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SPHERE-PAC FUEL DEVELOPMENT PROGRAM FIRST SEMI-ANNUAL PROGRESS REPORT

**FOR THE PERIOD
OCTOBER, 1979 - MARCH, 1980**

**ROWLAND E. FELT
MAY, 1980**

**WORK PERFORMED UNDER CONTRACT
DE-AC14-79ET34026**

**EXXON NUCLEAR COMPANY, INC.
2955 GEORGE WASHINGTON WAY
RICHLAND, WA 99352**

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ROWLAND E. FELT

EXXON NUCLEAR COMPANY, INC.
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PREPARED FOR THE

U.S. DEPARTMENT OF ENERGY
DIVISION OF NUCLEAR POWER DEVELOPMENT
UNDER CONTRACT DE-AC14-79ET34026

APPROVED

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ABSTRACT

Development of processes by Exxon Nuclear Company, Inc. for fabricating spherical particle nuclear fuel (sphere-pac) during October, 1979 through March, 1980 is reported. The program surveyed available technology to develop an initial flowsheet as a design basis for process development. An 0.1 ton/day pilot plant was built to develop and demonstrate the fabrication of sphere-pac fuel. Process and equipment efforts have been directed towards the demonstration of processes and equipment necessary to fabricate sphere-pac fuel on a commercial scale.

SUMMARY

The Sphere-Pac Development Program is directed toward commercialization of spherical particle (sphere-pac) uranium oxide fuel as an alternative to conventional pellet fuel for nuclear reactors. A program is jointly funded by Exxon Nuclear Company (ENC) and the Department of Energy (DOE). The incentive to consider sphere-pac fuel is based on the DOE Fuel Performance Improvement Program (FPIP), which is testing the in-reactor performance of sphere-pac fuel as an alternate to pellet fuels. The principal goal of the FPI Program is to identify fuel types which offer improved fuel performance by reducing fuel failures caused by fuel-cladding interactions. Sphere-pac fuel results in less "hard" contact between the fuel and the cladding than does pellet fuel, because the particle fuel column remains more mobile.

Six tasks were identified to carry the program from an initial technology review to a conceptual design of a commercial plant. Progress during the six-month period between October, 1979 and March, 1980 was the completion of the Survey of Technology and the Construction of Equipment to Test Unit Operations.

A continuous flowsheet was developed for the program based on available technology for spherical particle fuel. The technology for sphere-pac fuel originated in Europe and has been brought to a small batch-scale demonstration by Oak Ridge National Laboratory (ORNL).

Equipment was designed and constructed for demonstration of the sphere-pac fuel production on an 0.1 ton/day scale. The process was divided into three areas: uranium feed preparation, sphere forming,

and drying-calcining-sintering. Each is located in separate enclosures because of laboratory space arrangements. The equipment for each process area is considered developmental, but represents the results of lab scale experience, as well as ORNL experience.

The testing of unit operations is underway. Initial equipment tests have identified problem areas requiring changes. The feed preparation process has been demonstrated. Sphere forming tests are now underway. The special equipment and process development activities are awaiting completion of the unit operations tests.

1.0 INTRODUCTION

The Sphere-Pac Fuel Process Development Program is a joint Exxon Nuclear Company (ENC) and Department of Energy (DOE) funded effort to develop and demonstrate the preparation of uranium spherical particle (sphere-pac) fuel. The goal is to develop the process and equipment to a sufficient level to permit conceptual design of a commercial fuel fabrication plant. Sphere-pac fuel has potentially a higher burnup capability, lower fuel-cladding interaction, and greater capability for power ramping. From the fuel fabricators viewpoint, sphere-pac offers lower fabrication costs and the potential to easily recycle plutonium.

The original technology for spherical fuel was developed by Oak Ridge National Laboratory (ORNL) with their sol-gel process. Further developments were made in Europe, which resulted in a different sphere forming mechanism and the process title - sphere-pac. ORNL evaluated the European experience and recommended an "internal-gelation" sphere-pac process as being worthy of further development.⁽¹⁾

The Sphere-Pac Development Program schedule covers a period of four years, as shown in Figure 1. It is divided into six major tasks:

- I. Survey of Technology
- II. Construction of Equipment to Test Unit Operations
- III. Testing of Unit Operations
- IV. Equipment Development
- V. Development Studies
- VI. Commercial Facility Conceptualization.

FIGURE 1. Sphere-Pac Program Schedule - 1979-1983

The milestones associated with each of the program task milestones are also shown in Figure 1. Tasks I and II were completed during the October-March period covered by this report. However, initial work was initiated on all the tasks.

2.0 SURVEY OF TECHNOLOGY - (TASK I)

2.1 Technology Review

The purpose of the technology survey was to thoroughly review previous particle fuel fabrication technology and, as a result of this review, develop a flowsheet from which equipment can be designed to develop and demonstrate the process. There are two basic approaches for preparing spherical uranium fuel particles by chemical gelation processes: internal and external gelation. These two approaches were largely developed in Europe. Both were considered to be improvements over the Oak Ridge National Laboratory (ORNL) process known as "sol-gel" which utilized a UO_2 sol, which was gelled by water extraction after dispersion as droplets into an alcohol.

The internal gelation process uses a water-soluble chemical that, when heated, releases ammonia to precipitate the uranium as ammonium diuranate. An acid-deficient uranyl nitrate solution is mixed with the ammonia-donor (hexamethylenetetramine - HMTA) and urea to form what is termed a "broth." The broth is pumped through a vibrated nozzle to form spheres, which solidify as they settle through a hot organic liquid. The spheres are washed with ammonia (NH_4OH) to remove the excess HMTA, urea, and ammonium nitrate (NH_4NO_3). The spheres are then dried, calcined, and sintered in a reducing atmosphere to obtain high density UO_2 spheres. A comparison of an internal gelation process with pellet fabrication is shown in Figure 2.

FIGURE 2. Nuclear Fuel Fabrication.

The external gelation process is also known as the "gel-support" precipitation process. A water-soluble organic polymer is added to a uranium solution. The uranium solution is dispensed into drops which drop through ammonia gas and into an ammonium hydroxide solution. The polymer supports the particle spherical shape as ammonia diffuses into the sphere and precipitates ammonium diuranate. The process from this point is similar to the internal gelation process.

Oak Ridge National Laboratory compiled an assessment of the known technology on both internal and external gelation processes.⁽¹⁾ A second review was issued a year later specifically for Light-Water Reactor (LWR) application.⁽²⁾ The principal conclusions of the ORNL assessments are:

- External gelation process cannot make sintered spheres larger than 800 μm diameter,
- The organic polymer support for external gelation is highly proprietary and could not be adequately demonstrated by ORNL, and
- Internal gelation is, therefore, the preferred process.

The ENC review of the literature came to the same basic conclusions. One area where external gelation, or a modified internal gelation process, may prove to be superior is in the preparation of fine spheres (30 micron sintered diameter).

Pilot plants in Europe and the United States have produced different types of spherical particle fuel. Process details are often not available because of the proprietary nature of each nation's development efforts. The pilot plant development efforts of ORNL were made

available to our review. Their development experience was funded by the DOE Fuel Refabrication and Development (FRAD) Program and their sphere production operations were in support of test rod fabrication for the DOE Fuel Performance and Improvement Program (FPIP).

The sphere-pac fuel prepared by ORNL for the FPI Program consisted of three sphere sizes loaded into a zircaloy rod to a fuel density (smear) of 87% of theoretical. The size fractions are listed in Table I. Variations in the quantity of each size fraction produces a different fuel density in the rod. The higher fuel densities are obtained only with a large fraction of the 1200 μ m diameter spheres, which can only be produced by the internal gelation process.

TABLE I

SPHERE-PAC FUEL
SPHERE SIZES

<u>Size</u>	<u>Sphere Diameter (Micron)</u>	<u>Percentage (%)</u>
Large	1200	56
Medium	300	27
Fine	33	17

2.2 Flowsheet Development

A flowsheet for sphere-pac fuel process development was developed around the internal gelation process as demonstrated by ORNL. The flowsheet design is for 0.1 ton/day of spheres of the

three size fractions. For ease of presentation, the flowsheet is subdivided into three portions:

- Feed preparation
- Sphere Forming and Washing
- Sphere Drying and Sintering

2.2.1 Feed Preparation

The flowsheet for the preparation of acid-deficient uranyl nitrate from U_3O_8 is shown in Figure 3. The process consists of mixing U_3O_8 and water in a dissolver vessel to which concentrated nitric acid is slowly added. Steam and cooling water are used to maintain the dissolver temperature. After excess U_3O_8 has settled from the solution, it is blended with urea to react with nitrite formed during oxide dissolution.

2.2.2 Sphere Forming and Washing

The sphere forming and washing flowsheet is shown in Figure 4. It is based on a totally continuous fluid flow system. The acid-deficient uranyl nitrate (ADUN) and hexamethylenetetramine (HMTA) streams are cooled to $\sim 5^\circ\text{C}$ and then mixed before being forced through a nozzle at the top of the forming column. The mixture is dropped into a 65°C trichloroethylene (TCE) column where the HMTA decomposes to precipitate ammonium diuranate as the sphere falls through the column.

The spheres are continuously moved into the aging column where the solidification process is completed. A surfactant is added to the TCE to prevent spheres from coalescing together. The

FIGURE 3. Sphere-Pac Fuel Feed Preparation.

FIGURE 4. Sphere-Pac Fuel Sphere Forming and Washing.

spheres are separated from the TCE and washed with dilute ammonium hydroxide to remove residual nitrates and organics from the spheres. The spheres are then separated from the ammonia solution to be dried.

2.2.3 Sphere Drying and Sintering

The flowsheet for drying, calcining, and sintering is shown on Figure 5. Each of these operations employ a continuous flow of product through the process with batch feeds and discharges.

A. Drying - The drained wet spheres are dried and calcined by radiant heat as they progress along a vibratory conveyor. This process was selected after evaluation of batch systems and convection heat systems. The system was designed and fabricated at Exxon Nuclear Company.

B. Sintering - The dry UO_3 spheres are loaded into small boats of Mo and pushed through a high temperature muffle tube furnace containing a reducing atmosphere. The spheres exit the furnace as high density UO_2 .

C. Inspection - After inspection and certification for quality, the spheres are released for rod loading.

3.0 CONSTRUCTION OF EQUIPMENT - (TASK II)

3.1 Facility Design and Description

The sphere-pac pilot plant was designed from the continuous flowsheet (Figures 3, 4, and 5) to produce 0.1 ton/day uranium of sphere-pac fuel. Three laboratory rooms in the northeast wing of Exxon

FIGURE 5. Process Flow Diagram - Drying, Calcining and Sintering.

Nuclear Company's Research and Technology Center were modified to receive the pilot plant equipment. The floor plan in Figure 6 shows that the laboratories were divided into four areas for uranium preparation, sphere processing, process control laboratory, and a change room. Two walk-in hoods, constructed of stainless steel channel and polycarbonate sheet, were installed to house the major pieces of process equipment for ADUN preparation and sphere processing.

The ventilation system in the laboratories was modified to handle the additional load imposed on it by the added walk-in hoods. All off-gas from the hoods is double HEPA filtered and routed through a spray scrubber to remove noxious fumes. A closed loop chilled water system and a small, 20 kilowatt, steam boiler were installed to provide cooling and heating capabilities to the process. All condensates and process waste solutions are routed to a hold-tank system for sampling before release to the environs.

3.2 Equipment Design

A. ADUN Preparation - As shown in the uranium preparation flowsheet, the ADUN process uses three vessels: 1) a uranium dissolver; 2) a settling tank; and 3) a blend tank. The dissolver is a baffled, stainless steel vessel of 30 liters capacity equipped with heating/cooling coils and agitator. It serves to slurry the water and U_3O_8 and react the slurry with nitric acid, which is slowly added to the vessel. Steam and water are alternately routed to the heating coils to maintain a constant dissolving temperature. After dissolution is complete, the slurry is pumped to the settling tank to settle the excess U_3O_8 which is not dissolved. The settling tank is a glass and stainless vessel

FIGURE 6. Sphere-Pac Laboratory Arrangement (Aqueous Processes).

with a conical bottom, also of about 30 liters capacity. The ADUN solution is decanted from the settling vessel to the blend tank where urea is added for nitrite removal. The blend tank is a stainless steel tank with heating coils and agitator which has a working volume of 40 liters. During the reporting period, these vessels were designed, fabricated, and installed in the small walk-in hood. Installation of associated piping and other utilities were also completed.

B. Sphere Processing - The wet sphere processing portion of the sphere-pac process takes place entirely inside the large walk-in hood in Lab Room 136. Equipment for sphere forming, aging, and washing was designed and installed. The forming column is a glass column which contains heated trichloroethylene (TCE). The spheres are formed by dropping the broth from a vibrated nozzle into the hot TCE. The spheres are carried downward through the column co-currently with the TCE and are hydraulically transported to the aging column. The aging column is a glass vessel which provides additional time for the gelation to be completed. It is operated as a moving bed with the spheres moving downward and the TCE flowing upward through the bed. The spheres are removed from the bottom of the column and transported hydraulically to a vibrating screen separator to remove the TCE, and are then dropped into the washing column. The washing column is a glass vessel similar in design to the aging column. However, an ammonium hydroxide wash solution is pumped countercurrent to the moving bed of spheres to remove gelation byproducts. Other equipment designed and installed in the large hood included hold tanks, control panels, and sphere forming nozzles. A photograph of the large and medium-sphere nozzles appears in Figure 7.

C. Process Control and Data Acquisition - Temperature control and sequencing of most of the wet sphere processing operations are

Upper = Medium Size Spheres

Lower = Large Coarse Spheres

FIGURE 7. Sphere-Forming Nozzles.

controlled by a microprocessor-based data acquisition system. The computer and associated hardware were installed in the control room/laboratory of the sphere-pac pilot plant. Instrumentation was also installed in the processing areas to interface with the computer. Computer programs to perform process control and data logging functions were written and tested preparatory to the pilot plant start-up.

D. Drying, Calcining, and Sintering - The development-scale equipment is located in the Sphere-Pac Auxiliary Building adjacent to the ENC Research and Technology Center. This building had independent utilities such as electricity, HVAC, and process gases. The process equipment includes a pusher sintering furnace and three bench hoods for drying, calcining, inspection, and material transfers.

Drained wet spheres are received in sealed containers from the sphere forming process in the main R&T Center Building. These spheres are placed into a feed hopper on the sphere dryer. The spheres flow from the hopper at a controlled rate onto the dryer tray where they are exposed to radiant heat sources. The time of their exposure to these sources is controlled via vibratory conveyor parameters. The intensity of the heat sources is also adjustable. The dried and calcined spheres leaving the dryer are collected in a discharge hopper which is periodically transferred to another hood where the spheres are loaded into sintering boats.

The boats are pushed on schedule through a muffle tube furnace containing a cracked ammonia atmosphere. The spheres are reduced to UO_2 in the preheat zone and then sintered to nearly theoretical density in the high temperature (1500-1700°C) zone. The boats exit the furnace through a cooling chamber. The sintered spheres are then ready for inspection and transfer to the rod loading operation.

3.3 Equipment Installation and Checkout

Checkout and calibration of the equipment immediately followed its installation. A safety analysis report was also prepared before start-up of the pilot plant. The safety report analyzed potential hazards associated with the different sphere-pac operations and detailed the safety features designed into the process and maintained by administrative controls. A summary of the safety report is included as Appendix A.

4.0 TESTING OF UNIT OPERATIONS - (TASK III)

4.1 ADUN Preparation

During the reporting period, the pilot plant equipment was used to prepare two batches of ADUN for sphere processing. The physical properties of the ADUN produced in batches U-1 and U-2 are shown in Table II. Spheres of 4,000 micron wet diameter were successfully produced using the uranium solution from batch U-1. Except for some equipment problems, noted in the following section, the ADUN preparation portion of the sphere-pac pilot plant was successful on its first runs.

Some problems occurred during the preparation of the first batch. These problems and their resolution are listed below.

1. Some nitric acid fumes escaped through the cover on the dissolver during the acid add cycle. Since the unit is completely enclosed in a vented hood, no fumes escaped into the room. To prevent the escape of nitric acid fumes from the dissolver, a holddown latch and gasket were added to the dissolver cover.

TABLE II
ADUN PRODUCT PROPERTIES
BATCHES U-1 AND U-2

	<u>U-1</u>	<u>U-2</u>
Density	1.907 at 20°C	1.968 at 21°C
pH	1.50 at 20°C	1.43 at 21°C
Volume	13.5 liters	17.1 liters
Uranium Conc. (calculated)	2.88 molar	3.08 molar
Nitrate Conc. (calculated)	4.36 molar	5.18 molar
UO_3^-/U Ratio	1.685	1.683
Urea Added	2,950 g	3,953 g
Final Uranium Conc. (calculated)	2.42 molar	2.52 molar
Final Volume	16.1 liters	20.9 liters

2. The final 4,680 grams of U_3O_8 were added to the ADUN batch all at once. The reaction of the U_3O_8 with the excess acid still present caused foaming-over of the dissolver. Most of the material which spilled over was returned to the dissolver. As a result, the procedure was changed so that all U_3O_8 is added before the nitric acid.
3. The pump used to add the nitric acid failed shortly after the batch (U-1) was completed. It was found that the pump cylinder was not ceramic as had been ordered. The pump was replaced.
4. Much of the piping inside the hoods is nylon tubing. Almost immediately after completion of the first batch, the tubing connectors, also of nylon, began to fail. Although the tubing itself was not attacked, the nylon fittings were susceptible to chemical degradation by the ADUN and had to be replaced with stainless steel.

4.2 Sphere Forming

Testing of unit operations beyond the ADUN preparation have not yet begun.

5.0 EQUIPMENT DEVELOPMENT - (TASK IV)

The purpose of this task is to develop unique equipment which is needed to commercialize the sphere-pac process. Most development activities cannot begin until Task III is complete.

5.1 Sphere Forming Nozzles

A concept has been developed for using multiple nozzles simultaneously. A minimum of 6-8 nozzles is needed for a 6-inch diameter forming column to achieve sufficient throughput. The principal design problem is vibrating a manifold system containing multiple nozzles. The amplitude and frequency of vibration for each nozzle must be the same to produce consistent sphere diameters.

5.2 Sphere Size Control

A system has been procured for continuously analyzing the diameters of the spheres as they leave the forming column. The equipment is a Hiac* particle size analyzer. A sample of spheres would be continuously drawn through a photo cell which detects the light transmittance which then permits the diameter of the sphere to be calculated.

5.3 Continuous Dryer

A computer program was developed to analyze various drying equipment concepts for the gelled microspheres. A radiant heat transfer system was modeled using heat lamps and a vibratory feeder. The feeder vibrations move the spheres over a horizontal plate on which the heat lamps are focused. This provides a single layer of spheres moving-

* Trade name of Pacific Scientific Company, Montclair, CA.

with-agitation slowly through a controlled heat zone. Initial tests were with damp soybeans with subsequent tests using alumina microspheres of the proper diameter. This test program is now ready for uranium microspheres from the sphere forming operation.

6.0 DEVELOPMENT STUDIES - (TASK V)

Two process areas were defined which require significant development work to finalize a total process system for sphere-pac fuel fabrication. These are:

- UF_6 conversion to acid-deficient uranyl nitrate (ADUN)
- Treatment, recycle, and disposal of liquid wastes

Some conceptual work has started in these areas, with most activities awaiting start-up activities of Task III.

7.0 PLANT CONCEPTUALIZATION - (TASK VI)

Although a conceptual plant design is usually the last phase of a program, it was decided to do a preconceptual design to determine if process and equipment development programs are properly directed. The initial flowsheets have been prepared and are currently being reviewed. The major areas of uncertainty are the UF_6 conversion process and the waste treatment systems. These represent a significant quantity of equipment and operating manpower. Innovations in these two areas as outlined in Task V could result in some simplification of the sphere-pac fuel fabrication process.

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APPENDIX ASAFETY ANALYSIS SUMMARY

A safety analysis was prepared to analyze the adequacy of the safety systems associated with the sphere-pac test facilities. The unusual or significant items identified by the analysis are summarized below.

I. CHEMICAL SAFETY

Material safety data sheets for the potentially hazardous chemicals used in the sphere-pac process were analyzed. Chemical safety concerns were noted for the following:

- Hexamethylenetetramine (HMTA) - is a colorless, odorless crystalline compound with a sweet metallic taste. It can be readily ignited and burns with a bluish-yellow flame. Some persons suffer a skin rash if they come in contact with it or the fumes evolved when it is heated. It has no significant toxicity since it is used as a urinary antiseptic. HMTA is used as a starting material for explosives production, but chemicals necessary to make an explosive do not exist in the sphere-pac laboratory.
- Nitric Acid - is a relatively common acid used in laboratories and industry. The principal precautions are those associated with handling the acid. It is a powerful oxidizer and is highly irritant to the mucous membranes of eyes and respiratory tract and to the skin. Nitric acid is used to dissolve U_3O_8 to form acid deficient uranyl nitrate. The dissolution reaction liberates NO_x fumes which are a strong irritant. The NO_x fumes

are released in a controlled manner in the dissolver and vented from the feed makeup enclosure through the ventilation system to the scrubber before passing through the final HEPA filters and exiting the building. The scrubber contacts the offgas stream with an ammonium carbonate solution which effectively removes the NO_x fumes.

- Ammonium Hydroxide - is another common chemical found in most laboratories. A concentrated solution can emit toxic fumes if heated. The liquid can inflict burns to the skin.
- Uranium Oxide - constitutes a potential radiation hazard, but does not represent a chemical hazard in the usual manner. Special work procedures have been instituted to cover the laboratory operations with respect to uranium. Only depleted uranium will be used in the development program. The uranium compounds do constitute a heavy metal poison potential.

II. TOXIC MATERIALS

The toxic hazard associated with sphere forming is the control of trichloroethylene vapors. The current threshold limit value (TLV) is 100 ppm because of complaints of dizziness and nausea at this level. The odor threshold is 50 ppm. The vapor levels are controlled by placing all processing equipment containing TCE inside ventilated enclosures. All TCE additions to the process equipment are made from closed drums via a sealed pump.

III. WASTE DISPOSAL

The main liquid waste stream from the process will be from the ammonia wash column. All drains in the laboratory or change room are connected to a special drain system, the liquid from which is collected

in dual 500 gallon holding tanks. Any potentially contaminated liquid from the labs cannot leave except through the special drain system. When one tank is full it is sampled and analyzed for uranium. If the analysis is less than 5 ppm uranium, the tank is pumped to the sewer system. If the uranium content is greater than 5 ppm, the contents must be hauled to an evaporative lagoon for disposal.

Except for uranium, most of the chemical wastes that are produced by the sphere-pac process are nitrogen-containing compounds such as ammonia, ammonium nitrate, urea, and HMTA. These do not constitute a hazard to a sewage treatment plant since they are microbial nutrients.

IV. FIRE AND EXPLOSIONS

The fire and explosions hazards analyzed fall in two categories - trichloroethylene and hydrogen produced from ammonia in the sintering furnace.

- Trichloroethylene

The fire hazard associated with TCE is minimal. Most references indicate TCE is nonflammable and do not list a flash point. However, recent work at the U.S. Bureau of Mines Explosives Research Laboratory discloses that concentrations in air exceeding 12.5% can be ignited if the temperature exceeds 85°F. The operating temperature of the TCE system is 55°C or 131°F.

A detailed analysis of the potential fire hazard associated with TCE during accident conditions showed the maximum credible accident is the simultaneous breaking of two glass sphere forming columns containing TCE at 55°C or 131°F. The

contents of the columns could produce a vapor concentration in excess of the lower combustible limit of 12.5% and could heat a quantity of such vapor to the ignition temperature of 85°F. Further analysis showed approximately 10% of the liquid could be vaporized if all the latent heat of the liquid were involved. This could result in 300 ft³ of vapor containing 12.5% TCE.

All of the analyses are unable to eliminate the potential of TCE being a fire hazard. However, when the magnitude of a potential fire or explosion was analyzed, a different conclusion evolved. High concentrations of trichloroethylene vapor in high temperature air can be made to burn only mildly if plied with a strong flame. Though such a condition is difficult to produce, flames or arcs should not be used in closed equipment which contains any TCE residue or vapor. This would explain why it is impossible to measure a flash point with a standard open or closed cup apparatus, since the vapor in such an apparatus is ignited with a hot wire. Based on the above information, it was concluded that the TCE does not constitute a significant fire hazard.

- Hydrogen Atmosphere Sintering Furnace

The use of hydrogen to reduce UO_3 to UO_2 represents a potential fire or explosion hazard. Ammonia gas is primarily used as the source of hydrogen. The ammonia gas does not constitute a significant fire or explosion hazard until it is cracked in the sintering furnace. The furnace safety controls are designed to prevent any fire or explosion.

The ammonia gas is metered into the furnace shell and furnace muffle tube. A natural gas flame is provided as a flame curtain to ignite the exiting hydrogen containing gas as is standard on such furnaces. An exit port and ignition flame is also provided for the furnace shell gas. Ventilation ducting is located above each flame curtain or pilot light to provide a rapid exhaust of any combustion products or combustible gas. Appropriate electrical safety circuits and combustible gas alarms provide a safety system which minimize the potential for a fire or explosion. The safety system is standard for commercial or laboratory sintering furnaces using hydrogen.

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