal between the units must be designed and tested to determine that sheared fuel can be reliably transported between units while maintaining the separation of the off-gases. Some inleakage of air can be tolerated, which simplifies the problem; however, no such seal has thus far been devised or tested. Two approaches appear to merit further study. In both cases sheared fuel would be delivered to a cavity that would then be moved in such a manner that the opening above would be closed while an opening below would be created thus allowing the fuel to drop out while preventing intercommunication between units. This might be arranged by a horizontal disc rotating about a vertical axis, the disc to be separated into quadrants by vertical baffles. The second approach is similar but involves a horizontal motion only, activated by a hydraulic ram. Sheared fuel would be delivered to a cavity in a shuttle box which upon displacement would both close the opening to the shear and drop the fuel out the bottom.

Any such equipment could, of course, be used at the discharge end of the voloxidizer, the only difference being the high temperature of the products discharged.

The problem of ruthenium volatility has been previously mentioned. The question of quantity evolved is important as is the fate of the material: where does it deposit; and how can the site be decontaminated periodically? Shielding will have to be provided for all potential points of deposition.

Sampling and process control have not been extensively studied. Further work in this area is required not only to control the various operations within process parameters, but also to demonstrate that the effluents are within limits. Krypton discharges can probably be monitored satisfactorily at the levels proposed by a gamma detector. The detection and analysis of tritium and iodine, however, will be much more difficult, and process instrumentation will require development. The detection of a few μCi of iodine-129 is both difficult and time consuming in the laboratory, yet this level of detection will routinely be required to demonstrate that the desired level of effluent retention is being achieved.

The very fact that tritium, iodine and krypton are being recovered implies that some satisfactory means of disposing of the product is available. This, unfortunately, is far from being true. It is becoming increasingly clear that many states have serious reservations concerning land burial of tritium, iodine and krypton. Tritium is quite mobile and is a threat to water supplies. Iodine-129 has an exceedingly long half life, and as such will persist for periods of time measured in the geological time frame. The disposal of krypton has not been generally considered since the technique of recovery is only now being developed. It is obvious that krypton must be stored as a gas, and gases in general are not acceptable as low level waste.

Tritium and krypton with half lives of 12.2 and 10.7 years, respectively will decay to insignificant levels in 100-150 years and as such can probably be safely disposed of in low level burial areas for tritium and in engineered surface structures for krypton.

Iodine-129, with a half-life of 1.7×10^7 years, is an entirely different problem; it must be isolated from the biosphere forever. One suggested method of disposing of iodine-129 is disposal in the ocean depths which can be expected to retain the material for a long time due to the slow or non-existent circulation out of these areas. Should any of the iodine-129 migrate out of the ocean depth, it would be isotopically diluted in the vast amount of stable iodine in the ocean and would thus present no hazard to life.

There is one method of disposing of all three of these wastes that should be considered--deep well disposal. West Valley is fortunately located for such disposal in that a bed of porous Cambrian age sandstones lies immediately under the site with a thickness that is estimated at 1000 feet. The Potsdam-Theresa formation is covered with several hundred feet of impermeable cap rock and is saturated with brine that is unsuitable for salt recovery because of the high calcium and magnesium content. The formation lies some 3500 feet below sea level. The Cambrian deposits were laid down in the early Paleozoic era and are certainly much older than 200 million years--more than ten half-lives for even iodine-129.

If deep well disposal were deemed suitable for tritium, it would be practical to deliver suitably neutralized acid fractionator condensates to the formation in a few thousand gallons per day of wastes. The solubilities

of krypton and xenon are greater than that of oxygen or nitrogen, and these wastes could be dissolved in the liquid. By the same token, mercuric iodate could be converted to soluble sodium iodate which could then also be dissolved in a few hundred gallons of liquid waste and injected into the well. Such a system would safely, economically, and permanently isolate these materials from the biosphere.

CONCLUSIONS

It may be concluded that it appears possible to provide the plant containment factors of 100 for tritium and krypton and 10,000 for iodine that were the goals of this study; however, it should be clearly recognized that, especially for tritium, much work remains before these containment factors become reality. Continuous voloxidizer equipment must be designed and tested and the zirconium fire problem must be resolved. It would be desirable to prove out the use of the turbo-expander in actual service in a krypton unit to determine the efficiency and reliability of the equipment. The turbo-expander is not a critical item since the krypton recovery unit can be designed and operated without it, but at added cost for refrigeration.

The remaining portions of the flowsheet do not appear unduly difficult, and these can probably be installed with a minimum of startup difficulties. The principal remaining question then becomes "what is the cost/benefit ratio?"

It has been shown that the costs are substantial--$16,900,000 which can roughly be allocated as follows:

Tritium	$10,000,000
Iodine	2,900,000
Krypton	4,000,000
	$16,900,000

It is recognized that these costs are for the modification of an existing facility, and presumably the cost would be reduced if the flow sheet of a new, from the ground up, facility were designed with these goals in mind. Little or no savings would be achieved in the iodine and krypton units, for the former would in all likelihood be designed into any plant, and the latter does not require a large area nor heavy shielding. The major expense for an existing plant, and a significant cost item in a new plant will be due to tritium recovery. What are the benefits?

A study of the annual dose commitment to the population within 50 miles of West Valley was conducted using the release of 300,000 Ci. of tritium. It was assumed that the tritium was released in either of two modes: (a) 90% to surface water; 10% to air; and (b) 15% to surface water; 85% to air. Surprisingly, the annual dose commitment to the total population of roughly 1,200,000 people within 50 miles did not differ significantly between the two modes of release as is shown below:

Annual Population Dose Commitment from Tritium*

Pathway	Aquatic Release	Airborne Release
	(man-rem)	
Inhalation	2	13
Drinking Water	76	16
Water in food, milk, etc.	7	61
Fish Consumption	-	-
TOTAL:	85	90

*Based upon the release of 300,000 Ci, NFS West Valley Revised SAR-1973.

The decreased exposure in drinking water from the aquatic release was found to be offset by the increased ingestion of tritium from locally grown foods and milk that absorb tritium deposited on the ground from the airborne release. The important aspect of this study, however, is that the total annual dose commitment to over a million people is in the order of 100 man-rem per year; a truly insignificant dose compared to the 150,000 man-rem per year received by the same population from natural backgrounds. At $10,000,000 allocated to tritium recovery, the cost of reduction of the exposure is about $100,000 per man rem.

The situation is somewhat better, but hardly crucial, with regard to krypton. The costs allocated to krypton recovery are about $4,000,000. It has been shown that the total annual man-rem exposure to the population

within 50 miles is about 330 man-rem. The cost of dose reduction then is about $12,000 per man-rem.

These costs per man-rem reduction, coupled with the low world wide dose rates shown in Figure 1, might suggest that neither tritium nor krypton is a pressing problem in the near term. Iodine, on the other hand, deserves immediate attention, because of iodine-129, and also because the increased processing of short cooled fuels may lead to an increase in the evolution of iodine-131. Development of processes for improved containment of krypton and tritium should be continued in that order of priority so that application of the technology will be possible when the need arises. Alternative means of disposing of tritium, such as deep well disposal, should be investigated and a cost comparison to voloxidation should be made. Studies of existing facilities should be made with a view towards reducing the volume of tritium bearing liquids to a minimum value. Site geology should be studied to determine whether suitable conditions for deep well disposal are present.

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