MODULE 4.0: GAS CENTRIFUGE

Introduction

Welcome to Module 4.0 of the Uranium Enrichment Processes Directed Self-Study Course! This is the fourth of seven modules available in this self-study course. The purpose of this module is to assist the trainee in describing the general principle of the gas centrifuge technology and general facility and component layout, identifying the uses of the centrifuge process in industry and the production amounts of enriched uranium, and identifying the hazards and safety concerns for the process, including major incidents. This self-study module is designed to assist you in accomplishing the learning objectives listed at the beginning of the module. The module has self-check questions and an activity to help you assess your understanding of the concepts presented in the module.

Before You Begin

It is recommended that you have access to the following materials:

☐ Trainee Guide

Complete the following prerequisite:

☐ Module 1.0 Introduction to Uranium Enrichment

How to Complete This Module

1. Review the learning objectives.
2. Read each section within the module in sequential order.
3. Complete the self-check questions and activities within this module.
4. Check off the tracking form as you complete the self-check questions and/or activity within the module.
5. Contact your administrator as prompted for a progress review meeting.
6. Contact your administrator as prompted for any additional materials and/or specific assignments.
7. Complete all assignments related to this module. If no other materials or assignments are given to you by your administrator, you have completed this module.
8. Ensure that you and your administrator have dated and initialed your progress on the tracking form.
9. Go to the next assigned module.

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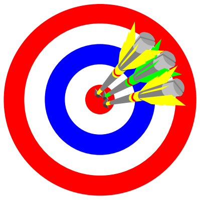


4.1 Upon completion of this module, you will be able to describe the gas centrifuge enrichment process.

4.1.1 Describe the principles of the gas centrifuge process.

4.1.2 Describe general facility and component layout of the gas centrifuge enrichment process.

4.1.3 Identify the uses of the gas centrifuge process in industry and the required production amounts of enriched uranium.

4.1.4 Identify the hazards and safety concerns for the gas centrifuge process, including major incidents.

4.1.5 Summarize Case Study 1: Summary of Proposed Claiborne Enrichment Center.

4.1.6 Summarize Case Study 2: Summary of Proposed National Enrichment Facility.

4.1.7 Summarize Case Study 3: Summary of Proposed American Centrifuge Plant.

Learning Objective

When you finish this section, you will be able to:

4.1.1 Describe the principles of the gas centrifuge process.

PRINCIPLE OF THE GAS CENTRIFUGE PROCESS

The use of centrifugal fields for isotope separation was first suggested in 1919, but efforts in this direction were unsuccessful until 1934, when J.W. Beams and coworkers at the University of Virginia applied a vacuum ultracentrifuge to the separation of chlorine isotopes. Although abandoned midway through the Manhattan Project, the gas centrifuge (GC) uranium enrichment process has been highly developed and used to produce both highly enriched uranium (HEU) and low enriched uranium (LEU).

The centrifuge separation process uses the principle of centrifugal force to create a density gradient in gaseous uranium hexafluoride (UF_6) that contains components of different molecular weights. In this uranium enrichment process, gaseous UF_6 is fed into a cylindrical rotor that spins at high speed inside an evacuated casing or stator. Because the rotor spins so rapidly, centrifugal force results in the gas occupying only a thin layer next to the rotor wall, with the gas moving at approximately the speed of the wall. Centrifugal force causes the heavier UF_6 molecule containing U-238 atoms to move closer toward the outer wall of the cylinder and the lighter UF_6 molecule containing U-235 atoms toward the axis, thus partially separating the uranium isotopes. This separation is increased by a relatively slow axial countercurrent flow (CCF) of gas within the centrifuge that concentrates gas enriched in U-235 at one end and gas depleted in U-238 at the other. This flow can be driven mechanically by scoops and baffles or thermally by heating one of the end caps. The stream that is enriched in U-235 is withdrawn and fed into the next higher stage, while the depleted stream is recycled back into the next lower stage. The principle of the countercurrent gas centrifuge is illustrated in Figure 4-1, “Idealized Schematic of Gas Centrifuge.”

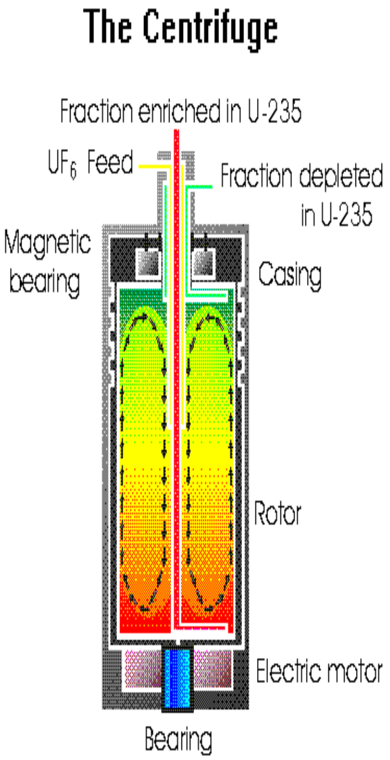
The Process

The renewed interest in the GC process is driven by the promise of lower cost enrichment. Enrichment cost estimated in 2007 for GC process was \$60/SWU vs. \$120/SWU or more for GDP. GC promises:

- Larger enrichment effect per stage (>1.05 vs. 1.004 for GDP)
- Smaller facilites than GDPs
- Reduced uranium inventories in cascades
- Better energy efficiencies

- More rapidly achieves equilibrium/steady-state (< 1 day vs. “weeks” GDP)

Figure 4-1. Idealized Schematic of Gas Centrifuge



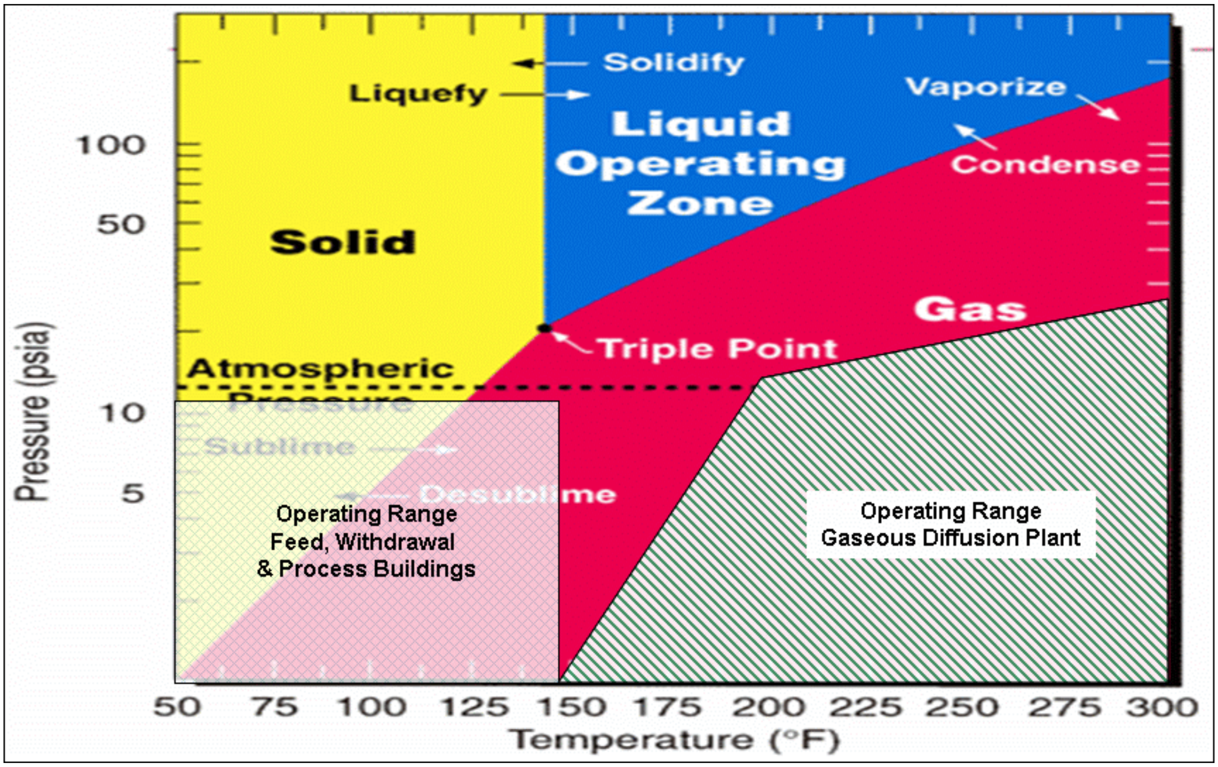
Note:
- Axial connections
- Rotor in casing (stator)
- Vacuum pull on stator
- CCF effect
  - heat bottom
  - cool top
- Bearings

The main operations and steps of the gas centrifuge process are similar to the steps in the gaseous diffusion process:

- Feed cylinder receipt and storage
- Cylinder purification and vaporization/feed to the cascade
- GC enrichment cascade
- DU tails withdrawal and storage
- Product withdrawal
- sampling (usually the product cylinders)
- Product storage and shipping
- Associated emissions, effluent, and waste management systems

As shown in Figure 4-2, GC facilities generally operate at lower temperatures and pressures than gaseous diffusion plants, and provide higher separation effects. Hazards are generally lower, particularly if liquid UF_6 is minimized during plant operations. This can be accomplished, for example, by using sublimation and desublimation in the feed and withdrawal areas, and restricting liquid UF_6 to the interiors of autoclaves (e.g., during sampling, and no movement of liquefied cylinders).

Figure 4-2. UF_6 Phase Diagram



GCs achieve higher separations per machine, and thus, fewer stages are needed to produce the desired enrichment assay. However, more GCs/stages are needed in parallel in order to meet throughput requirements. This combination of GCs is termed a cascade. Figure 4-3 shows a schematic of a GC cascade. In general, multiple cascades are used in operating facilities. Thus, implementation of GC enrichment can be accomplished in an incremental, modular manner, allowing enrichment operations to begin before the entire plant is completed or to meet additional demand.

As noted, GC uranium enrichment has been around for a long time. Large scale implementation was limited by engineering and material difficulties, and the success of the gaseous diffusion process. However, small groups of researchers continued working on GC enrichment technology and sufficient, significant improvements were made by the 1960s to prove the viability of the process. The U.S. teams favored larger GCs (200 and now 300+ SWU per GC) while the European researchers focused on smaller machines (40-100 SWUs per GC). The larger GCs require maintenance every two years or so, while the smaller GCs are more reliable and are usually allowed to fail in place, with isolation. The use of metallic components (first aluminum and then maraging [nickel] steels) and then composite materials allowed for increased production per GC. On average, it has taken about eight years for implementation of each new GC series – about 2-3 years for R&D, about 2-3 years for production testing, and about 2-3 years for manufacturing and installation. Figure 4-4 graphically shows the improvements. Currently, Urenco is implementing their sixth generation GCs.

Figure 4-3. Schematic of Gas Centrifuge Cascade Arrangement

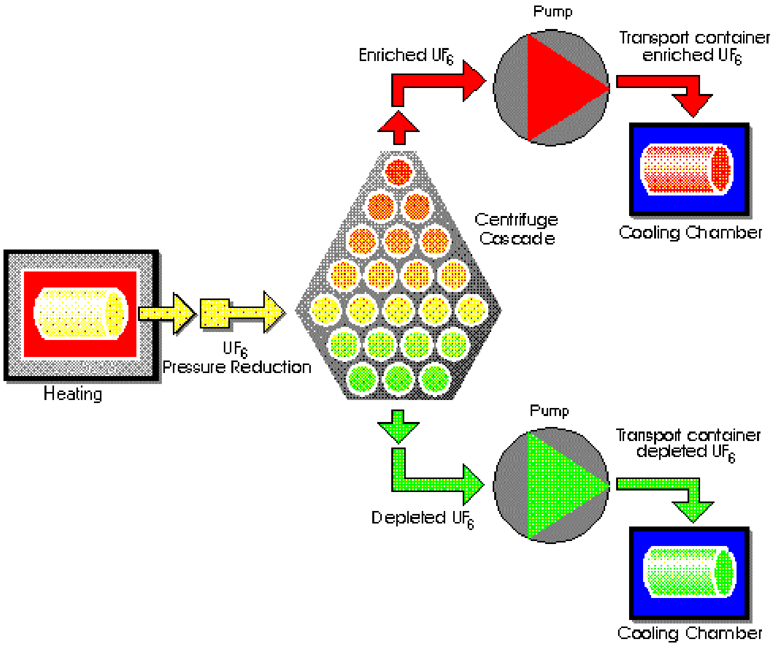
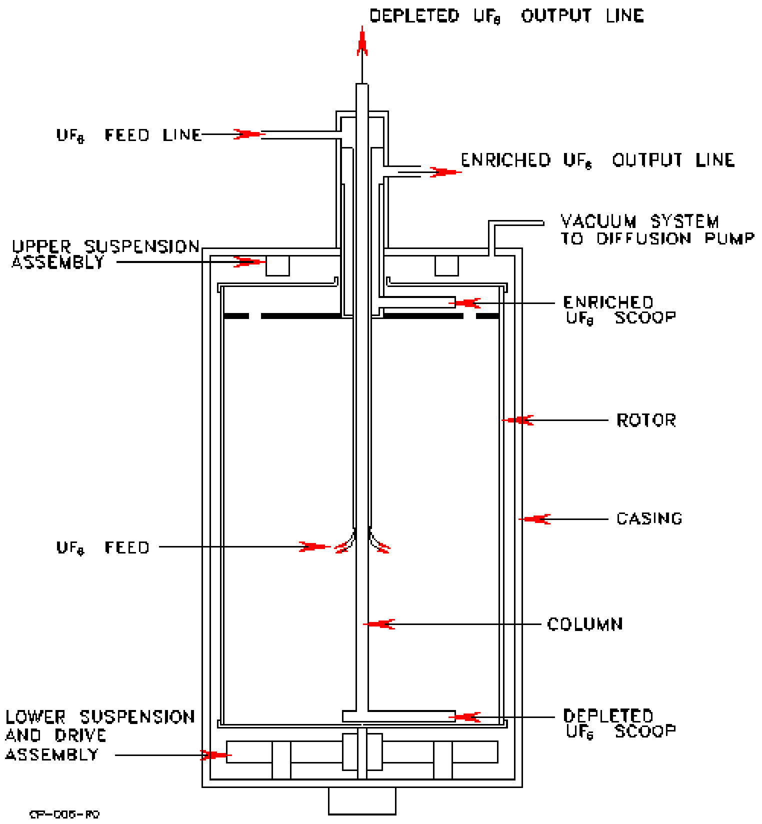


Figure 4-4. Gas Centrifuge Schematic



The GC must operate at rotational speeds above natural harmonics of the gas centrifuge, so controls must monitor vibrations and allow rapid traversing of rotational speeds corresponding to natural harmonics. The bearings and drives must accommodate imperfections and vibrations during acceleration and deceleration.

There are tens of thousands of GCs in a plant. GCs do "break." Reliability and isolation after failure are important issues in the process. The GC design must accommodate repair and replacement and ES&H standards must be maintained throughout the process. The current approach to NRC regulation is to use revised Part 70 and Subpart H as guidance.

See Section 4.1.3, “Industrial Use,” for more information on GC technology world-wide.

Principal Components The principal components of a gas centrifuge and a brief description of each component are listed in Table 4-1.

Table 4-1. Gas Centrifuge Components and Brief Description

Component	Description
Center post	The gaseous UF_6 feed, enriched, and depleted streams are introduced and withdrawn through a three-chambered, stationary center post. The post penetrates through a hole in the center of the top end cap. The feed stream is introduced at a constant rate into the rotor through the center post.
Scoops	The enriched and depleted fractions are withdrawn at opposite ends of the rotor through stationary scoops that extend from the center post outward into the spinning gas. A scoop also introduces aerodynamic drag, which induces an axial circulatory UF_6 gas flow.
Rotor	A thin-walled cylinder (12 mm or less and a diameter of 75 mm to 400 mm) that is rotated inside the casing. Multiple rotors can be joined together by bellows to extend the length of the centrifuge. The rotor is driven by an electric motor. The motor armature is a flat, hardened steel plate attached to the bottom of the rotor. The stator is fed by an alternator at a frequency synchronous with the rotor speed.
Baffle	Disc shaped and has holes to allow the gas to leak from the main rotor cavity into the area near the scoop. A baffle is needed at one end to keep the scoop from imposing a vertical flow that would counteract the circulatory flow generated by the scoop at the other end.
End caps	Disc shaped and used to close the rotor at the top and bottom so that the UF_6 cannot escape from the rotor. The top end cap has a central hole through which the center post enters the rotor.
Molecular pump (optional)	Used to maintain a low pressure between the rotor and the casing. Trace amounts of gas may leak from the interior of the rotor through the small annular gap around the stationary central post at the top of the centrifuge. This gas is confined to the cavity above the rotor by a close-fitting, spiral-grooved sleeve that serves as a very efficient pump. The cavity above the rotor is evacuated by an external vacuum system.

Table 4-1. Gas Centrifuge Components and Brief Description

Component	Description
Top and bottom suspension systems	Serve the following functions: (1) reliably support the rotor at full speed, (2) control the rotor at startup and run-down speeds, and (3) allow the rotor to rotate about its center of mass. The suspension consists of an oil-lubricated pivot and cup bearing at the bottom of the rotor and a magnetic bearing at the top of the rotor. The rotor spins about a thin, flexible steel needle that rotates in a hardened depression in a metallic plate at the base of the centrifuge. The bottom bearing assembly includes a mechanism for damping lateral and axial rotor vibrations. The magnetic bearing supports and centers the top end of the rotor without touching the rotating components. It provides some lift to relieve the load on the bottom bearing and dampens vibration by providing radial stabilizing forces.
Casing	Provides a vacuum-tight enclosure for the rotor to minimize the drag on the rotating parts and thus reduce power consumption resulting from gas friction when the rotor is spinning. Provides a physical barrier for protection from flying debris in the event of a machine failure. It is important to the operation of the plant that the failure of one machine does not cause the failure of adjacent machines.

Because UF_6 is corrosive, all components in contact with UF_6 must be corrosive resistant. The process operates at essentially room temperature and at low concentration or pressure of UF_6. For these reasons, much use is made of aluminum for piping and machine components. Aluminum can be used at centrifuge operating conditions because when aluminum reacts with UF_6 a tightly adhering aluminum fluoride coating is formed and that coating protects the underlying metal.

Separative Capacity

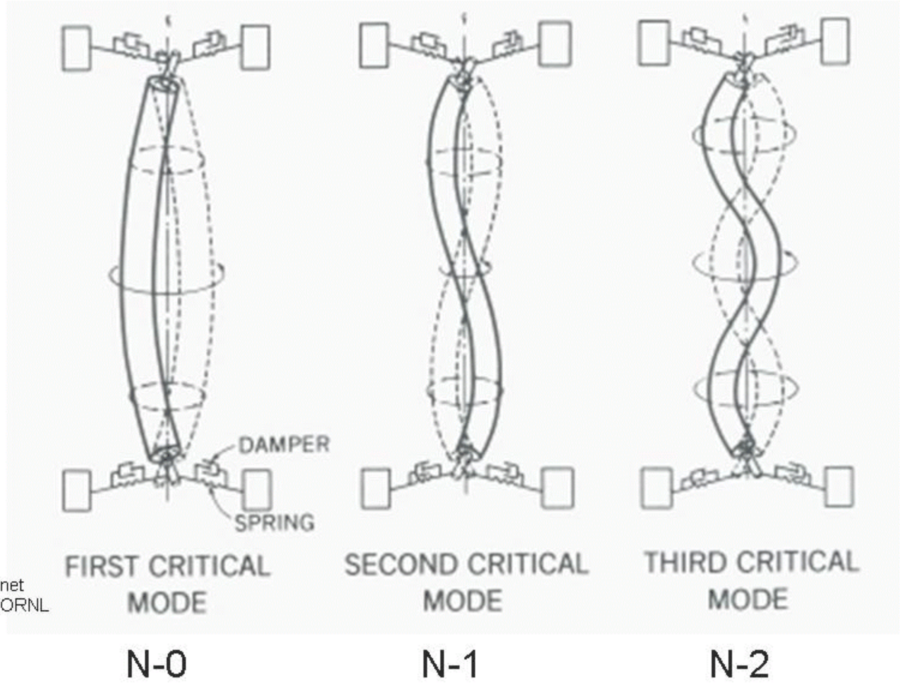
The theoretical maximum separative capacity is proportional to rotor length and varies with the fourth power of the rotor speed. In practice, the obtainable separative capacity varies approximately as the square of the rotor speed.

The very high rotational speed of centrifuge causes mechanical stresses in the outer wall. These stresses increase with rotor speed (rpm) and diameter. The peripheral speed of the rotor is limited by the strength-to-density ratio of the rotor construction materials. Suitable rotor materials include alloys of aluminum or titanium, maraging steel, or composites reinforced by certain glass, aramid, or carbon fibers. Aluminum alloys and stainless steels are capable of rotor peripheral speeds slightly in excess of 400 m/s. Peripheral speeds can exceed 500 m/s using maraging steels (strong, low-carbon steels which contain up to 25% nickel). Even higher speeds have been achieved using glass-fiber and carbon-fiber composites. Consequently, composite technology is preferred for large scale commercial plants. The choice of materials suitable for centrifuge components is limited by the corrosive nature of the UF_6 process gas.

The length of the rotor is limited by rotor dynamics. The rotor must be carefully balanced and damped to prevent wobbling and vibration. This is especially critical to avoid early failure of the bearing and suspension systems. Because perfect balance is not possible, the suspension system must be capable of damping some amount of vibration. Major factors affecting the rotor dynamics include the straightness of the rotor, the uniformity of the wall, and the damping characteristics of the bottom bearing system.

Another concern with centrifuges that have a large length to diameter ratio is the problem of achieving operating speeds after shutdowns, say, caused by power interruptions. Centrifuges have natural harmonic resonance frequencies that can result in standing wave patterns, often called critical modes. These induce additional vibrations and stresses on GC rotors, and often result in failures. The problem is more pronounced for longer and higher speed machines, and smaller diameters. Figure 4-5 illustrates several mode patterns, each one of which corresponds to a certain speed for the materials and geometries involved. Attempted operation in a critical mode would likely result in excessive vibration and wall stresses, leading to mechanical failure of the GC rotor. Operation at higher rotational speeds to achieve higher separation or SWU capacity often requires exceeding one or more critical modes. These are termed supercritical GCs. Therefore, during rotor acceleration for resuming operations after a shutdown, the rotor must rapidly traverse these critical modes, which requires special motor controls, bearings, and dampening systems.

Figure 4-5. Natural Harmonics



[from Internet And DOE/ORNL Papers]

A typical peripheral speed for an aluminum rotor is 350 meters per second (m/s). For a more representative sense of this speed, you can convert the peripheral speed in m/s to revolutions per minute (rpm). This is done by dividing the peripheral speed by the circumference (Pi diameter) of the rotor and converting seconds to minutes. For example,

Given: centrifuge diameter = 12 in. (30 cm)
typical peripheral speed = 350 m/s (this is the speed of the outer edge of the spinning rotor)

In rpm, calculate how fast a centrifuge rotates.

circumference = $\pi(0.30\text{ m}) = 0.94\text{ m/rev}$

@ 350 m/s, the centrifuge rotates (350 m/s)/(0.94 m/rev) = 371 rev/s

Therefore, speed = (371 rev/s)(60s/min) = 22,282 rpm

An increase in the speed to, say, 700 m/sec would require double the rpms, or 44,564.

One of the key components of a gas centrifuge enrichment plant is the power supply (frequency converter) for the gas centrifuge machines. The power supply must accept alternating current (ac) input at the 50- or 60-Hz line frequency available from the electric power grid and provide an ac output at a much higher frequency (typically 600 Hz or more). The high-frequency output from the frequency converter is fed to the high-speed gas centrifuge drive motors (the speed of an ac motor is proportional to the frequency of the supplied current). The centrifuge power supplies must operate at high efficiency, provide low harmonic distortion, and provide precise control of the output frequency.

The casing is needed both to maintain a vacuum and to contain the rapidly spinning components in the event of a failure. A gas centrifuge unit operating at high speeds could generate flying pieces of equipment and material as a result of the destruction of the rotor and other spinning components. If the shrapnel from a single centrifuge failure is not contained, a "domino effect" may result and destroy adjacent centrifuges. A single casing may enclose one or several rotors.

Many gas centrifuges are needed in commercial facilities – typical numbers exceed 10,000 per plant. Consequently, capacity per machine (SWU), reliability, and detection/isolation (after failure or for maintenance) become very important. Reliability can be measured several different ways; the two most applicable to GCs are mean time between failures (MTBF) and failure rate (as a number or percentage per year). Mechanical equipment in the chemical industries have typical MTBFs of 3-10 years (this is why annual shutdowns or preventative maintenance are performed). Using 10,000 GCs as a basis, this implies half the facility's capacity would be lost in ten years or less – potentially several a day (linear basis) – without maintenance and/or replacements; the latter are difficult to do in the confines of a commercial GC plant. Urenco has taken the approach of using very reliable small GCs, without routine repair or replacement, and has stated failure rates of less than 0.5%/yr. and, more recently, less than 0.1%/yr. A failure rate of 0.5%/yr. corresponds to 50 GCs/yr. or 1,500 GCs over a 30 year period (a typical planned operational lifetime for GC plants) for a 10,000 GC plant, a loss of 15% of capacity. A failure rate of 0.1%/yr. would correlate with 10 GCs failing per year or 300 over 30 years, a more manageable loss of 3% of capacity. Urenco has stated additional GCs are installed in its facilities to account for these failures. Urenco had a high percentage of GCs installed in its facilities in the 1970s that are still operating today. Urenco includes additional, extra GCs in its design to accommodate the small production loss from failed centrifuges.

The larger GCs are also very reliable, although reliability information has not been published. However, the operational philosophy is to perform routine, preventative maintenance on a schedule, such as every two to five years or so. Consequently, the facility designs incorporate this planned maintenance with additional cranes, access/spacing, valves, transporting containers, maintenance facilities, and ES&H requirements. The intent is to make this as simple as changing a light bulb. A two year maintenance interval corresponds to about 15 GCs/day while a five year interval gives about 6 GCs/day, for a 10,000 GC facility. The larger GCs have not been operated as long as the smaller designs and have not been operated commercially.

The physical size and separative capacity of gas centrifuges vary. European and Japanese centrifuges are relatively small (25 centimeters in diameter and 2 meters to 4 meters long) and have separative capacities in the range of 5 SWU/year to 100 SWU/year. The U.S.-designed centrifuges were substantially larger and had separative capacities up to 10 times larger.

Enrichment theories show that a higher degree of U-235 enrichment can be obtained from a single unit gas centrifuge than from a single unit gaseous diffusion barrier. The separation factor available from a single centrifuge is about 1.05 to 1.2 as compared to 1.004 for a gaseous diffusion stage. However, the throughput rate of UF_6 that can be processed by a single centrifuge is very small compared to a gaseous diffusion stage. Although they differ in the type and function of the enrichment equipment used to process the UF_6, gas centrifuge and gaseous diffusion enrichment plants use similar process, equipment, and safety systems for UF_6 feed and withdrawal of product and tails. However, most new GC facility plants and designs minimize the use of liquid $UF_{6.}$ Feed is sublimed, while tails and products are withdrawn by desublimation.

The electrical consumption of a gas centrifuge facility is much less than that of a gaseous diffusion plant of the same SWU capacity: a typical GC plant consumes less than 5% of the electricity used by an equivalent sized GDP. Consequently, a centrifuge plant will not have the easily identified electrical and cooling systems typically required by a gaseous diffusion plant.

Self-Check Questions 4-1 ✓

Complete the following questions. Answers are located in the answer key section of the Trainee Guide.

1. What is the feed material for the gas centrifuge enrichment process?

2. The centrifuge separation process uses the principle of centrifugal force to create what?

3. What happens to U-235 and U-238 atoms in the centrifuge process?

4. What increases separation?

5. What are the major components of a gas centrifuge?

6. How and through what component is the feed stream introduced into the rotor?

7. Why and how can multiple rotors be joined together?

8. How is a rotor driven?

9. What is the purpose of a baffle?

10. How are end caps used?

11. Why is an optional molecular pump used?

12. What are the three functions of the top and bottom suspension systems?

13. What is the purpose of the casing?

14. What factors influence the separative capacity of a gas centrifuge?

15. What is limited by the strength-to-density ratio of the rotor construction materials?

16. What are some major factors that affect the rotor dynamics?

17. What concern exists with centrifuges that have a large length-to-diameter ratio?

18. One of the key components of a gas centrifuge enrichment plant is the power supply (frequency converter) for the gas centrifuge machines. How should the power supply operate?

19. List two differences between a gas centrifuge facility and a gaseous diffusion facility.

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

Learning Objective

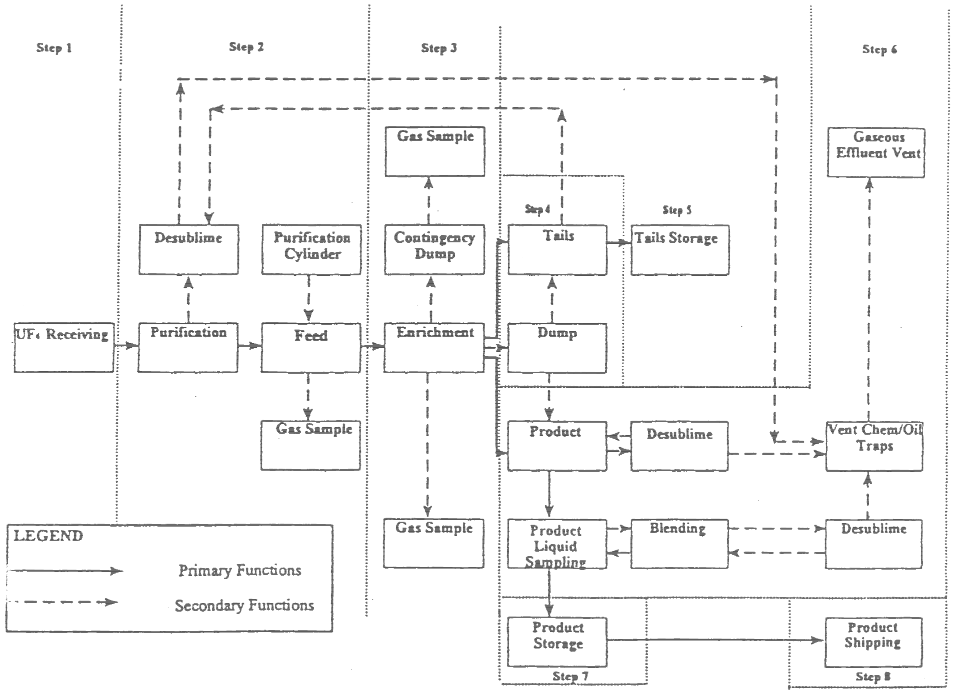
When you finish this section, you will be able to:

4.1.2 Describe general facility and component layout of the gas centrifuge enrichment process.

GENERAL FACILITY DESCRIPTION AND COMPONENT LAYOUT

This section describes a generic layout for a gas centrifuge facility. The proposed Claiborne Enrichment Center centrifuge process block diagram illustrated in Figure 4-6 has been included to assist in visualizing steps in a gas centrifuge process.

Figure 4-6. Block Diagram of Proposed Claiborne Enrichment Center (CEC) Centrifuge



Process Material Flow

Major nuclear material flows at a gas centrifuge enrichment facility include receipt of UF_6 feed material onsite, transfer of feed material from UF_6 cylinders to the process system, transfer of enriched and depleted process gas to product and tails cylinders, and shipment of product cylinders offsite. Minor material flows include sample transfers to an analytical laboratory, process equipment transfers for decontamination and repair, and waste transfers to the scrap recovery and waste treatment areas.

Feed Receipt and Storage

Upon receipt at the enrichment plant, UF_6 feed cylinders may be weighed, inspected, and liquid sampled (optional) to establish nuclear materials accountability values (via destructive analysis) and to verify specifications by the enricher and customer. The cylinders are then placed in a storage area. When it is time for the contents of a full feed cylinder to be fed into the process, the cylinder is moved from the storage area to the feed area.

Feed Purification and Vaporization

In the feed area, cylinders containing feed material are placed in autoclaves (heating stations) where they are heated to convert the UF_6 from solid to gas. Light gas impurities are removed from the UF_6 at this time before the UF_6 is introduced into the enrichment system. The UF_6 is purified by venting the cylinders to remove light gases such as oxygen, nitrogen, and hydrogen fluoride (HF). This is accomplished in two purification steps. The initial step is called cold purification and involves venting the cylinder while the UF_6 is solid at ambient temperature. During cold purification, safety controls automatically disable the feed autoclave heater and prevent inadvertent heating of the cylinder. The vented light gases pass through a desublimer and chemical traps to remove uranium and HF before being released to a gaseous effluent vent system. This provides assurance of contaminant control by filtering the vent gases through cold feed high efficiency particulate air filters and activated carbon filters before releasing the gas to the atmosphere. This purification process is repeated until the desired purity is achieved.

Note: The feed and purification segment of the plant includes the feed autoclaves, purification desublimers and cubicles, and associated valves, piping, and controls. The primary controls are the heater protection circuits of the autoclaves and the state switches for the autoclave, desublimer, and purification cubicle. A state switch is a multifunctional selector which activates control circuits for process elements including valves and pumps.

The primary process control functions of the autoclave are heating and evaporating or subliming the UF_6 and controlling the flow leaving the autoclave. Control of heating rate is determined by monitoring the cylinder exit pressure, which is directly related to UF_6 temperature and phase state. Flow rate of UF_6 is controlled by monitoring autoclave exit line pressure, which is determined by the pressure drop across the control valve located inside the autoclave. Positioning of valves other than the autoclave exit flow control valve is determined by the states selected on the autoclave and desublimer state switches. Thus, for cold purification, the autoclave state switch is in the cold purify position, the desublimer state switch is in the purification position, the valves leading to the cascades and the purification cubicle are closed, the inlet valve to the desublimer is open, and cold refrigerant cools the desublimer. Similar considerations and valve positioning are also determined for other purification and feed functions.

The new designs for GC facilities use sublimation and avoid liquid UF_6. Sublimation can be performed in an autoclave or an oven.

The second step is called hot purification and involves heating the UF_6 cylinder. In traditional FC facilities and designs (older Urenco facilities and the LES-1 design) the cylinder contents are liquified. The UF_6 is liquified by heating the exterior of the feed cylinder with hot air within the autoclave. The temperature of air is controlled to maintain specific pressure as the UF_6 is liquified. The cylinder is again vented to the desublimer to remove light gas contaminants that may have been trapped in the solid UF_6. Typically, only one hot purification cycle is performed for each cylinder. Once the desired purity is reached, the feed cylinder vent valve is closed and the cylinder is maintained in a standby mode with the UF_6 still in the liquid state.

New GC facilities and designs heat the cylinder to about 125°F and sublime the contents for hot purification and subsequent UF_6 feeding.

After feed purification, a valve in the line from the cylinder to the cascade is opened and gaseous UF_6 flows from the cylinder to the cascade. The UF_6 feed cylinder temperature and pressure are controlled during the feed cycle. The UF_6 gas is above atmospheric pressure when it leaves the cylinder, but is passed through a motor-operated pressure reduction valve located inside the autoclave. When the contents of the feed cylinder are nearly removed, another autoclave is brought on-line to supplement the decreasing flow of UF_6 from the original feed cylinder, thereby maintaining a continuous feed flow to the cascade.

When the feed cylinder is almost empty, it is isolated from the feed header. The cylinder is then vented to the purification desublimer to evacuate residual UF_6 (cylinder heel). After removal of the residual UF_6, the cylinder is allowed to cool.

When the desublimer reaches its UF_6 operational fill limit, it is heated by Freon supplied by a hot refrigerant system to sublime the trapped UF_6 for gaseous transfer and collection in a feed purification cylinder.

The gaseous UF_6 recovered is desublimed by spraying the cylinder with cooled water at 4°C (39°F). Cooling water is supplied by a spray cooling water system.

Enrichment (Stage and Cascade System)

The gaseous UF_6 passes through piping to a pressure-reduction station and is drawn through pipes leading into the cascade system. The pressure-reduction station and the piping leading to it are heated to prevent the gaseous UF_6 from cooling and solidifying in the pipes and valves. Heating is not required downstream from this station because the UF_6 is at low pressures and remains gaseous at ambient temperatures. However, operating plants and designs sometimes include heating as a precaution.

GC facilities are organized into cascades. Each cascade is the discrete smallest unit of the facility that produces uranium of the desired enrichment. The cascade includes GCs connected in parallel or series with a cascade capacity of 10,000–150,000 SWU/yr. The total number of GCs in a single cascade is typically 500–3,000, for a cascade capacity of 10,000–150, 000 SWU/yr. Centrifuges are connected in parallel groups called "stages" using a sufficient number of centrifuges to provide the desired material flow rate for that intermediate assay level. Sufficient numbers of stages are connected in series to achieve the desired enrichment span (or "concentration range") for the plant. The stages between the points where the feed is introduced and the product is withdrawn are called the "enriching stages," or more simply, the "enricher." The stages between the points where the feed is introduced and the depleted stream is withdrawn are called the "stripping stages" or the "stripper." See Figures 4-7 and 4-8.

Figure 4-7. Centrifuge Stage Arrangement

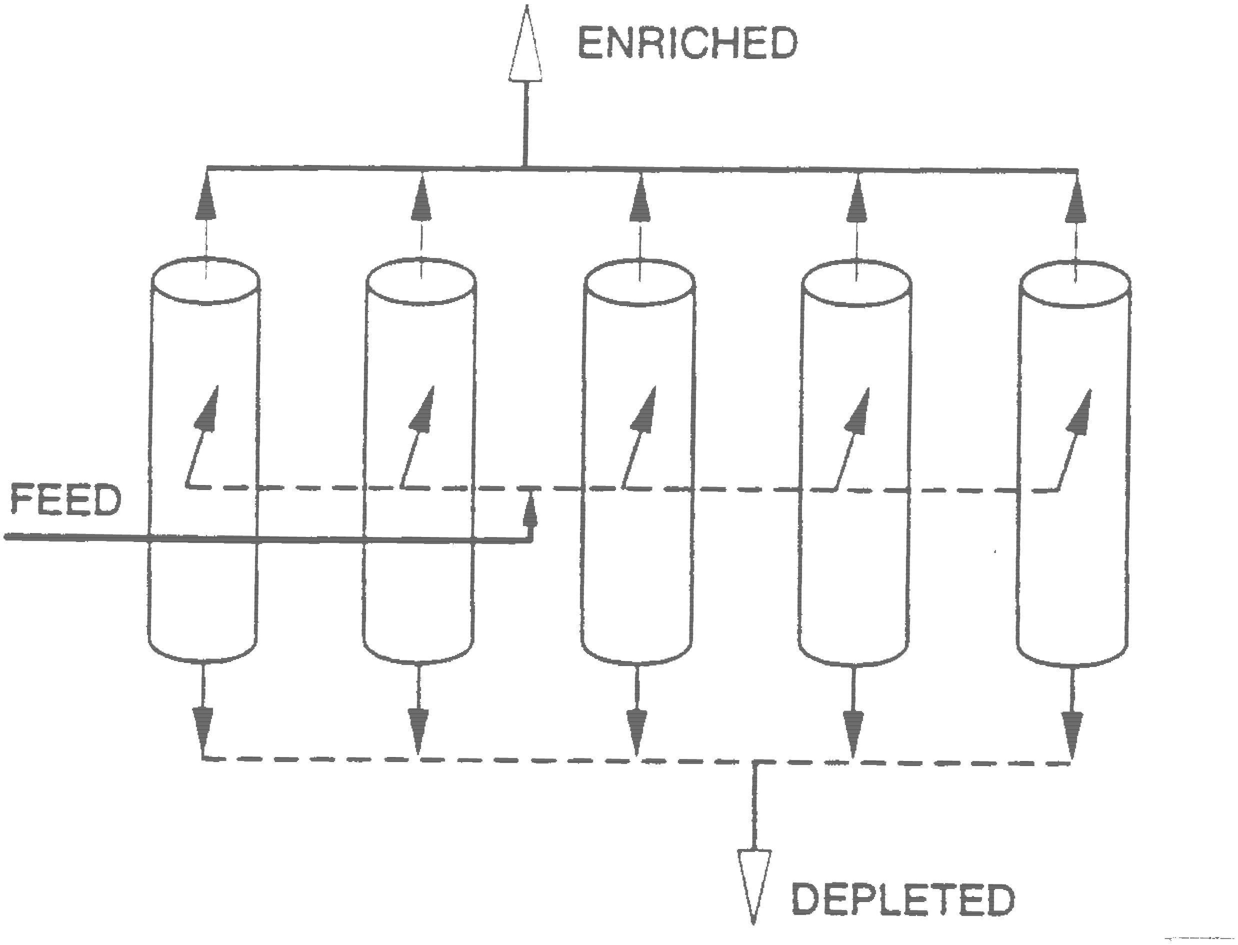
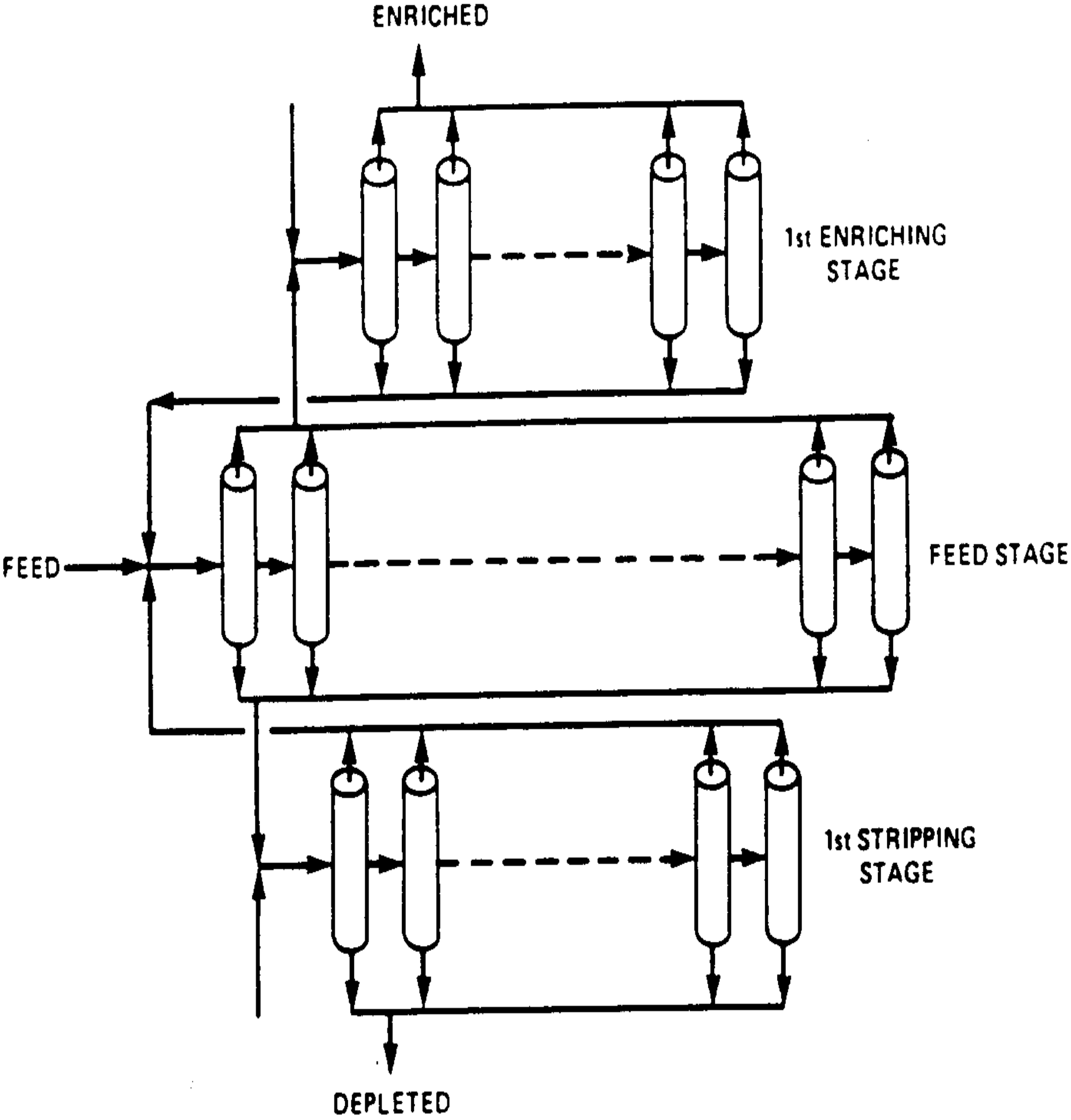


Figure 4-8. Centrifuge Cascade

Enriching, Feed, and Stripping Stages Require a Different Number of Centrifuges for an Efficient Cascade.



The number of stages that are connected in series to form a cascade depends on the desired U-235 concentration of the feed, product, and tails streams and on the magnitude of the stage separation factor.

Stages are cascaded so that the enriched stream of a stage is introduced as feed material to the next stage and the depleted stream is introduced as feed material to the previous stage. In other words, the feed material to a specific stage is composed of enriched material from the previous stage and depleted material from the next stage. With this arrangement, only streams of identical isotopic concentrations are blended, which minimizes separative work losses resulting from mixing streams of differing concentrations. The enriched stream concentration from a stage matches the feed stream concentration to the next stage, and the depleted stream concentration matches the feed stream concentration to the previous stage.

The number of centrifuges that are connected in parallel in each stage depends on the desired product withdrawal rate from the cascade and the throughput of the individual centrifuges. Each centrifuge connected in parallel has the same values for the feed stream rate and concentration, enriched stream rate and concentration, and depleted stream rate and concentration. A typical throughput for a modern gas centrifuge is 0.02 g U/s or 1.7 kg U/day.

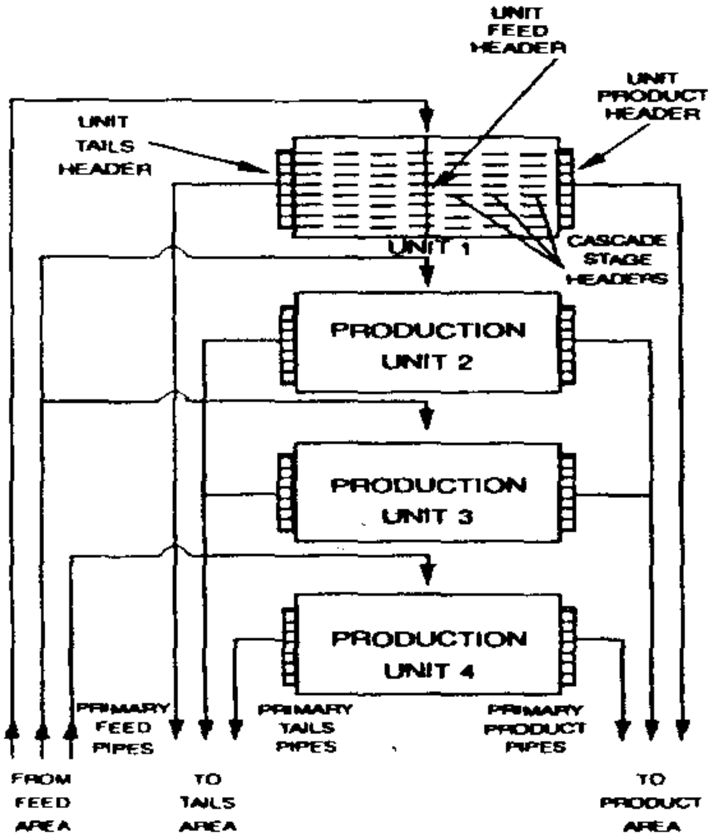
The material flow rates (and the number of centrifuges connected in parallel) are different for each stage to ensure that the streams between stages match concentrations. The material feed rate to a specific stage is dependent on the separation factor, the isotopic concentrations of the streams, and the flow rates of the exiting streams.

Because the amount of material fed into each stage is different, the width of each stage (i.e., number of centrifuges in parallel) is different. The feed stage to the cascade has the largest material flow rate and, therefore, has the greatest number of centrifuges connected in parallel. The number of GCs per stage is greatest around the feed points. The number of GCs per stage decreases slightly in the stripper section. The number of GCs per stage decreases more rapidly in the enricher section because of the greatly reduced mass flows (10–50% of the feed). It should be noted that all individual centrifuges in a cascade are physically identical. From visual observation, one cannot distinguish the isotopic concentrations or flow rate of the process gas contained within a centrifuge, stage, or cascade.

As previously mentioned, the process gas transferred to the cascades from the feed area is contained in primary feed pipes at low pressures. Multiple feed pipes may be present to supply material at different concentrations to separate production units or a set of production units (one pipe may be used to feed all of the production units if the feed material is of the same concentration and purity). The unit feed header pipe is connected to the cascade feed header pipes for each of the parallel cascades in that production unit. Here the gas pressure is further reduced to achieve cascade operating pressure.

The feed gas to the cascade enters the feed stage header and is distributed to each centrifuge in the stage. See Figure 4-9.

Figure 4-9. Production Unit Process Piping



THE CENTRIFUGES IN UNIT 1 PROVIDE A QUANTITY OF MATERIAL AT A SPECIFIC PRODUCT ASSAY.

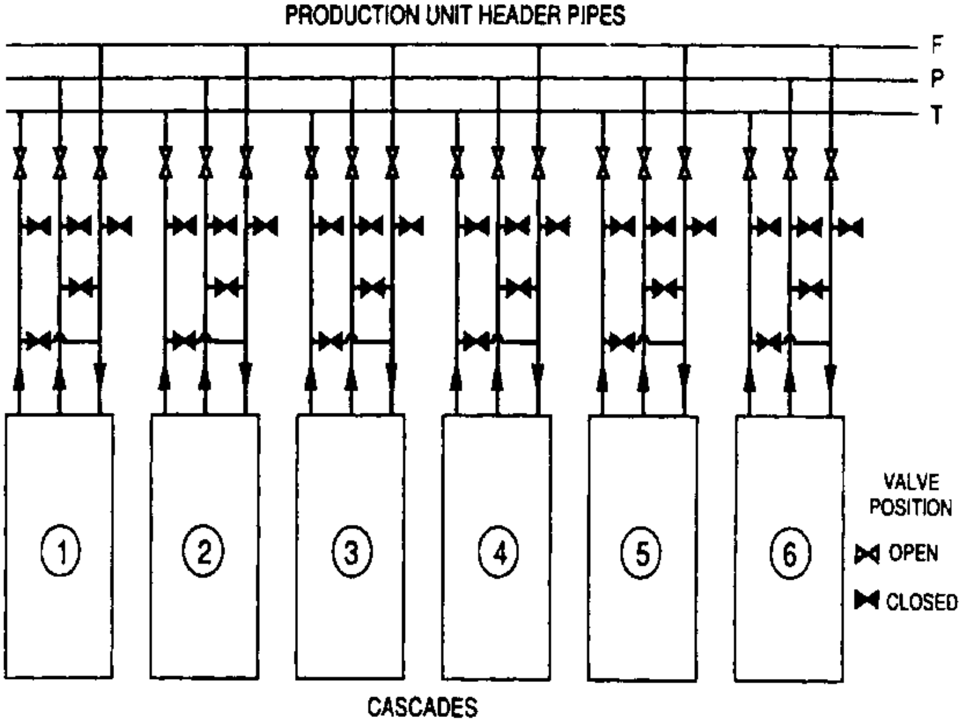
THE CENTRIFUGES IN UNITS 2 AND 3 ARE ARRANGED TO PROVIDE A SECOND PRODUCT ASSAY, AND THE UNITS ARE CONNECTED IN PARALLEL TO PROVIDE A LARGER THROUGHPUT.

THE CENTRIFUGES IN UNIT 4 ARE ISOLATED FROM THE OTHER EQUIPMENT TO PROCESS RECYCLED MATERIAL.

In practice, cascades may have more than one feed point as well as more than one product withdrawal point, and some separative work losses are sustained due to mixing. In addition, operating centrifuges differ slightly in manufacturing characteristics or operating conditions and therefore may differ slightly in flow rates or composition. Great care is taken to minimize differences between centrifuges during the design and manufacturing so that the concentrations of the enriched and depleted streams withdrawn from individual centrifuges connected in parallel match.

A plant designed for the production of 100,000 SWU/year can be arranged as a single high-throughput cascade or as multiple low-throughput cascades connected in parallel. See Figure 4-10. The plant, in either arrangement, contains the same number of stages to span a desired enrichment range. However, each state in the single high-throughput cascade is comprised of hundreds to thousands of centrifuges. This cascade arrangement has the advantage that the random failure of a few centrifuges does not affect the overall cascade performance. The disadvantage, however, is that one large cascade does not permit production flexibility. In practice, the 1,000,000-SWU/year plant would be composed of a number of small cascades operating in parallel. The individual stages of these small cascades are comprised of tens to hundreds of machines. If each small cascade is identical and produces the same product and tails concentrations as the described single large cascade, the sum of the outputs from each small cascade is equivalent to the output of the single large cascade.

Figure 4-10. Parallel Arrangement of Cascades to Form Production Units



The advantages of multiple parallel cascades are easier maintenance (e.g., a single cascade can be taken off-stream for repairs) and production flexibility (e.g., variety of product enrichments can be produced). The disadvantage is that the failure of several machines may affect cascade performance. In practice, the operational flexibility of a multiple cascade plant far outweighs the disadvantage of reduced cascade performance due to failed machines.

Product and Tails Removal

After processing, the enriched gas from each centrifuge in the feed stage enters the stage product header; simultaneously, the depleted gas from each feed stage centrifuge enters the stage tails header. The stage product header becomes the feed header for the next stage in the cascade; the stage tails header becomes the feed header for the previous stage. The gas is similarly processed through the enriching and stripping stages to achieve the desired concentration range. The product header of the top stage in the cascade is the cascade product header and empties into the unit product header; the tails header of the bottom stage is the cascade tails header and empties into the unit tails header.

The material in the unit headers is transferred directly to the withdrawal areas through primary product and tails withdrawal pipes. (If the product and tails concentration for the production units are identical, there may be only one primary product pipe and one primary tails pipe.)

In the withdrawal areas, cylinders are filled with the product and tails material. After the enriched and depleted streams leave the cascades, they are collected in desublimers where the gas solidifies. When full, the desublimers are heated and the UF_6 is transferred, either as a gas or liquid (depending on the design), to empty cylinders where it solidifies. At some facilities, a compressor system may be used instead of desublimers to collect the product and/or tails material. Tails cylinders containing the depleted material are weighed and then moved to an onsite storage yard for long-term storage. The product cylinders containing the enriched material are weighed, liquid sampled, possibly blended or rebatched, and then transferred to a storage area to await shipment offsite.

A secondary function of the product and tails removal systems is to provide a rapid means of evacuation of UF_6 from the centrifuge cascades to avoid damages to the centrifuges produced from abnormal operating conditions, such as high or low temperature, high pressure, or loss of drive to the centrifuges.

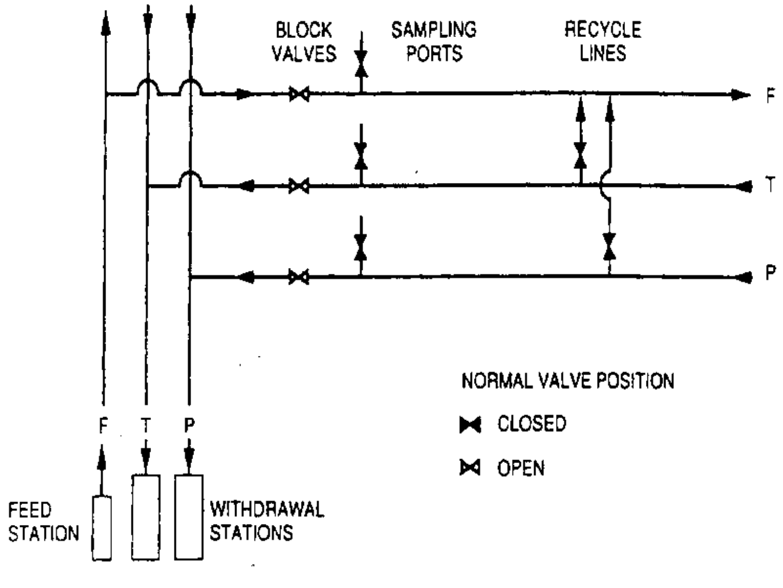
Dumping of a cascade to the product or tails removal system is effected through bypassing of the cascade terminal control valve, which allows elevated flow rates of UF_6 to the product or tails cylinders. In the event of loss of electrical power or instrument calibration, dumping of the cascades to the product or tails removal system is not possible. In this case, the contents of the cascades may be dumped to a contingency dump system. The contingency dump system is comprised of multiple trains of NaF absorber beds, surge vessels, and vacuum pumps. One train of contingency dump equipment is provided for each cascade. When the cascade gas is vented through this system, UF_6 is bound to the NaF absorber, and the remaining light gases are released to a gaseous effluent vent system.

Additional Piping-Structure Components

Sampling ports are used to remove process samples from the cascade while it is operating. Evacuation and sampling ports are used to evacuate the process system before operation begins, to remove process samples from the cascade while it is operating, and to remove process gas prior to maintenance activities. The cascade feed header port can also be used to fill the cascade with process gas. Depending on the design of the cascade, only one port may be present on each header, or there may be multiple ports throughout the cascade to permit the withdrawal of samples from individual stages.

An additional component is a cascade recycle line that joins the cascade product and tails headers to the feed header. With proper setting of the header pipe valves, the cascade can run indefinitely on the same process gas by continuously recycling it. The recycle mode of operation is generally used to permit a cascade to reach the design product and tails concentrations (e.g., initial startup or restart following maintenance) before the cascade output is introduced to the process system and when the cascade is in standby mode. See Figure 4-11.

Figure 4-11. Cascade Header Piping



Product Cylinders

Empty product cylinders are weighed, inspected for contaminants, and evacuated. As needed, empty product cylinders are transported to product take-off stations and connected to process piping. Any process piping exposed to air is evacuated by a mobile vacuum pump.

During normal operations, enriched gaseous UF_6 is continuously withdrawn from the centrifuge cascades. Vacuum pumps are used to move the UF_6 to product cylinders where the UF_6 is solidified. The product cylinders are located on a scale in an air-cooled cold chest. The fill weight is controlled to prevent cylinder rupture during product sampling when the cylinder is heated, causing the solid UF_6 to expand during transformation to the liquid state.

Each filled product cylinder is placed inside an autoclave, connected by manifold to a product sample bottle, and heated. After the sample is drawn, both the autoclave and sample bottle are cooled by chilled water so that the UF_6 is solidified before movement outside the autoclave.

Sampling Analyses

Standard analyses performed on a sample include: (1) the determination of the uranium concentration by the gravimetric method, (2) the determination of the isotopic abundances and U-235 content by gas-phase mass spectrometry, and (3) the determination of impurity content by a variety of techniques. Samples that may require analyses include UF_6 samples from feed, product, and tails cylinders; process gas samples from the cascades; and other uranium-bearing samples from scrap materials.

Product Blending

A product blending system provides the means by which the contents of two product cylinders can be mixed to give a final product of the desired U-235 enrichment. For example, a system can consist of two autoclaves containing larger donor product cylinders (e.g., 10 ton 48X cylinders) selected for blending, plus five receiver stations that house receiver cylinders (usually 2.5 ton 30B cylinders). Four of the five cylinders are blending products, while the fifth receives the heels from the donor cylinders and the contents from the desublimer.

Blending is achieved by melting and vaporizing the UF_6 in two donor autoclaves, then transferring the desired amount from each donor cylinder to air-cooled receiver cylinders. Flow control is used to achieve the desired mixture. Unblended heels are collected in a heels cylinder. This process would yield intermittent radioactive gaseous streams vented through a gaseous effluent vent system.

Product Storage and Shipping System

The product storage and shipping system serves as a storage area for the sampled and blended product cylinders. Product cylinders are stored resting on chocks. Cylinders are not stacked and adequate clearance should be provided for mobile carriers access. A cylinder is retrieved from storage with a mobile cylinder transporter and conveyed to a shipping area where it is weighed. With the use of an overhead crane, the cylinder is then loaded onto a truck for shipping.

Tails Storage

Tails cylinders, which contain solid UF_6 and are under vacuum, are carried via mobile transporter to a tails storage area. Cylinders are supported by reinforced hardstand chocks. Cylinders are adequately spaced for loading and unloading needs. Commercial enrichment companies currently plan to deconvert the DUF_6 into U_3O_8 for long term storage or disposal.

Waste Confinement and Management

Scrap recovery and waste treatment areas serve as the collection and processing point for all scrap and waste streams. Scrap and waste materials from all areas in the plant are collected and stored until recovery or disposal occurs. Typical materials include contaminated burnable and nonburnable wastes; alumina and/or sodium fluoride from chemical traps; decontamination solutions, other solutions, oils, and sludge from the decontamination and maintenance areas; and samples and analytical wastes from an analytical laboratory.

Sewage

In the case of liquid effluents, all releases are batched and can be sampled before release, and all liquids leaving the centrifuge facility can be added to the normal continuous flow of sewage treatment water. That flow should be continuously sampled, composited, and analyzed quarterly. Due to the batch nature of potential radioactive releases to the sewage treatment water, an accidental release from failure of a single liquid waste line or tank is unlikely to reach the sewage effluents due to the series of holding tanks in the liquid effluent treatment system. For example, a facility can be designed so that if a line or tank fails or overflows, the contents can flow to a floor drain that can divert the flow to another holding tank. However, if an accident were to occur resulting in a serious liquid effluent release, additional samples could be taken as necessary for laboratory analysis of releases on a more frequent basis (e.g., daily or hourly) for gross alpha and beta radioactivity screening.

Sampling of sewage sludge for possible uranium accumulation should be done on a semiannual basis.

Self-Check Questions 4-2

Complete the following questions. Answers are located in the answer key section of the Trainee Guide.

1. What usually happens to UF_6 feed cylinders upon receipt at the enrichment plant?

2. What is cold purification?

3. What is hot purification?

4. What happens to the feed cylinder when it is almost empty?

5. What happens when the desublimer reaches its UF_6 operational fill limit?

6. After feed purification, how is gaseous UF_6 transferred from the feed cylinder to the cascade?

7. Why are centrifuges connected in series?

8. Why are centrifuges connected in parallel to form stages?

9. What are the stages between the points where the feed is introduced and the product is withdrawn called?

10. What are "stripping stages" or the "stripper"?

11. The number of stages that are connected in series to form a cascade depend on what?

12. What is the advantage of blending streams with identical isotopic concentration?

13. Why are the material flow rates different for each stage?

14. What is the material feed rate to a specific stage dependent on?

15. Which stage has the largest material flow rate and has the greatest number of centrifuges connected in parallel?

16. Are the centrifuges located at the product end of the cascade physically different from those at the tails end?

17. What are the advantages of using multiple small cascades connected in parallel?

18. What happens after the enriched and depleted streams leave the cascades?

19. What typically happens to filled tails cylinders?

20. What typically happens to filled product cylinders?

21. What is a secondary function of the product and tails removal systems?

22. What is a contingency dump system comprised of and how does it work?

23. When are evacuation and sampling ports used?

24. When is the recycle mode of operation generally used?

25. Why is fill weight controlled on product cylinders?

26. What standard analyses are performed on samples?

27. Where in the gas centrifuge process might samples be required for analyses?

28. How can product blending be achieved?

29. How are product cylinders stored?

30. What are some typical waste materials at a gas centrifuge facility?

31. How often should sampling of sewage sludge for possible uranium accumulation be done?

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

Learning Objective

When you finish this section, you will be able to:

4.1.3 Identify the uses of the gas centrifuge process in industry and the required production amounts of enriched uranium.

INDUSTRIAL USE

United States

The first gram quantities of enriched uranium were produced at the University of Virginia in 1941. An improved device was operated by Standard Oil at the Bayway Refinery, New Jersey, in 1944. Westinghouse Electric manufactured the centrifuges in East Pittsburgh and built a small pilot plant in Bayonne, New Jersey. Engineering difficulties during World War II led to a decision to concentrate efforts on the other processes. Gas centrifuge research and development activities resumed in the early 1960s. In 1978 the U.S. Department of Energy committed itself to the construction of a Gas Centrifuge Enrichment Plant (GCEP) on the site of the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio. A pilot plant comprised of 120 plant prototype centrifuges arranged in a single process unit was constructed and successfully operated at Oak Ridge, Tennessee. A larger pilot plant of about 840 GCs was operated at Portsmouth for several months. This facility was shut down in 1985 when, in the face of a diminished world nuclear power commitment and the potential use of the AVLIS enrichment process, the DOE terminated all of its centrifuge activities including centrifuge research and development and GCEP construction.

Recent NRC Licensing Experience

Louisiana Energy Services (LES), a private consortium of Urenco, Fluor Daniels, Duke Power, Louisiana Power and Light and Northern States Power, filed a license application on January 31, 1991, to build the Claiborne Enrichment Center near Homer, Louisiana. The plant design was based on the Urenco Gas Centrifuge technology (see Urenco below). Construction was expected to be complete in five years and produce 1.5 MSWU per year. However, after seven years of delays in the licensing process (due to a number of issues that arose) and investments of $34 million dollars, LES withdrew the application. Some of the issues included environmental justice concerns, enrichment needs, and DUF_6 disposition. This is discussed further in Case Study 1, Claiborne Enrichment Center.

LES initiated discussions with the NRC on a new, larger GC facility of 3 million SWU capacity in 2000–2002. Initially, the plant was proposed for Hartsville, Tennessee (near Nashville). LES encountered difficulties with obtaining all of the local permits and subsequently moved the proposed site to New Mexico. LES submitted a license application in December 2003. The plant is named the National Enrichment Facility (NEF). The license was issued in 2006 and construction has begun on the actual facility. This is discussed further in Case Study 2.

USEC has had continuing discussions with the NRC about installing new enrichment technologies since 1998. USEC applied for a license for a Lead Cascade Facility in February 2003, which was planned as a pilot plant for testing cascade operations of up to 240 of the DOE GC design. Materials would be recycled, without any product streams. Only samples would be taken of the enriched product. The NRC issued the license in February 2004 – a fast turnaround was possible because it would be a small facility without an enriched product, and no EIS was required. Construction of this facility has been completed and operation is anticipated in late 2007 or early 2008. USEC submitted a license for the large scale plant, termed the American Centrifuge Facility (ACP), in August 2006. ACP is planned as a 3.8 million SWU/yr facility. The license was issued in 2007 and construction has commenced on the actual facility. This is discussed further in Case Study 3.

Areva has initiated discussions with the NRC about licensing a new GC enrichment facility in the U.S. Few specifics are currently available but it appears to be a 1 MSWU/yr or larger plant utilizing Urenco GC technology.

United Kingdom, the Netherlands, and Germany

In Europe, gas centrifuge has been developed to a commercial level by Urenco–Centec, an industrial group formed by British, German, and Dutch companies. The group operates enrichment plants in the United Kingdom, the Netherlands, and Germany. By 1972, pilot plants at Capenhurst (United Kingdom) and Almelo (the Netherlands) were well under construction and, in fact, partially operational, having been already started under the national programs even before the formation of Urenco. These pilot plants have been shut down except for the SP2 pilot plant at Almelo.

Urenco followed the pilot plants with two demonstration plants (200 tonne SWU/year [200,000 SWU/yr] each) to further establish the commercial viability of its process, and these were in turn followed by commercial plants of larger size. The Capenhurst E21 Demonstration Facility was shut down in 1991. The centrifuge cascades at the Almelo plant are individually-mounted machines (i.e., machines with a single rotor in each vacuum casing). Each machine requires three small process lines: one each for the feed, product, and “waste” DU. These lines connect to the three main piping headers (for feed, product, and tails) running the length of the cascade.

The centrifuge cascades at Gronau, Germany, are an example of block-mounted design (i.e., centrifuges comprised of a number of rotors mounted in a common vacuum housing). Gronau also has a large number of the newer, higher capacity, individually mounted centrifuges. The British version of a block-mounted design has also been installed at Capenhurst. Urenco has introduced a new generation of machines every five to seven years. Some first generation machines have operated 30 years with a failure rate of less than one percent. Urenco has installed fifth generation machines and has brought sixth generation machines into production in the 1998–2001 time frame. The fifth and sixth generation machines are termed TC-12 and TC-21, with capacities of cirica 40 and 90 SWU/per yr GC, respectively. Centrifuge improvements include increasing the length, as well as introducing new materials, and increasing the rotor speed.

Other centrifuge plant improvements have been to move towards individually-mounted machines and providing higher outputs. New plants withdraw process gas directly into product and tails cylinders eliminating the need for sublimers. In the future, more concentration will be placed on manufacturing and plant performance rather than developing another generation of centrifuge.

The current capacity of the combined Urenco enrichment facilities is 7.5 million SWU per year. In 1998, Urenco was in the process of installing seven new cascades at the Capenhurst site in the United Kingdom. There are also plans to expand the Almelo plant in the Netherlands. In late 1998, Urenco applied for a license to increase the capacity of the Gronau plant in Germany from one million to four million SWU per year. Figure 4-12 shows an Urenco cascade. Figure 4-13 shows block mounted designs.

Figure 4-12. View of an Urenco Cascade

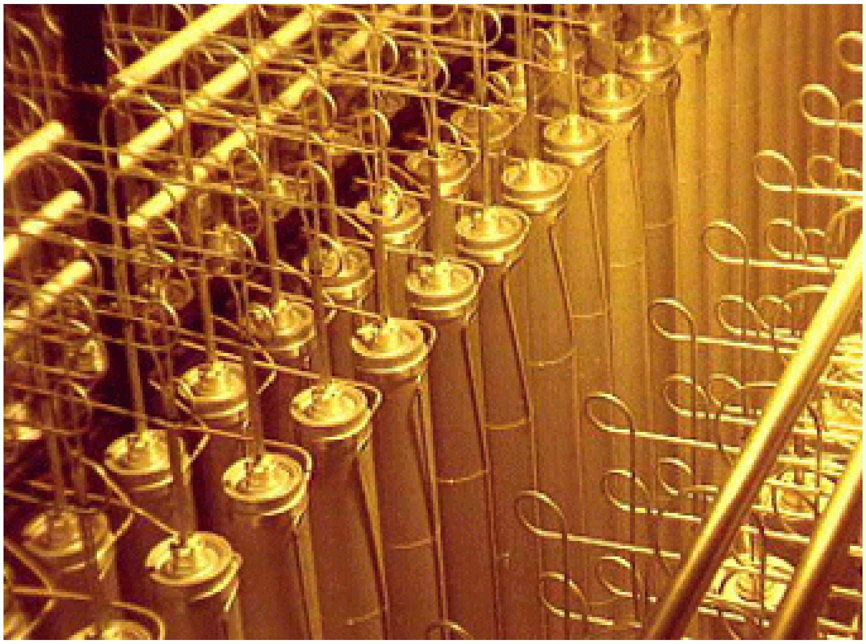
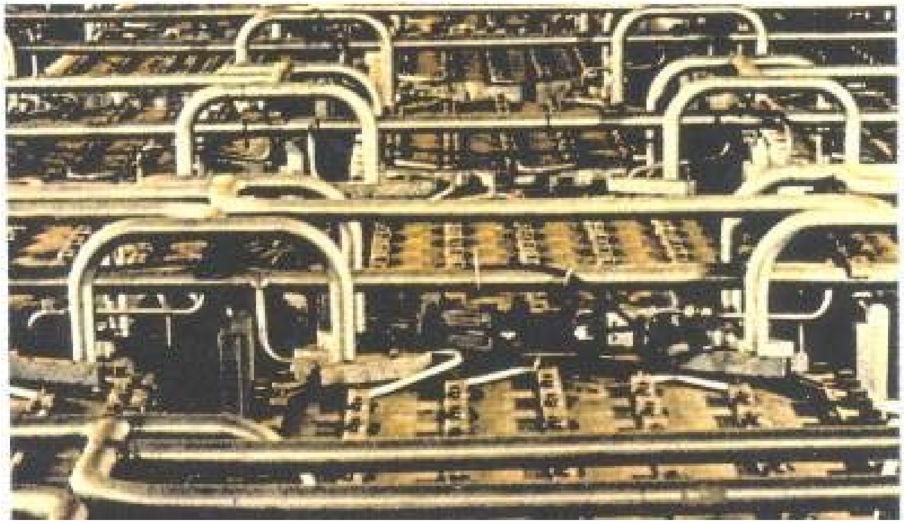


Figure 4-13. Block Mounted Designs



Japan

In Japan, the Power Reactor and Nuclear Fuel Development Corporation (PNC) and the Japan Nuclear Fuel Limited (JNFL) operate small centrifuge plants. The PNC of Japan operates gas centrifuge facilities at Ningyo Toge. The pilot plant was completed in 1982 with a nominal separative capacity of 75,000 SWU per year. This facility was shut down in 1990 and dismantled. The Ningyo Toge Works demonstration plant consists of two operation units, DOP-1 and DOP-2. Each unit has a separation capacity of 100,000 SWU per year. DOP-1 began operating in April 1988, and DOP-2 started up in May 1989.

Technology developed at the Ningyo Toge Works facility was applied to Japan's commercial enrichment plant at Rokkasho-mura. The Rokkasho Uranium Enrichment Plant is operated by Japan Nuclear Fuel Limited (NJFL) and its initial unit output of 150,000 SWU per year became fully operational in March 1992. Phase I of the plant was completed in September 1994 adding another 450,000 SWU per year for a total annual capacity of 600,000 SWU. Phase II, which commenced construction in September 1993, will add increments of 150,000 SWU per year until it reaches an annual capacity of 900,000 SWU. One half of this planned capacity (450,000 SWU per year) was operational by October 1998. This will bring Rokkasho capacity to 1,050,000 SWU.

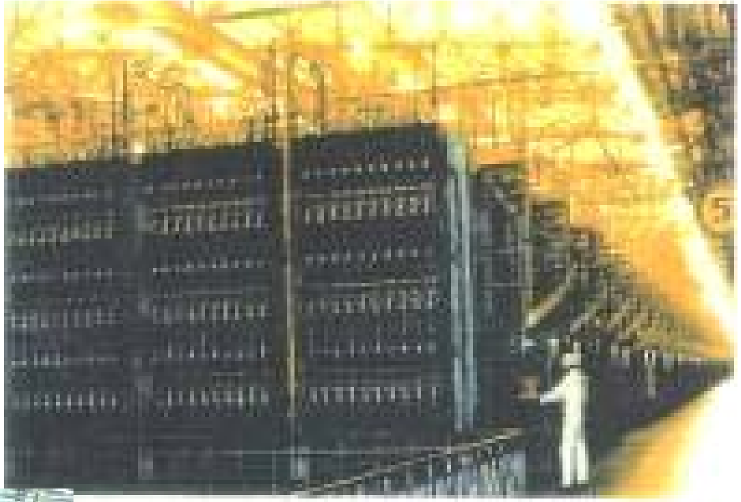
The Rokkasho-based Nuclear Fuel Machinery Corporation, established in May 1998 by Japan Nuclear Fuel Limited, was merged with Uranium Enrichment Machinery Limited in November 1998. The shareholders of the merged company will be JNFL, Toshiba, Hitachi, and Mitsubishi Heavy Industries. The company will work to integrate Japan's enrichment technologies and develop and manufacture advanced centrifuges. It will be responsible for the development, design, and manufacture of enrichment plant equipment, while JNFL will retain responsibility for plant operation. Currently, Rokkasho is running at about 1.5 MSWU/yr.

Russia

Russia's gas centrifuge project began in October 1957 by the startup of its first pilot plant. The world's first gas centrifuge production plant located near Ekaterinburg commenced operation in 1959. Russia currently has four operating gas centrifuge plants located in Novouralsk (also referred to as Ekaterinburg and Verkh Nervinskiy), Krasnoyarsk, Tomsk, and Angarsk. Russia's 18 to 20 million SWU per year enrichment capacity is entirely centrifuge based. Russia initially employed gaseous diffusion technology but it was phased out in the early 1960's. It is still sometimes used as a first stage to eliminate chemical impurities. The Urals Electro-Chemical Plant near Ekaterinburg has the largest capacity (approximately 10 million SWU per year) and can achieve the highest enrichments. In their technology, the cascades consist of a compact arrangement of vertically stacked gas centrifuges. (Figure 4-14) The stack may consist of three to five individual centrifuges.

Figure 4-14. Russian GCs

Floor view
GCs also stacked vertically



Top View

[from Internet and DOE/ORNL papers]

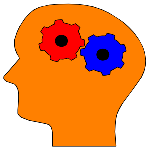
China

In April 1996, Russia announced that they had signed a contract to deliver centrifuges for a 200,000 SWU per year plant in China. China had planned to have this capacity installed by the end of 1996, although enrichment requirements would not arise until after the year 2000. This ambitious schedule for installing the 200,000 SWU has not been reached. Knowledgeable persons in the enrichment field believe that about 50,000 SWU per year may have been installed by early 1999. In January 1999, Russia and China signed a further nuclear cooperation protocol that provided for Russian involvement in the construction of a gas centrifuge enrichment plant in China and joint development of new generation centrifuges. In early 1999, it was announced that the third and fourth sections of the enrichment plant (50,000 SWU per year per section) using current generation machines are scheduled for completion in 2001.

France

France (Areva), via the Eurodif consortium, operates the Gaseous Diffusion Plant at Tricastin, discussed in Module 2. Eurodif has decided to convert the facility to a GC plant because of increases in the prices of energy and electricity. A contractual relationship has been formed with Urenco, including the formation of a company called ETC for GC manufacture. Urenco, via ETC, will supply new GCs and receive old or damaged GCs back; Eurodif and Areva will not have access to GC technology. The Eurodif plan has three phases spread out over the next 5–10 years. Each phase introduces 2-3 MSWU/yr of GC capacity and retires an equivalent amount of GDP capacity. When completed, the new GC facility will have a SWU capacity equivalent to the existing GDP (about 7.5–8 MSWU/yr) but use 100 MWe or less, as compared to about 2,500 MWe for the existing GDP. Current plans utilize the Urenco TC-12 design. The phased approach allows the use of the higher capacity, TC-21 design as an option if Eurodif decides it is needed to meet customer demand.

Activity 1 - Gas Centrifuge WorldWide Web Sites*



Purpose: The purpose of this activity is to view international gas centrifuge information posted on the World Wide Web.

Instructions: Access the Internet. Search the World Wide Web by keying in one of the following addresses:

http://www.urenco.com (Urenco - check out the locations and associated facility pictures)

http://www.jnfl.co.jp (Japan Nuclear Fuel Limited)

* This is an optional activity and is not required for module completion.

Self-Check Questions 4-3

Complete the following questions. Answers are located in the answer key section of the Trainee Guide.

1. Is there a gas centrifuge enrichment facility operating in the United States?

2. What countries presently have gas centrifuges in operation?

3. How are the centrifuge cascades at the Almelo plant in the Netherlands mounted?

4. What type of centrifuge cascade design is used at Gronau, Germany?

5. What are some centrifuge plant improvements achieved by Urenco?

6. What is unique about the cascade technology that Russia has imported to China?

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

Learning Objective

When you finish this section, you will be able to:

4.1.4 Identify the hazards and safety concerns for the gas centrifuge process, including major incidents.

HAZARDS AND SAFETY CONCERNS

The primary hazard at a gas centrifuge facility is uranium hexafluoride. A secondary potential hazard is stored quantities of chlorinated compounds, primarily refrigerants, used in traps and desublimer coils. Expected UF_6 release events include leaks from process connections and equipment with a minimal impact on and off the gas centrifuge site. Releases from process piping following an earthquake could produce uranium intakes offsite. The largest impact could occur following a catastrophic failure of a hot cylinder containing liquefied UF_6. Liquefied UF_6 is normally present in the autoclaves where process control systems and redundant protection circuits limit the likelihood of cylinder overheating.

Gas centrifuge enrichment plants pose hazards associated with handling UF_6 and enriched uranium, as well as hazards that are also found in other industries–particularly those posed by the use of high-speed rotating equipment. A gas centrifuge unit operating at high speeds could generate flying pieces of equipment and material (shrapnel) as a result of the destruction of the rotor and other spinning components.

The plants are designed to be run continuously for periods in excess of ten years, and reliability and ease of maintenance are of paramount importance, for both safety and economic reasons. Operational experience with centrifuge plants has been good. Plants have generally been very reliable and performed well with low levels of UF_6 release during normal operations. In addition, there have been only a few minor mechanical failures.

Potential significant accidents at one GC facility are summarized on Table 4-2.

Table 4-2. Potential Significant Accidents at a GC Facility (from NUREG – 1827)

High-Consequence Events	Intermediate-Consequence Events
• Natural Phenomena – Earthquake – Tornado – Flood • Inadvertent Nuclear Criticality • Fires Propagating Between Areas • Fires Involving Excessive Transient Combustibles • Heater Controller Failure • Over-filled Cylinder Heated to Ambient • Product Liquid Sampling Autoclave Heater Failure Followed by Reheat • Open Sample Manifold Purge Valve and Blind Flange • Pump Exhaust Plugged - Worker • UF_6 Sub-sampling Unit Hot Box Heater Controller Failure • Empty UF_6 Cold Trap (UF_6 Release) • Cylinder Valve/Connection Failure During Pressure Test • Chemical Dump Trap Failure • Worker Evacuation (UF_6 Release due to a seismic event, fire, or other unplanned release)	• Carbon Trap Failure • Pump Exhaust Plugged - Public • Spill of Failed Centrifuge Parts • Dropped Contaminated Centrifuge • Fire in Ventilated Room

Chemical and Chemical Reaction Hazards

Nitrogen is used for purging, blanketing, and drying vessels and lines to make sure that uranium does not react with trapped moisture in the system and deposit on surfaces.

Sodium hydroxide (NaOH) is used to adjust the pH of wastewater from decontamination facilities. It is in powder form and then mixed with water. Releases from NaOH spills would damage vegetation.

Citric acid ($C_6H_8O_7$) is used to decontaminate equipment. It is transported in granular form. Spills of $C_6H_8O_7$ may lead to pH reduction of water solutions and if sufficient amounts are released it could damage vegetation in the immediate area of a spill.

Chlorofluorocarbons (CFCs) are used to cool water and air and to improve the enrichment process efficiency. They are also used as solvents for degreasing equipment.

The gaseous chemical effluent of major concern is hydrofluoric acid (HF) produced by the hydrolysis of UF_6.

The following are contributing factors to chemical and chemical reaction hazards:

- UF_6 reacts explosively with organic material to form fluorinated compounds and HF
- HF and F_2 releases from fluorine generation and feed processes
- UF_6 reacts with H_2O or wet air to form highly corrosive and toxic HF
- H_2 formation within process stream
- Contaminants introduced with recycled UF_6 feed (e.g., transuranics and Tc)
- Potential UF_6 reaction with H_2O in autoclave, resulting in formation of HF and UO_2F_2 and a resultant increase in pressure
- Exothermic reactions resulting in uranium compound deposits (e.g., UF_4)
- Hydrostatic burst of an over-filled UF_6 cylinder when the liquid UF_6 solidifies and its volume increases sharply

Physical/Mechanical Hazards

The following are contributing factors to physical/mechanical hazards:

- High-speed rotating equipment

- A gas centrifuge unit operating at high speeds could generate flying pieces of equipment and material as a result of the destruction of the rotor and other spinning components
- Failure of centrifuge could cause centrifuge to fall over
- Normal heavy industrial chemical processing plant hazards in assembly, disassembly, and cleaning areas (solvents, acids)
- Hoisting and rigging and crane movement hazards
- Normal electrical shock hazards from faulty equipment or maintenance at switch yards and transformers
- Rupture of product cylinder by overfilling

Radiological Hazards

The predominant radioactive material utilized at a gas centrifuge site is natural, low-enriched, and depleted uranium primarily in the form of uranium hexafluoride. A primary concern for gas centrifuge operations is incidental or accidental inhalation of uranium, which can cause non-stochastic chemical damage to the kidney (nephrotoxicity) if intakes exceed a threshold within a specified period of time. Significant releases of UF_6 to work areas are unlikely, since the entire centrifuge system, with the exception of the autoclaves, is operated in a partial vacuum so that leaks are into the system, not into the work areas.

Most of the radioisotopes that could be encountered emit alpha and beta particles, which are non-penetrating forms of radiation that would be shielded from workers by UF_6 storage cylinders and primary containment systems (i.e., process lines). Due to high density of UF_6 when stored as a solid, the material would also provide considerable self-attenuation of x-rays and gamma rays from the uranium series nuclides present. A significant portion of the direct radiation encountered would be in the form of Bremsstrahlung radiation, which would be generated by the interaction of beta radiation with high atomic number atoms, such as uranium in UF_6 and, to a lesser extent, iron in UF_6 cylinders.

The following are contributing factors to radiological hazards:

- Low-level alpha radiation from U oxide
- High gamma radiation from cylinders (with heels) and tails cylinders
- UF_6 release from failure of safety systems on autoclaves, cold traps, and vacuum pumps

Most of the other sources of radioactivity utilized at a gas centrifuge facility are calibration and radiochemistry (quality control) standards which pose little radiation exposure risk to workers and none to the public.

Note: Neutron dose primarily for cylinder handlers can also occur at a gas centrifuge facility. Please refer to the discussion of neutron dose addressed in Module 2.0, "Gaseous Diffusion."

Radiological doses at existing GC facilities are low. Urenco radiation workers receive on average, about 40 mrem/yr with the highest individual dose around 260 mrem/yr.

Nuclear Criticality Safety

Nuclear criticality safety depends on several key parameters, including assay level, quantity, concentration (for solutions), moderators (presence and type), reflectors (presence, type, and thickness), chemical forms, geometry, and physical properties, such as density. Figures 4-15, 4-16, and 4-17 show some of these effects. Most notably, the required critical mass quantities increase considerably as the assay decreases, and are asymptotic (about 1% for homogeneous and about 0.7% for heterogeneous reflection). In Figure 4-15, note that the heterogeneous water full reflected critical mass at 10% assay is about 11 kg, about 30 kg at 5% assay, and about 150 kg at 2% assay. Figure 4-16 represents UO2 systems and indicates similar critical mass values. Figure 4-17 shows the multiplying factors for criticality masses and geometries as compared to 100% assay. Although not explicitly shown on the Figures 4-15, 4-16 and 4-17 a moderator is not required for criticality at assays above approximately 7%. Criticality safety reviews use experimental data, and validated and benchmarked computer codes as part of their assessment.

Figure 4-15. The Effect of the Assay Level Upon the Minimum Critical Mass (from LA-0860-MS, “Criticality Dimensions of Systems Containing U-235, Pu-239, and U-233")

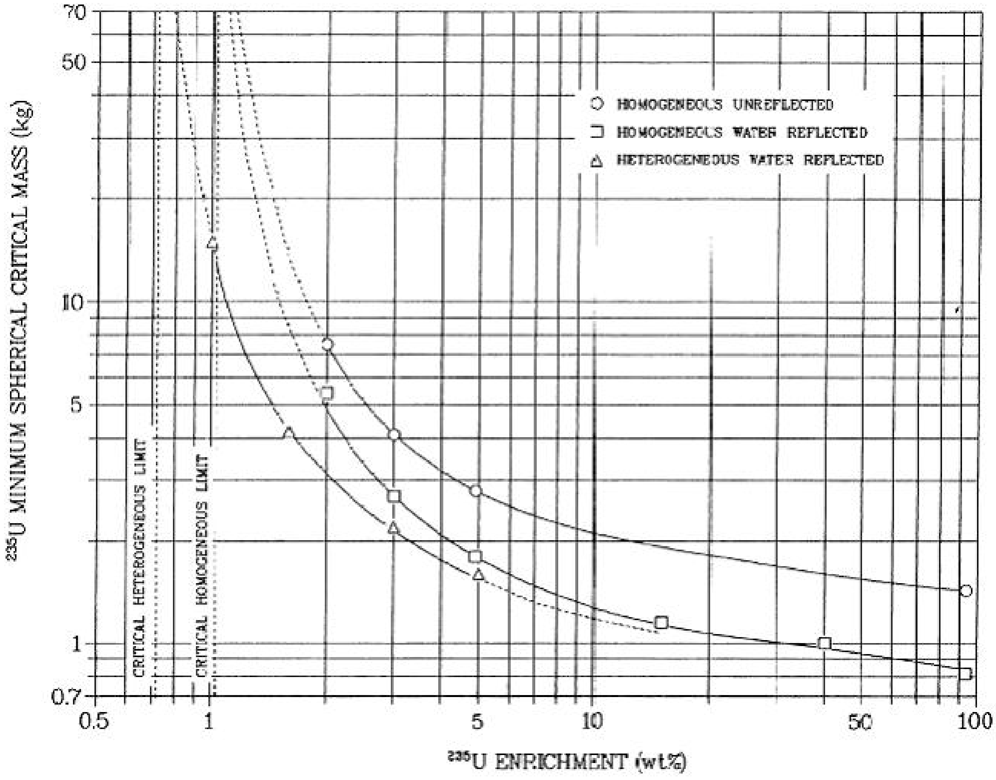


Figure 4-16. UO_2 and Water Systems (from TID-7016, “Nuclear Safety Guide,” Rev. 2)

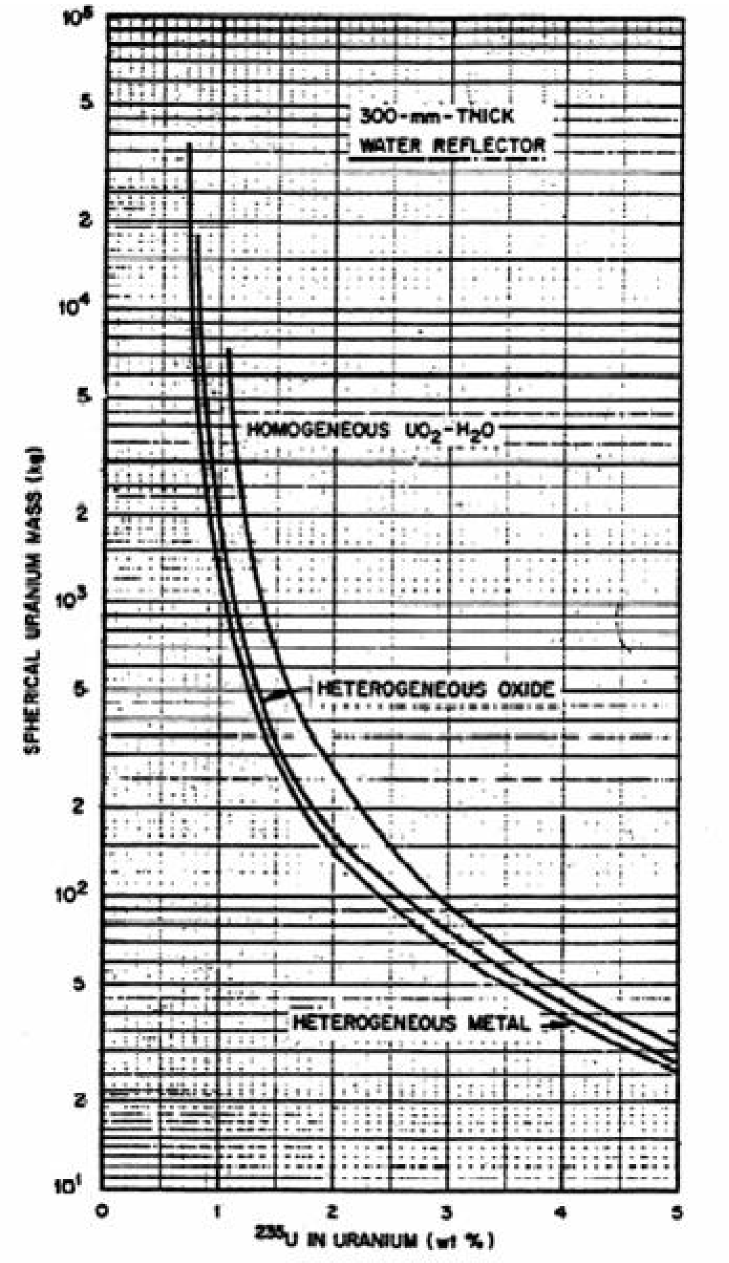
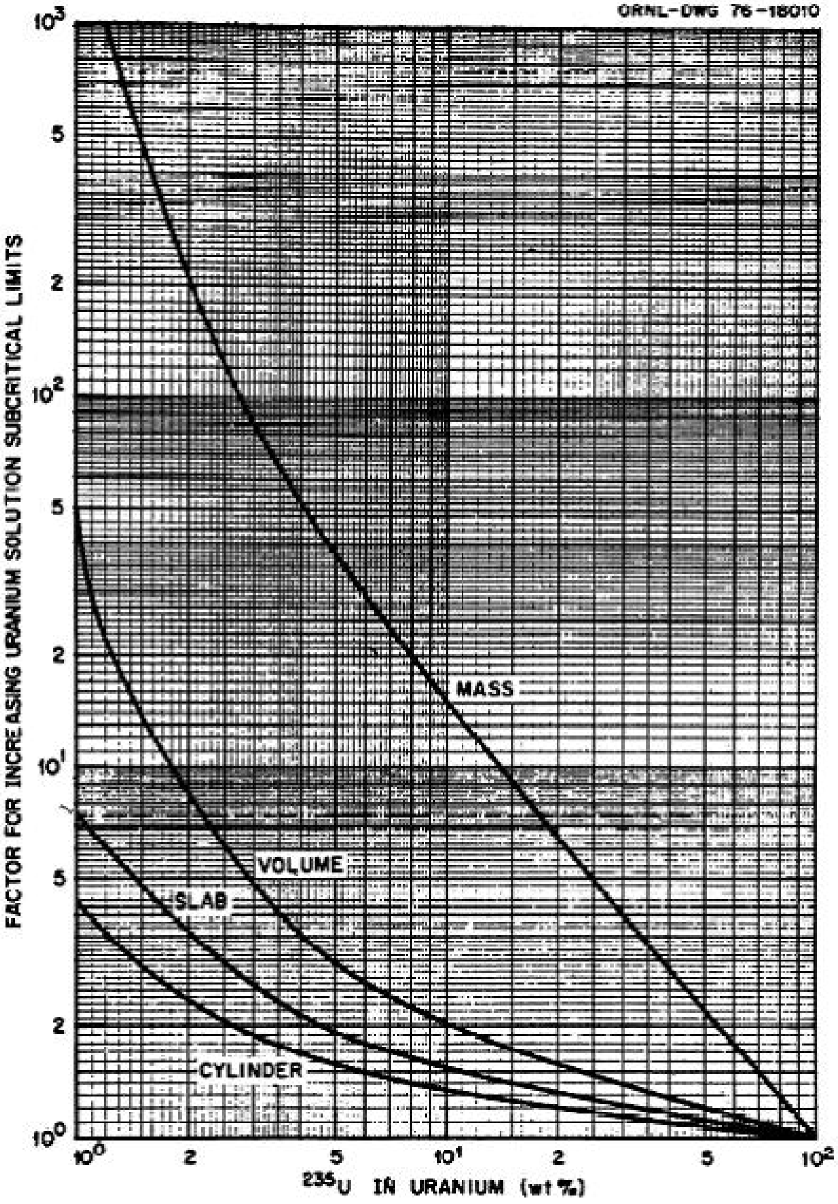


Figure 4-17. The Impact of Assay Upon Critical Masses, Volumes, and Geometries (from TID-7016)



Abnormal operations that could affect nuclear criticality safety at GC facilities include the presence of moderating material in an empty product cylinder, the presence of moderating material in or added to a filled cylinder, and the production of enrichments above 5 wt % U-235.

Product cylinders containing UF_6 enriched to 5.020 wt % U-235 are critically safe if moderators are limited and controlled. If a filled cylinder at ambient temperature were punctured, enough water could enter the cylinder and moderate enough enriched uranium to form a critical mass. Avoiding this occurrence requires that special handling equipment be used by trained operators.

The following are contributing factors to nuclear criticality safety hazards:

- Uncontrolled acceleration of rotor could cause increased assay within multiple centrifuges
- Possible vacuum pump oil in unsafe geometry for assay present if pump demister fails
- Critical reaction possible in decontamination/cleaning area if solutions are stored/mixed incorrectly or allowed to assume unsafe geometry
- Breach of UF_6 containment (centrifuge, piping, cylinders, valves, etc.) could cause critical reaction if moderation is present
- Safe spacing violation

The uranium in all centrifuges is normally in the form of gaseous UF_6 at substantially below atmospheric pressure. As a result, only small quantities (a few grams) of uranium exist in the centrifuges at any one time. Loss of containment of the UF_6 gas does not provide a significant criticality hazard or risk because the density of the gas below atmospheric pressure is very low and only a few grams of uranium are in any centrifuge. Thus, the release of UF_6 would have to occur from many centrifuges before a critical mass of uranium would be released. If containment were lost while the containment was below atmospheric pressure, in-leakage of moist air would occur. The moisture would react with the UF_6, and the resulting UO_2F_2 would settle out in small quantities in each centrifuge. The increased pressure in the cascades would cause control room alarms and the solid UO_2F_2 would likely cause GC failure but it is unlikely to have any criticality safety significance.

Significant quantities of enriched uranium are handled in the product areas. The use of moderators such as water and hydrocarbon oils in the UF_6 process areas must be controlled. A general approach to nuclear criticality safety is to prevent enrichment excesses, use favorable geometry equipment when practicable, provide moderation control within the UF_6 enrichment process, and sampling transfer, and withdrawal operations and use strict mass and geometry controls on solutions. In general moderation control is more crucial in sampling, transfer, and withdrawal than in actual enrichment, and geometry control is usually used with solutions.

Fire and Explosive Hazards

The chance of fires in a centrifuge plant should be less than in a gaseous diffusion plant. The presence of large motors and compressors in a diffusion plant creates elevated temperatures that could cause materials of construction to be at a higher temperature than those in a centrifuge plant. Also, the presence of lubricating oil around motors and compressors presents a fire hazard.

The following are contributing factors to fire and explosive hazards:

- Presence of flammable cleaning solutions
- HF and F_2 presence in the feed process
- Potential explosive reactions during mechanical failures

Gas centrifuge facilities may include fire protection features such as the use of noncombustible or limited combustible materials for construction and fire barriers rated for fire resistance to meet compliance with National Fire Protection Association (NFPA) requirements. Buildings may be protected by wet-pipe sprinkler systems, except certain areas such as a central control room that contain electrical switch gear and batteries. These areas require protection by automatic pre-action sprinkler systems. Water deflectors or enclosures should also be provided in areas presenting a potential hazard of criticality.

A fire water system with redundant equipment in addition to portable fire extinguishers enhances fire protection. A facility-wide fire alarm, a trained and equipped fire brigade, and a fire protection equipment maintenance program are also needed for adequate fire protection.

Environmental and Natural Disasters

Enrichment plants are designed to protect equipment, the workforce and the public in the cases of weather and seismic events. Designs must accommodate such site area specific factors as expected wind and snow loads on the building, flooding history, and ground movement parameters in the event of an earthquake. Generally, the design accommodates 1000-year or longer occurrence conditions that are judged to be sufficiently rare that all interests are protected.

Past Events

The types of off-normal events that have occurred in operating the European gas centrifuge plants are summarized in Table 4-3. The data indicates that leaks from disconnecting piping and from pump seal failures are the most frequent events that lead to UF_6 releases. For these two types of events, estimated release quantities are on the order of tens of grams and frequencies are on the order of twice per plant operating year. Line disconnection losses have occurred with mobile pump set equipment, with pump maintenance, and with sampling manifold handling. Operator error related to degassing lines and handling sampling manifolds played a role in this type of event. Pump failures involved failure of seals on rotating equipment, in some instances, related to blockage of the pump exhaust line. Off-normal events in the autoclaves have been limited to small leaks in the flexible piping and in valves in the cylinder exhaust line. Response to the in-plant leaks have included revision of operating procedures and training of workers. Off-normal events related to cylinders were limited to damage to cylinder valves due to collision with handling equipment and leaks from cylinder valve packing nuts. Leaks of this type were temporarily sealed with tape prior to replacement of the damaged valve. Response to the events included reconfiguration of the cylinder storage area and redesign of the packing nuts. Events that have occurred at the Urenco plants have not produced significant releases of UF_6 to the environment.

Table 4-3. Urenco Operating Experience with UF_6 Leaks

Type of Incident	Number of Incidents	Cause	Response
Line connect/disconnect leak	5	Inadequate degassing of lines	Revise operating and maintenance procedures
Pump seal failure	5	Mechanical failure of seals	Review pressure monitoring, instrument calibration
Sampling manifold leak	5	Rupture of temporary containment	Revise training and operating procedure, train staff
Flexible line leak	1	Steam condensation/ galvanic corrosion	Remove lagging
Feed system valve leak	1	Formation of deposits	Reposition and inspect valves
Cylinder packing nut cracking	several	Stress corrosion cracking	Redesign and replace packing nuts
Cylinder valve leak	2	Mechanical impact	Revise procedures
Inadvertent UF_6 venting	1	Operating error	

SAFETY SIGNIFICANT SCENARIOS

Centrifuge Containment Failure

In a centrifuge failure, rotational energy is converted to heat, the rotor disintegrates, and a quantity of gas is generated in the disintegration process and subsequent reaction with UF_6. A pressure pulse occurring during the crash closes isolation valves and separates the failed centrifuge from the balance of the cascade. Solid reaction products accumulate in the bottom of the failed centrifuge, and over a period of weeks, the reaction gases leak into the cascade header and are removed through the gaseous effluent vent system. The failed centrifuge remains in place but no longer contributes to the separation capacity of the cascade.

UF_6 Cylinder Failures

UF_6 cylinder failures may include:

- Introduction of reactive hydrocarbons into a cylinder
- Impact of a liquid-filled cylinder against or from an object
- Valve or pigtail failure due to movement of a connected cylinder containing UF_6
- Hydraulic rupture of a cylinder exposed to fire
- Hydraulic rupture of an overheated cylinder
- Hydraulic rupture of an overfilled cylinder
- Heating or filling a defective cylinder
- Heating a cylinder containing excessive volatile and/or gaseous contaminants
- Dropping a liquid-filled cylinder

UF_6 Process System Failures

UF_6 process system failures may include:

- Excessive heating of process equipment containing solidified UF_6
- Fatigue failure of a process system
- Impact of an object on a process system containing UF_6
- Valve failure of a cylinder or a system containing UF_6
- Pigtail failure

- Process system loss of containment caused by natural phenomena
- Heating a cold trap containing excessive volatile and/or gaseous contaminants
- Heating an overfilled cold trap
- Overheating a cold trap
- Cold trap failure caused by corrosion, fatigue, or thermal shock
- Venting of UF_6 through a hydrolyzer

Failure to De-Gas Process Lines

Connection and disconnection of lines potentially containing UF_6 occurs as a normal element of gas centrifuge operations. Operating procedures should specify that the lines are evacuated or de-gassed prior to disconnection. Past experience has demonstrated that procedures are occasionally misunderstood or improperly executed resulting in an uncontrolled release of UF_6 into the process area. Events of this type are represented by consideration of disconnection of a vacuum pump for maintenance. Surveys conducted after events of this type at Urenco facilities have reported negligible worker doses.

Flexible Pipe Leak in Desublimer Transfer

Feed purification desublimers containing solid UF_6 are emptied by indirect heating with Freon and transfer of the sublimed material to a cylinder in the purification cubicle. The take-up cylinder is connected to the transfer piping using flexible pipe for which leaks have been experienced.

Self-Check Questions 4-4

Complete the following questions. Answers are located in the answer key section of the Trainee Guide.

Fill in the missing words in each statement. Answers are located in the answer key section of the Trainee Guide. Choose from the following words:

autoclaves
Bremsstrahlung
cleaning
compounds
controlled
critical
criticality
decontaminate
density
empty
enrichment
F_2
5 wt%
hydrofluoric acid
inhalation
kidney
liquefied
manifold
material
mechanical
mobile
moderators
nitrogen
nuclear
pH
piping
procedures
public
radioisotopes
rotor
seal
solvents
uranium hexafluoride

1. The primary hazard at a gas centrifuge facility is ______________________.

2. A secondary potential hazard is stored quantities of chlorinated_____________________, primarily refrigerants.

3. The largest impact could occur following a catastrophic failure of a hot cylinder containing ____________________UF_6.

4. A gas centrifuge unit operating at high speeds could generate flying pieces of equipment and material as a result of the destruction of the_______________________ and other spinning components.

5. ____________________is used for purging, blanketing, and drying vessels and lines to make sure that uranium does not react with trapped moisture in the system and deposit on surfaces.

6. Sodium hydroxide (NaOH) is used to adjust the______________________of wastewater from decontamination facilities.

7. Citric acid ($C_6H_8O_7$) is used to ______________________equipment.

8. Chlorofluorocarbons (CFCs) are used to cool water and air and to improve the ____________________ process efficiency. They are also used as___________________ for degreasing equipment.

9. The gaseous chemical effluent of major concern is_____________________ produced by the hydrolysis of UF_6.

10. The predominant radioactive______________________ utilized at a gas centrifuge site will be natural, low-enriched, and depleted uranium primarily in the form of uranium hexafluoride.

11. A primary concern for gas centrifuge operations is incidental or accidental ______________________ of uranium, which can cause non-stochastic chemical damage to the______________________ (nephrotoxicity) if intakes exceed a threshold within a specified period of time.

12. Significant releases of UF_6 to work areas are unlikely, since the entire centrifuge system, with the exception of the______________________, is operated in a partial vacuum so that leaks are into the system, not into the work areas.

13. Most of the ______________________ that could be encountered emit alpha and beta particles, which are non-penetrating forms of radiation that would be shielded from workers by UF_6 storage cylinders and primary containment systems (i.e., process lines).

14. Due to the high______________________ of UF_6 when stored as a solid, the material would also provide considerable self-attenuation of x-rays and gamma rays from the uranium series nuclides present.

15. A significant portion of the direct radiation encountered would be in the form of ____________________radiation, which would be generated by the interaction of beta radiation with high atomic number atoms, such as uranium in UF_6 and, to a lesser extent, iron in UF_6 cylinders.

16. Abnormal operations that could affect nuclear criticality safety include the presence of moderating material in an_____________________ product cylinder, and the production of enrichments above _____________________U-235.

17. Product cylinders containing UF_6 enriched to 5.020 wt % U-235 are critically safe if moderators are limited and________________________.

18. If a filled cylinder at ambient temperature were punctured, enough water could enter the cylinder and moderate enough enriched uranium to form a _____________________ mass.

19. Loss of containment of the UF_6 gas does not provide a significant_____________________ hazard or risk because the density of the gas below atmospheric pressure is very low and only a few grams of uranium are in any centrifuge.

20. The use of_____________________ such as water and hydrocarbon oils in the UF_6 process areas must be controlled.

21. A general approach to______________________ criticality safety is to prevent enrichment excesses, use favorable geometry equipment when practicable, provide moderation control within the UF_6 enrichment process, and use strict mass control on solutions.

22. Fire and explosive hazards may include the presence of flammable____________________ solutions, HF and ________________ presence in the feed process, and potential explosive reactions during ______________________failures.

23. Enrichment plants are designed to protect equipment, the workforce and the ______________________ in the cases of weather and seismic events.

24. Past incidents indicate that leaks from disconnecting________________________ and from pump ______________________ failures are the most frequent events that lead to UF_6 releases.

25. Line disconnection losses have occurred with_______________________ pump set equipment, with pump maintenance, and with sampling_____________________ handling.

26. Response to the in-plant leaks have included revision of operating____________________ and training of workers.

Complete the following questions. Answers are located in the answer key section of the Trainee Guide.

27. What happens during a centrifuge containment failure?

28. List three contributing factors that may cause a UF_6 cylinder failure.

29. List three contributing factors that may cause a UF_6 process system failure.

30. Have leaks occurred when a take-up cylinder is connected to the transfer piping using flexible pipe?

Learning Objective

When you finish this section, you will be able to:

4.1.5 Summarize Case Study 1: Summary of Proposed Claiborne Enrichment Center.

CASE STUDY 1: CLAIBORNE ENRICHMENT CENTER

Overview

On January 31, 1991, Louisiana Energy Services (LES) submitted a license application to construct and operate a uranium enrichment facility near Homer, Louisiana, in Claiborne Parish. The facility, to be called Claiborne Enrichment Center (CEC), would enrich uranium to a maximum 5 percent uranium-235 by the gas centrifuge process, and would have a capacity of about 1.5 million separative work units (SWUs) per year. If licensed, LES would receive a combined 30-year license for construction and operation. This facility would become the first privately owned enrichment facility in the United States.

The staff completed its review of the license application. The Safety Evaluation Report was issued in January 1994 as NUREG-1491; the Final Environmental Impact Statement was issued in August 1994 as NUREG-1484. The U.S. Nuclear Regulatory Commission staff concluded that the CEC could be constructed and operated with small and acceptable impacts on the environment and that the facility did not pose undue risk to the public health and safety. The aforementioned documents supported issuance of a combined construction/operating license for the facility.

Issues related to environmental justice, facility need, applicant finances, contracts for the LEU product, and DU disposition were raised during the hearing process. There were several iterations between the Commission and the Atomic Safety Licensing Board (ASLB), and, ultimately, the Commission decided to revisit the Final EIS primarily on the environmental justice and DU disposition issues. LES was concerned about the numerous delays and the non-safety issue focus of the Commission and ASLB interactions. LES saw no reason to revisit the Final EIS given its conclusion of no undue impact and safe operation of the Urenco facilities in Europe. Expended licensing costs rose to about $34 million. LES ultimately concluded the Commission/ASLB interactions appeared endless and withdrew the application on April 22, 1998.

Site Location and Description

The site for the proposed CEC was located in Claiborne Parish in northwest Louisiana, about 5 miles northeast of the town of Homer and 50 miles east-northeast of Shreveport (Figures 4-18 and 4-19). The proposed site covered 440 acres. The controlled area, located in the center of the site, would have occupied 70 acres and included seven main buildings, enclosed by a fence. In general, the terrain ranged between flat and gently rolling hills, with pine forests.

Figure 4-18. Map of Area Around Homer, LA

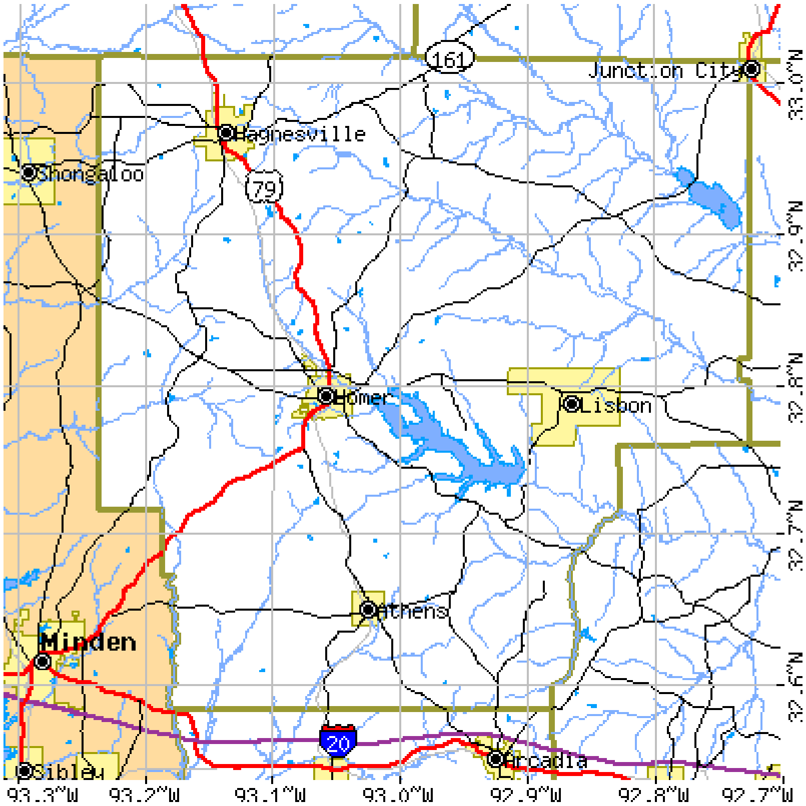


Figure 4-19. Location with Respect to Major Cities

Building Description

The site included a separations building, centrifuge assembly building, product and feed storage building, various support buildings, and DU/tails storage areas. Construction costs were estimated at $816 million (1992). Decontamination and decommission costs were estimated to be $518 million, 90% of this cost was associated with DU tails deconversion and disposal.

The separations building utilized pre-cast/pre-stressed concrete construction, approximately 780 feet long and 460 feet wide, with a ground level floor area of about 358,700 square feet. The separations building consisted of three units of approximately 500,000 SWU/yr capacity each, each divided into two cascade halls. Each hall had seven cascades. Each cascade was to be housed within its own enclosure within the building and would have consisted of approximately 1,000 centrifuges of the Urenco TC-12 design. Thus, the CEC would have contained approximately 42,000 GCs. Under normal operating conditions, each cascade would use about 86 KW of electricity. Total plant electricity load was estimated to be about 1.5-2 MWe for normal plant operations. In addition to the cascade halls, the separations building included UF_6 handling, electrical/HVAC, technical services, cylinder handling, and product blending areas.

Other buildings would have had metal framed, insulated metal wall on concrete slab construction. Most UF_6 cylinders were to be stored outside, on paved areas. About 16.2 acres of cylinder storage was provided; the majority was for DU/tails cylinders.

Process Description

The plant would have been licensed for 5% assay LEU. At the time, it was anticipated it would produce LEU around 3.5% assay to satisfy the reactor market of the late 1980s/early 1990s (i.e., a lower burnup than today).

DU feed cylinders would be placed in autoclaves and cold vented several times (to a gas vent system) to remove light gases. Next, the cylinders were heated in autoclaves, using air heated by resistance heaters. Once liquefied, the cylinder would be hot vented (usually only once) and flow directed to the cascade header piping. Pressure is reduced below atmospheric by valves. Typical feed pressures are below 1 psia and typical cascade pressures are on the order of 0.04 psia.

The cascade would house the GCs. Each GC consists of a thin-walled, vertical, cylindrically shaped rotor that spins around a central post within an outer casing (the stator). The rotor is fabricated from carbon-reinforced epoxy and the casing is aluminum. The stator/housing would be mounted on a specially designed and leveled floorplate called a flornel. Rotor drag is reduced by maintaining the rotor/stator space under a vacuum. An electromagnetic motor drives each GC, using power at the same frequency as the rotor speed (in revolutions per second). Each cascade would have a closed loop, cooling water system to remove heat from friction and the motors. Cooling coils at the top and bottom of the rotor also remove heat and provide a temperature gradient that improves the separations factor and assists enrichment. Feed, product, and DU streams enter and leave the GC via a central post. Each GC includes an exit safety valve that closes if there is excess pressure in the GC; separate isolation valves automatically operate in response to a GC failure. Each GC would contain 10 grams of UF_6 during normal operations.

The enriched product would be desublimed into cylinders placed inside cold boxes, using cold air as the coolant. DU would be desublimed into tails cylinders in insulated boxes using a closed-loop, spray water system upon the external surfaces of the cylinder. There are separate autoclave and desublimer stations for product sampling and blending.

Equipment decontamination would have used solutions of citric acid.

Plant construction, operation, and decontamination and decommissioning were expected to take 5, 30, and 7 years, respectively. At full production for a given year, the plant would have received approximately 4,700 tonnes of feed and produced 870 tonnes of LEU product, with 3,830 tonnes of DU. The calculated SWU and feed factors are 2 and 5.5, respectively.

Depleted Uranium and Wastes

Gaseous effluents in the venting system pass through carbon, alumina, and HEPA filters for contaminant removal, followed by monitoring prior to release. Gas exiting the potentially contaminated area of the Separations Building would be treated by HEPA filtration prior to release. The average annual uranium release to the atmosphere was estimated to be 120 microcuries. The average release rate of HF was expected to be less than 6.5 kg/yr. These values were found to be well below applicable limits.

Likewise, liquid effluents would be treated prior to release. After treatment, an estimated maximum of 28 microcuries/yr would be released. This would be less than 0.5% of the Part 20 limit.

Liquid and gaseous effluent treatment, traps/filters, and personal protective equipment would be the principal solid radioactive wastes. These were expected to contain less than 100 kg of uranium annually.

The plant would generate about 3,830 tonnes of DU annually. The NRC concluded there were few uses for the DU and that most of it would have to be dispositioned as if it were low level waste. LES planned to have the DUF_6 deconverted into DU3O8 at an offsite facility, followed by disposal in a mine cavity or deeper type of disposal unit. DU would be stored onsite until the deconversion and disposal facilities and arrangements were completed; DU shipment offsite was to occur within 15 years of the generation of DU.

Safety

NRC reviewed the LES/CEC application using the Atomic Energy Act (as amended), 10 CFR 70 (the older, pre-ISA version), the Draft General Design Criteria for Uranium Enrichment, and NUREG-1391 on uranium and UF_6 toxicity. Site dispersion analyses were based upon five years of data collected at Shreveport, LA. The main hazards were found to involve liquid UF_6 in quantities greater than 1,100 kg (buoyant releases) and 119 kg of UF_6 in non-buoyant releases (e.g., desublimers, cascade hall piping, and moderate leaks from cylinders). Staff concluded the Separations Building would adequately resist design basis tornados and earthquakes (10,000 and 500 year return periods, respectively), and protect liquid UF_6 containing equipment, such as the autoclaves. The general approaches and safety programs were found to be consistent with accepted practices and ALARA. The maximum exposed individual would receive no more than approximately 0.6 mrem/yr CEDE from all pathways at 400 meters. Potential accidents involving liquid UF_6 were found to be the greatest hazards, such as in the autoclaves (from heater malfunctions) and cylinder storage areas (e.g., from fires; LES did not plan to move liquid cylinders outside of the autoclaves).

Safety controls on autoclaves and fuel limits on cylinder carriers in the yards would address these hazards.

Staff analyses on DU disposition indicated that near-surface, shallow land disposal would result in ingestion doses far above the 25 mrem/yr limit. Staff concluded disposal in a site deeper than normal shallow land disposal practice (e.g., a mine cavity) would experience reducing leaching chemistry that would not exceed the 25 mrem/yr limit. However, subsurface disposal, such as in a mine, does not currently exist.

Staff Assessment

The staff concluded the proposed facility presented no undue risk based upon the applicant's submissions and commitments. Staff proposed several conditions related to facility inspection and radiation monitoring instrumentation.

Licensing/Status

LES was concerned about the numerous delays and the non-safety issue focus of the Commission and ASLB interactions. LES saw no reason to revisit the Final EIS given its conclusion of no undue impact and safe operation of the Urenco facilities in Europe. Expended licensing costs rose to about $34 million. LES ultimately concluded the Commission/ASLB interactions appeared endless and withdrew the application on April 22, 1998.

Learning Objective

When you finish this section, you will be able to:

4.1.6 Summarize Case Study 2: Summary of Proposed National Enrichment Facility.

CASE STUDY 2: NATIONAL ENRICHMENT FACILITY

Overview

On December 12, 2003, Louisiana Energy Services (LES) submitted, to the NRC, an application requesting a license, under 10 CFR Parts 30, 40, and 70, to possess and use byproduct, source, and special nuclear material (SNM) in a gas centrifuge uranium enrichment facility. LES proposes that the facility be located in Lea County, New Mexico, and have a nominal capacity of 3 million separative work units (SWUs). The facility will possess natural, depleted, and enriched uranium, and will enrich uranium up to a maximum of 5 percent uranium-235. The applicant also requested a facility clearance for classified information, under 10 CFR Part 95.

The NRC staff conducted its safety review in accordance with NUREG-1520, “Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility.” The staff’s safeguards review involved reviews of the applicant’s Fundamental Nuclear Materials Control Plan (FNMCP); the Physical Security Plan, which includes transportation security; and a “Standard Practice Procedures Plan for the Protection of Classified Matter.” The staff also reviewed the applicant’s Quality Assurance Program Description and Emergency Plan. Where the applicant’s design or procedures should be supplemented, the NRC staff has identified license conditions to provide assurance of safe operation. The staff’s safety evaluation report is NUREG-1827. The applicant also submitted an Environmental Report, which was used to prepare, in a separate document, an Environmental Impact Statement for the facility (NUREG-1790).

The NRC issued the license to LES and construction has commenced on the facility.

Site Location and Description

The proposed site is in Southeastern New Mexico in Lea County, approximately 1.6 km (1 mi) west of the New Mexico–Texas border on the north side of New Mexico Highway 234. Figure 4-20 displays the location, and Figure 4-21 denotes an artist’s representation of the facility. Andrews County, Texas, lies across the border from the site.

The site is about 8 km (5 mi) east of Eunice, New Mexico, and 32 km (20 mi) south of Hobbs, New Mexico. The site is 220 ha (543 acres) in size and is located within County Section 32, Township 21 South, Range 38 East. The site is owned by Lea County. The proposed site is relatively flat with elevations between 1033 and 1045 m (3,390 to 3,430 ft) above sea level. The site slopes to the southwest, is undeveloped, and is used for domestic livestock grazing.

Figure 4-20. Proposed Facility Location

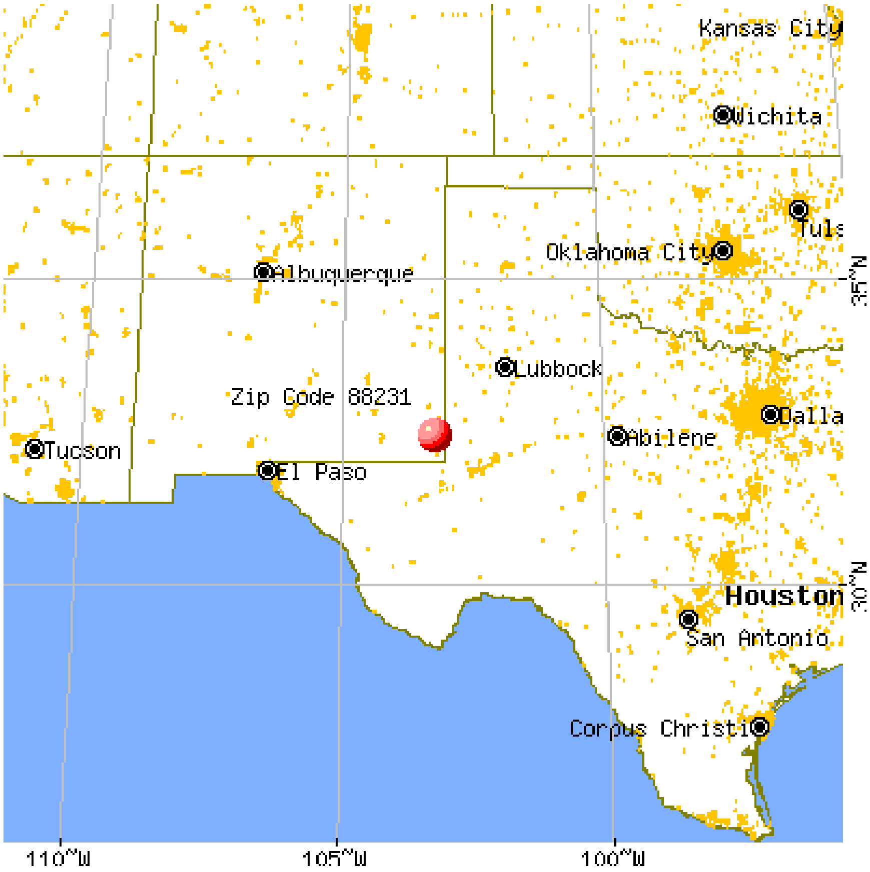


Figure 4-21. Artist Representation of the Proposed Facility

NEF Administration Aerial Drawing

Building Description

The site included three separations buildings, centrifuge assembly building, product and feed storage building, various support buildings, and DU/tails storage areas. Construction costs were estimated at \$1.5 billion (2006). Decontamination and decommissioning costs were estimated at \$942 million; \$131 million for structures/equipment, \$622 million for DU/Tails (conversion and disposal), and \$188 million contingency (2004 values).

The proposed plant will be constructed to have three Separations Building Modules, each having two Cascade Halls, with each Cascade Hall having eight cascades. Each Separations Building consists of a UF_6 Feed System, Cascade Systems, a Product Take-off System, and a Tails Take-off System. The plant also has a Product Liquid Sampling System and a Product Blending System.

Each Separations Building Module includes two cascade halls. Each Separations Building Module has a uranium hexafluoride handling area and a process services area. A Separations Building Module is 170 m (557.75 ft) long, 67.9 m (222.75 ft) wide, and 13 m (42.7 ft) high, and has 12,703 m2 (137,025 ft2) of space. The Technical Services Building is a two-story building with 9,192 m2 (98,942 ft2) of space. The Cylinder Receipt and Dispatch Building is 246.2 m (807.75 ft) long, 45.9 m (150.6 ft) wide, and 13 m (42.7 ft) high, and has 11,300 m2 (121,638 ft2) of space. The Centrifuge Assembly Building is 195.5 m (641.4 ft) long, 50.9 m (167 ft) wide, and 11 to 16 m (36.1

to 52.5 ft) high, and has 11,364 m2 (122,322 ft2) of space. The Blending and Liquid Sampling Area is 33.5 m (109.9 ft) long, 45.9 m (150.6 ft) wide, and 10 m (32.8 ft) high, and has 1,538 m2 (16,555 ft2) of space.

Process Description

The proposed facility is licensed to produce LEU with a maximum assay of 5%. The plant itself is designed for 6% enrichment and higher enrichments may be possible, but these would require license amendments. It is anticipated that the facility will produce LEU at or near its license limit of 5% assay.

The enrichment processes and equipment analyzed as part of the ISA process are described in the LES ISA Summary, Section 3.4. The enrichment systems are comprised of the Uranium Hexafluroide (UF_6) Feed System, Cascade System, Product Take-off System, and Tails Take-off System. Major support systems include the Product Blending System, Product Liquid Sampling System, and Contingency Dump System. Systems used to support the enrichment process and the handling of UF_6 are the Gaseous Effluent Vent System (GEVS), Centrifuge Test Facility and Centrifuge Post Mortem Facility, and Material Handling. A subsection containing information pertaining to the functional description, major components, design description, interfaces, design and safety features, operating limits, instrumentation, and IROFS is provided for each of the 10 enrichment and supporting systems.

The process function is to enrich the amount of the 235U isotope in UF_6 from 0.711 weight percent up to a maximum of 5.0 weight percent through a mechanical centrifuge separation process. The application and issued license are based upon the Urenco TC-12 GC; LES has stated they may substitute a TC-21 model for one or more of the cascades after construction has initiated, based upon enrichment market demand. The TC-21 has the same footprint as the TC-12 centrifuge but double the height, which effectively doubles its enrichment (SWU) capacity and increases the enrichment capacity of the entire facility. Such a modification would require a license amendment.

Naturally occurring uranium will be received from a conversion facility in the form of UF_6 shipped in Type 48Y or 48X cylinders qualified to American National Standard Institute (ANSI) Standard N14.1 (ANSI, 1995). The UF_6 will be in a solid state under vacuum. The UF_6 feed system will heat the cylinder to 53°C (127°F) to sublime the UF_6 into a gas. The feed purification system removes light gas components from the feed to a specified level prior to admittance to the cascade in order to protect the centrifuges and enhance efficiency. At the feed purification Low Temperature Take-off Stations, Type 48X or 48Y cylinders are cooled to -25°C (-13°F). Gaseous UF_6 enters the cylinders and desublimes into the solid phase. UF_6 coldtraps, aluminum oxide (Al2O3) traps, and vacuum pumps are used to transfer residual light gas to the GEVS. The traps remove any UF_6 or hydrogen fluoride (HF) from the effluent stream.

From purification, UF_6 is transferred to the cascades where enrichment occurs. The cascades are operated under a significant vacuum (about 65 mbar or 0.09 psia) to assure the UF_6 does not desublime back into a solid state at ambient temperatures. The proposed design uses the TC-12 centrifuge – some 84,000 would be installed and only a small number would fail over the lifetime of the plant. Use of the larger TC-21 centrifuge would reduce the number of GCs installed or increase the plant's capacity; Urenco has not made a decision yet regarding use of the larger TC-21 GC at this facility. Use of the TC-21 would require a license amendment from the NRC. The cascade systems separates the UF_6 feed stream into a product stream and a tails stream. The product stream is routed to the Product Take-off System, where it is transported by vacuum pumps to the Product Low Temperature Take-off Station. These stations are operated at -25°C (-13°F) and the UF_6 desublimes into the solid form inside a Type 30B or 48Y cylinder. The Type 30B cylinder is used for final product, while the Type 48Y cylinder is used for future blending operations. Any light gas impurities are purged through cold traps followed by product vent vacuum pump/chemical trap sets. The Tails Take-off System withdraws the depleted UF_6 stream and provides a means to withdraw UF_6 from the centrifuge cascades under abnormal conditions. The UF_6 is routed to a Low Temperature Take-off Station operated at -25°C (-13°F). The gaseous UF_6 is desublimed into a solid form inside a Type 48Y cylinder.

The Product Blending system is used to provide a specific enrichment of 235U by blending UF_6 at two different enrichment levels. The donor stations can handle Type 30B and 48Y product cylinders. The UF_6 is sublimed back into a gas and transported to a Blending Receiver Station containing an empty Type 30B cylinder operated at -25°C (-13°F), where the UF_6 desublimes back into a solid form.

The only system at the facility that changes solid UF_6 into liquid UF_6 is the Product Liquid Sampling System. A filled Type 30B cylinder is placed in an autoclave that is heated to 70°C (158°F) by electric heaters. When the pressure reaches +2.5 bar (36.3 psia), the temperature is stabilized for about 16 hours to allow homogenization prior to sampling. The sample bottles are connected to the cylinder via a header, all located within the confines of the autoclave. The main safety feature of the autoclave is to provide a secondary confinement barrier in the event of a UF_6 leak. All Type 30B cylinders are required to meet ANSI N14.1 requirements, which include a cylinder design pressure of 1380 kPa (200 psi) and testing to 2760 kPa (400 psi).

Section 3.5 of the ISA Summary emphasizes capacities, redundancies, and other provisions for coping with routine and non-routine events. The system descriptions include functional requirements, design capacities, system interfaces, and descriptions of major components. Operational characteristics and safety considerations are also described.

Plant construction, operation, and decontamination and decommissioning were expected to take 5, 30, and 9 years, respectively. Production would start incrementally, as each hall or separations building is completed (e.g., in 500,000 or 1,000,000 SWU/yr increments). At full production for a given year, the plant would have received approximately 8,600 tonnes of feed (about 700 48Y cylinders) and produced 800 tonnes of LEU product, with 7,800 tonnes of DU. The calculated SWU and feed factors are about 4 and 11, respectively. Substitution of the larger TC-21 GC for the TC-12 GC would require a license amendment and double the associated mass and SWU values.

Depleted Uranium and Wastes

Gaseous effluents in the venting system pass through carbon, alumina, and HEPA filters for contaminant removal, followed by monitoring prior to release. Gas exiting the potentially contaminated area of the Separations Building would be treated by HEPA filtration prior to release. Gaseous airborne effluents will be released from the proposed facility. The applicant estimates that less than 10 grams (0.35 ounces (oz); 240 microcuries) of uranium and less than 1 kilogram (kg) (2.2 pounds (lbs)) of HF will be released annually in 2.47 $\times 10^9$ cubic meters of air discharge. The CEDE was estimated to be below 0.1 mrem/yr to the MEI. Worker doses were estimated to average 20-25 mrem/yr, roughly comparable to the doses at the Urenco facilities in Europe. The effluents are significantly below 10 CFR Part 20 and U.S. Environmental Protection Agency National Emission Standards for Hazardous Air Pollutants (NESHAPs) airborne release limits.

The applicant estimated the maximum individual CEDE for liquid effluents during normal operations at the proposed facility. The applicant estimated maximum annual quantity of radiological material in liquid effluent would be 14.4 MBq (390 microCi) of uranium as discharge to the Treated Effluent Evaporative Basin (TEEB) (LES, 2005b). There are no offsite releases to any surface waters or publicly owned treatment works. Therefore, the release pathway the applicant assumed is airborne resuspension of particulate matter from the bottom of the basin, if waste water should evaporate. The applicant evaluated the dose for the 30th year of operations, which represents a realistically conservative upper bound on the amount of uranium available for resuspension and atmospheric dispersion. As noted in Section 8.7 of the applicant's ER, potential radiological impacts from operation of the proposed facility would result from controlled releases of small quantities of uranium hexafluoride (UF_6) during normal operations. The CEDE to the maximally exposed member of the public located at the south side of the controlled area boundary, resulting from the annual release to the atmosphere of 2.1 MBq (56 :Ci) of uranium from the TEEB, would be less than

0.017 :Sv (0.0017 mrem) per year if the TEEB is dry only 10 percent of the year (LES, 2005b). If the TEEB is dry the entire year, the CEDE to the maximally exposed member of the public located at the south side of the controlled area boundary would be less than 0.17 :Sv (0.017 mrem) per year. The estimated maximum public dose is also well below the 0.1 mSv (10-mrem) ALARA constraint on liquid emissions described in 10 CFR 20.1101 (e.g., less than 2 percent).

Wastes expected to be generated include non-hazardous industrial, Class A radioactive, hazardous, and mixed wastes. Construction wastes will also be generated in construction of the plant. Radioactive wastes approximate 12 te/yr and will be disposed of at properly licensed low-level radioactive waste disposal facilities. Hazardous chemical wastes will be properly treated and disposed of at permitted treatment and disposal facilities. Mixed low-level radioactive and chemically hazardous wastes will be treated and disposed of at facilities having the proper licenses and permits for these wastes. All quantities are small.

Depleted uranium tails will be stored on-site on the Uranium Byproduct Cylinder (UBC) pad until they are transferred to another licensee for commercial use or they are designated for disposal as waste. If designated as waste, the applicant is proposing to use either a commercial disposition path or the U.S. Department of Energy (DOE) disposition path set out in the USEC Privatization Act of 1996. As part of an agreement with the State of New Mexico, LES has committed to not store any depleted uranium cylinder for longer than fifteen years, not store more than 5,016 DU cylinders onsite at any time, and increase the contingency to 50% if more than 4,000 cylinders are in storage at any one time.

LES estimated that the facility will generate 132,942 MT of depleted uranium over a nominal 30 years of production, and did not reduce the estimate of depleted uranium based on the planned operations approach where production would actually end 5 years earlier (note: this estimated DU quantity value varies between documents). The applicant identified the waste processing and disposal cost of UF_6 tails as \$4.68 per kilogram of uranium (kg U) or \$4,680 per metric ton of uranium (MTU). This cost is based on the total of the three cost components that make up the total disposition cost for DUF_6 (i.e., deconversion, disposal, and transportation). The deconversion cost was based on proprietary information on a previously proposed private deconversion plant using the Cogema dry conversion process producing U3O8 and aqueous hydrogen fluoride (HF). The proposed process was the same as the plant Cogema has been operating in Pierrelatte, France for 20 years. The cost estimate was adjusted to account for differences in planned operating capacities, Euros-to-dollars conversion, and other costs associated with “Americanization.” “Americanization” refers to costs to obtain regulatory approval and costs to convert European equipment standards to standards used in the United States. These cost estimates used a proprietary Urenco business study of a proposed 3,500 Metric Tons (MT) U/year deconversion plant for the Capenhurst site. The study was based on a Cogema response to a Urenco request for proposal. LES modified the Cogema information to reflect a 7,000 MT U/year capacity by doubling the operating costs and by adding funds to reflect the increased capital and construction costs of a larger capacity plant considering the shared nature of some systems. Additional funds were also added for Americanizing the design and for licensing. The Cogema proposal assumed that HF would be sold commercially and did not include the costs to neutralize aqueous HF to calcium fluoride. NRC staff considered that neutralization would have no effect on the overall deconversion costs because those costs would be balanced by the elimination of costs for equipment for storing HF prior to commercial sale. The cost of disposing the calcium fluoride ($0.02/kg U) was included in the estimate.

The transportation and disposal costs were based on estimates provided by vendors of transportation and disposal services (LES, 2005a). Transportation costs were based on an estimate from Transportation Logistics International. This transportation estimate ($0.85/kg U) was independent of distance. The disposal cost of $1.14/kg U for depleted uranium oxides was based on an estimate provided by Waste Control Specialists. Staff compared the Waste Control Specialists estimate to an estimate for disposal of decommissioning wastes the applicant had obtained from Envirocare of Utah and found it to be consistent. The Envirocare disposal estimate for decommissioning waste was $2.12/m3 ($75/ft3) (LES, 2004). For the disposal of U3O8, the equivalent disposal cost at Envirocare is $1.07/kg U. Further, the applicant submitted an estimate for tails disposition from the U.S. Department of Energy (DOE) (DOE, 2005) as additional evidence of the reasonableness of their estimate. The DOE estimate included conversion, transportation, storage, disposal, and decommissioning costs of the conversion facility and totaled $3.34/kg DUF_6 ($4.91/kg U) in 2004 dollars. This is less than 5 percent of the difference in the applicant's estimate of $4.68/kg U. Staff considers that the DOE estimate provides additional assurance that the applicant's estimate of depleted uranium disposition costs is reasonable.

Safety

LES submitted, to the U.S. NRC, an application requesting a license, under 10 CFR Parts 30, 40, and 70, to possess and use byproduct, source, and special nuclear material (SNM) in a gas centrifuge uranium enrichment facility, located in Lea County, New Mexico, and have a nominal capacity of 3 million separative work units (SWUs). The facility will possess natural, depleted, and enriched uranium, and will enrich uranium up to a maximum of 5 percent uranium-235. The applicant also requested a facility clearance for classified information, under 10 CFR Part 95.

The NRC staff conducted its safety review in accordance with NUREG-1520, “Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility.” The staff’s safeguards review involved reviews of the applicant’s Fundamental Nuclear Materials Control Plan (FNMCP); the Physical Security Plan, which includes transportation security; and a “Standard Practice Procedures Plan for the Protection of Classified Matter.” The staff also reviewed the applicant’s Quality Assurance Program Description and Emergency Plan. Where the applicant’s design or procedures should be supplemented, the NRC staff identified license conditions to provide assurance of safe operation.

The LES design approach minimizes the presence of liquid UF_6 in the facility. This, combined with the low operating pressures inherent in GC facilities greatly reduces source terms of routine operations and potential accidents. Routine exposures were estimated in the 20-25 mrem/yr range for workers and 0.1 mrem/yr or less for the MEI.

LES would use ASTM methods to sample a cylinder. These methods involve liquefaction of the UF_6 in an autoclave. This is the only part of the operations that involve liquid UF_6. A potential accident involving the release of this material was found to have the highest consequence.

The health and environmental consequences of this accident are high. A facility worker in the vicinity of the blending donor station would, within seconds, be exposed to lethal UF_6, UO2F2, and HF concentrations. The environmental consequences are higher than the 5.4 U mg/m3 threshold for an intermediate consequence. An individual located at the CAB in the southwest sector would suffer high consequences from both uranium and HF exposure. The collective dose to the offsite population in the north sector indicates a risk of several LCFs in the population in the years after the accident. In accordance with the performance requirements of Part 70, Subpart H, the applicant has identified IROFS to reduce the risk to the facility workers, the public, and the environment from the effects of this accident. To prevent this accident, the applicant will rely on fail-safe hardwired high-temperature heater trips and redundant independent fail-safe capillary high temperature heater trips. Each control will be tested annually to ensure its availability and reliability to serve its intended safety function on demand. The purpose of these controls is to ensure that the accident is highly unlikely to occur. In addition, there have been no similar heater control failures at the Urenco facilities in Europe in over 30 years of operation.

Staff concluded the Separations Building would adequately resist design basis tornados and earthquakes (100,000 [F3] and 10,000 [0.15g] year return periods, respectively), and protect UF_6 containing equipment. The general approaches and safety programs were found to be consistent with accepted practices and ALARA.

Staff Assessment

The NRC staff concluded that the applicant's descriptions, specifications, and analyses provide an adequate basis for safety and safeguards of facility operations and that operation of the facility did not pose an undue risk to worker and public health and safety.

License conditions have been added to the license to ensure that IROFS boundaries will be defined using the applicant's IROFS boundary definition procedure and that the applicant will submit license amendment requests if digital instrumentation and controls are used in IROFS . In the facility SAR, LES provided preliminary design basis information for I&C systems that it identified as IROFS for the facility. The design information is at the system functional level. Individual components and vendors had not yet been selected. Based on the staff's review of the SAR, supporting information provided by the applicant, and the applicant's commitments to the industry standards and guidance cited in the sections above for I&C systems, the staff found that the preliminary design meets the requirements of 10 CFR 70.61 and 70.64(a)(10).

Given that these conclusions were based on preliminary design information and the possibility that the applicant may choose to implement design changes as discussed in the SER section on I&C, the staff imposed a license condition to ensure that the final design is adequate and acceptable to the staff. Specifically, the following condition will be included in the license:

"Currently, there are no IROFS that have been specified as using software, firmware, microcode, PLCs, and/or any digital device, including hardware devices which implement data communication protocols (such as fieldbus devices and Local Area Network controllers), etc. Should the design of any IROFS be changed to include any of the preceding features, the licensee shall obtain Commission approval prior to implementing the change(s). The licensee's design change(s) shall adhere to accepted best practices in software and hardware engineering, including software quality assurance controls as discussed in the in the Quality Assurance Program Description throughout the development process and the applicable guidance of the identified industry standards and regulatory guides as specified in SAR Chapter.

"If any changes result in IROFS requiring operator actions, the licensee shall conduct a human factors engineering review of the human-system interfaces using the applicable guidance in NUREG-0700, "Human-System Interface Design Review Guidelines," Revision 2, dated May 2002, and NUREG-0711, "Human Factors Engineering Program Review Model," Revision 2, dated February 2004."

Licensing/Status

The license has been issued and construction has commenced.

Learning Objective

When you finish this section, you will be able to:

4.1.7 Summarize Case Study 3: Summary of proposed American Centrifuge Plant.

CASE STUDY 3: AMERICAN CENTRIFUGE PLANT

Overview

On August 23, 2004, USEC Inc. (the applicant) submitted, to the U.S. Nuclear Regulatory Commission (NRC), an application requesting a license, under 10 CFR Parts 30, 40, and 70, to possess and use byproduct, source, and special nuclear material (SNM) in a gas centrifuge uranium enrichment facility. The applicant proposes that the facility be located on the U.S. Department of Energy (DOE) reservation in Piketon, Ohio, and have a nominal capacity of 3.5 million separative work units (SWUs). The facility will possess natural, depleted, and enriched uranium, and will enrich uranium up to a maximum of 10 percent uranium-235. The applicant also requested a facility clearance for classified information, under 10 CFR Part 95.

NRC staff conducted its safety review in accordance with NUREG-1520, “Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility.” The staff’s safeguards review involved reviews of the applicant’s Fundamental Nuclear Material Control Plan (FNMCP); the Physical Security Plan, which includes transportation security; and a “Standard Practice Procedures Plan for the Protection of Classified Matter.” The staff also reviewed the applicant’s Quality Assurance Program Description and Emergency Plan. Where the applicant’s design or procedures should be supplemented, NRC staff has identified license conditions to provide assurance of safe operation. The staff’s safety evaluation report is NUREG-1851. The applicant also submitted an Environmental Report, which was used to prepare, in a separate document, an Environmental Impact Statement for the facility (NUREG-1834). USEC identified the potential to increase the capacity at the site to 7 MSWU/yr at a later time; such an expansion would require a license amendment but the EIS studies were conducted at the 7 MSWU/yr capacity level.

The NRC has issued the license to USEC and preliminary construction has commenced.

Site Location and Description

In Section 1.1 of the license application, the applicant provides a summary description of the proposed gas centrifuge uranium enrichment plant and processes. The applicant is proposing to use a gas centrifuge enrichment process to enrich uranium. The proposed plant, known as the American Centrifuge Plant (ACP), will have a nominal production capacity of 3.5 million separative work units (SWUs). The process uses uranium in the chemical form of uranium hexafluoride (UF_6). Gaseous UF_6 enters a high-speed rotor at subatmospheric conditions where centrifugal forces press the heavier isotope of uranium, uranium-238 (U-238), to the outer wall of the rotor. The lighter isotope, uranium-235 (U-235), remains slightly closer to the center, away from the rotor wall. Internal scoops are used to collect the heavier and lighter fractions and circulate them to other centrifuges piped in a cascade arrangement.

The applicant has proposed that the ACP be located at the U.S. Department of Energy's (DOE's) Portsmouth Gaseous Diffusion Plant (PORTS) reservation in Piketon, Ohio, in refurbished existing buildings, newly constructed facilities, and grounds to be leased from DOE by the United States Enrichment Corporation, a subsidiary of the applicant. Figure 4 -22 provides a view of the existing site; Figure 4-23 superimposes the proposed facilities on the site. The applicant will in turn, sub-lease the ACP buildings and grounds from the United States Enrichment Corporation.

NRC will not issue a license until the lease is signed and NRC confirms that the contents of the lease agreements do not contradict any license conditions or considerations and assumptions documented in the applicant's LA and its supporting documents and NRC's licensing basis as documented in this Safety Evaluation Report (SER), Final Environmental Impact Statement, and their supporting documents.

Building Description

The ACP facility will consist of multiple buildings, each one of which will perform a specific function. The current (Summer 2007) estimated cost for the facility is $2.3 billion. The plant capacity has been revised to 3.8 MSWU/yr. A listing of selected buildings and their specific functions follows:

1. Two existing Process Buildings, X-3001 and X-3002, which will be refurbished to:

   (a) house operating centrifuge machines;
   (b) associated process piping;
   (c) instrumentation and controls;
   (d) computer systems; and
   (e) auxiliary support equipment.

   The X-3001 and X-3002 buildings will be similar in construction, layout, and design.

2. The facilities will include the existing X-3012 Process Support Building to provide operational control and maintenance of the equipment in the Process Buildings.

Figure 4-22. **Existing Portsmouth Site** (view from Northeast looking Southwest; existing buildings for the proposed GC facility are just above the photograph's center and right)

Figure 4-23. Proposed GC Facility at Portsmouth (view from Northwest looking Southeast; as noted in the text, some buildings are pre-existing)

3. The existing X-3346 Feed and Customer Services Building will provide for process feed, sampling, and product transfer requirements. The Feed Area of the building will house electrically heated feed ovens to provide the UF_6 feed. UF_6 feed will be processed through purification burp systems before being fed into the process piping in X-3001 and X-3002. A bridge crane will be used to place feed cylinders on railcarts.

4. The Customer Services Area of the X-3346 building will house the back-end equipment necessary for sampling and transfer of UF_6 material to customer cylinders. The Customer Services Area will be the only area where liquid UF_6 may be present. In this building, UF_6 product contained in 10-ton cylinders will be liquefied in electrically heated containment autoclaves for the purpose of sampling and transferring the UF_6 into 2.5 ton customer cylinders.

5. The new X-3346A Feed and Product Shipping and Receiving Building will serve as the focal point for the receipt and shipping of natural and enriched uranium in U.S. Department of Transportation approved containers.

6. The new X-3356 Product and Tails Withdrawal Building will house the equipment for withdrawal of the enriched and depleted UF_6 from the X-3001 and X-3002 Process Buildings. In this building, UF_6 product will be desublimed into cold traps before transfer into 10-ton product cylinders via sublimation in the cold traps, followed by desublimation in the cylinders. Tails withdrawal will be performed via compression and direct desublimation of the UF_6 into 14-ton tail cylinders.

7. The X-7725 Recycle/Assembly Facility will provide an area where centrifuge machines can be manufactured, assembled, tested, and maintained.

8. The X-7726 Centrifuge Training and Test Facility will provide areas to receive and test centrifuge components, and to assemble and repair the centrifuges. The facility may also be used as a machine assembly training area for the ACP.

9. The X-7727H Interplant Transfer Corridor will provide a protected pathway for transporting centrifuge machines between the X-7725 or X-7726 buildings and the Process Buildings.

10. Cylinder Storage Yards will support the movement and storage of cylinders containing UF_6 material.

11. The X-2232C Interconnecting Process Piping connects the X-3346 Building to the X-3001 and X-3002 Process Buildings and will be external to the primary facilities.

12. Secondary facilities for the ACP will include data processing facilities, emergency response facilities, electrical distribution systems, security fencing and portals, a pumphouse, an air generation plant, a cooling tower, a boiler system, a training facility, a maintenance facility, storage facilities, and waste accountability facilities.

Process Description

The ACP will be comprised of various buildings/facilities and areas on the U. S. Department of Energy (DOE) reservation in Piketon, Ohio. The ACP will primarily utilize existing buildings and facilities which were part of DOE's Gas Centrifuge Enrichment Plant, built in the early 1980s, but will also use newly constructed buildings and facilities. The facility the applicant proposes will be divided into the following operations:

- Receipt of UF_6
- Feeding of UF_6 into the enrichment process
- Enrichment processing using the cascade centrifuge machines
- Enriched and depleted UF_6 withdrawal
- UF_6 sampling to ensure it meets customer specifications
- UF_6 product material transfer into customer cylinders

- Loading of UF_6 cylinders for shipment to customers
- Handling of waste generated from the entire process

Cylinders containing feed UF_6, cylinders containing enriched product, and customer shipping cylinders and overpacks, as well as new and/or cleaned empty cylinders, will be received onsite through the X-3346A building. The cylinders will be off-loaded, weighed, and transferred to the appropriate cylinder storage areas.

The major equipment used in the UF_6 feed process (X-3346 building) will be the feed ovens. Natural UF_6 will be delivered to the plant in American National Standards Institute (ANSI) N14.1, “Nuclear Materials - Uranium Hexafluoride - Packaging for Transport” standard type 14-ton international transit cylinders. Feed cylinders will be loaded into the electrically heated feed ovens; vented for removal of light gases, primarily consisting of air and hydrogen fluoride (HF); and heated to sublime the solid UF_6. Solid UF_6 left in the cylinder after the feed operation will be recovered by being “heeled” to a freezer-sublimer in the Burp System.

The cascade centrifuge machines will be contained in the Process Buildings (X-3001 and X- 3002). UF_6 feed material will be supplied to the process from the Feed and Customer Service Building (X-3346) via heated interconnecting piping at subatmospheric pressure. Since individual centrifuges will not be able to produce the desired product and tails concentration in a single step, the centrifuges will be grouped together in series and in parallel to form arrays known as cascades. Figures 4-24 and 4-25 show cascades using DOE GCs – the ACP cascades would be similar. A centrifuge consists of a vertical, cylindrically-shaped rotor that spins within an outer casing. As the UF_6 feed enters the cascade, it will be mixed with material already in the cascade and separated into enriched and depleted material streams.

Figure 4-24. Top View of DOE GCs (ACP GCs would be similar)

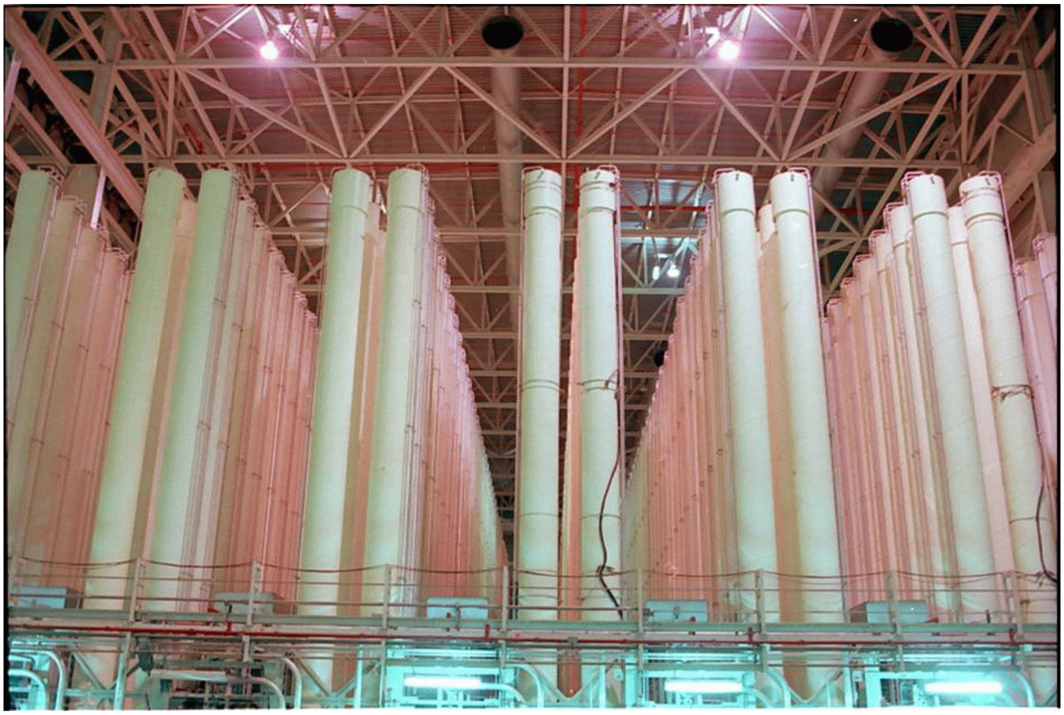
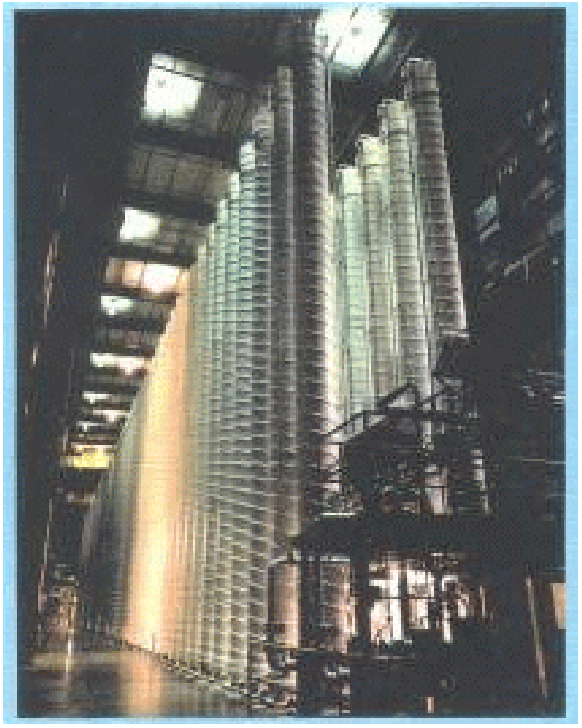


Figure 4-25. Side View of DOE GCs (ACP GCs would be similar)



Depleted UF_6 (tails) exiting the cascade will be transferred to the X-3356 building. Tails withdrawal will be accomplished through compression and direct desublimation into 10-ton or 14-ton cylinders. The major components that support the tails withdrawal operations will be the withdrawal (compression) trains, cold boxes, cold traps, assay spectrometers, and vents.

Product withdrawal will occur in the X-3356 building via desublimation into cold traps. Any “light gases” will be vented during this process. The cold traps will be heated to sublime the UF_6 which will be subsequently desublimed into 10-ton and 2.5-ton cylinders located in cold boxes. The filled source cylinders will then be moved to interim storage and subsequently moved to the X-3346 building sampling and transfer area.

UF_6 sampling and transfer operations will be carried out in the product operations area of the X-3346 building. The major components of these operations will be autoclaves, cold traps, and vents. The applicant will use the American Society for Testing and Materials (ASTM) C1052, “Standard Practice for Bulk Sampling of Liquid Uranium Hexafluoride,” standard which requires that samples be taken from homogenized UF_6. The applicant will use ASTM C787-03, “Standard Specification for Uranium Hexafluoride Enrichment,” and ASTM C996-04, “Standard Specification for Uranium Hexafluoride Enriched to Less than 5% 235U,” as part of its design which involves liquid UF_6 material during sampling, blending, and transfer operations (ASTM, 2003, and 2004). Electrically heated autoclaves will be used to liquify UF_6 in the source cylinders in order to facilitate the mixing of product and the transfer of liquid UF_6 to customer cylinders. To contain a UF_6 release, the autoclaves will be designed according to the American Society of Mechanical Engineers (ASME) standard, “Boiler for Pressure Vessel Code Section VIII, Pressure Vessels,” 2004. The applicant will design process piping following ASME B31.1, “Process Piping,” 2004, to minimize the potential for release of licensed material.

Filled customer product cylinders, emptied feed cylinders, and other UF_6 cylinders will be prepared for shipment in the X-3346A building. These cylinders will meet the ANSI N 14.1 standard.

Depleted UF_6 is handled in the ACP. No process waste water will be expected to be discharged from the liquid effluent tanks. Each process area vent system in the Process Buildings (X-3001and X-3002), Feed and Customer Service Building (X-3346), Sampling and Transfer Area (X-3346), Product and Tails Withdrawal Building (X-3356), and the Recycle/Assembly Facility (X-7725) will have gas flow monitoring and analytical instrumentation to continuously sample, monitor, and alarm if UF_6 is detected in the effluent gas stream.

The entire enrichment process system will operate at subatmospheric pressure with the exception of the sampling and blending process. This safety feature will help to minimize gaseous releases of UF_6 and HF since the leakage of material will typically be inward to the system. During sampling and blending operations, UF_6 will be liquefied within an autoclave that will provide the heating required to homogenize the material for sampling and/or blending. The cylinders containing liquid UF_6 will be designed following the ANSI N 14.1 standard while the autoclaves will be designed following the ASME Boiler for Pressure Vessel Code Section VIII standard. The cylinder and the autoclave will serve as the primary and the secondary containment, respectively, of UF_6 in liquid state.

Plant construction is estimated to take approximately 5 years, followed by about 30 years of operations. USEC does not envision exceeding 5% enrichment assay for supplying fuel to the existing LWR fleet and proposed evolutionary designs. The 10% assay design limit might be needed for Generation 4 reactors, but is assay is limited to not exceed 5% due to a license condition from the NRC. Maximum feed levels are 14,500 te NU/yr, at the 10% assay level.

Depleted Uranium and Wastes

For radiological ALARA goals for air effluent control, the applicant proposes an ALARA goal for the American Centrifuge Plant (ACP) of 5 percent (0.5 mrem/year) of the 10 CFR 20.1101 constraint of 10 mrem/year for the maximally exposed member of the public. The applicant's proposal is less than the 10 mrem/year ALARA goal recommended in NRC Regulatory Guide 8.37 (NRC, 1993), Regulatory Position C.1.2, "ALARA Goals," and is, therefore, acceptable to the staff. The applicant's approach also is in general agreement with the acceptance criterion found at 9.4.3.2.1(1) of NUREG-1520 (NRC, 2002) and is, therefore, acceptable to the staff.

Section 4.6.3.2 of the ER generally describes several effluent controls to reduce emissions of radioactivity to the atmosphere to maintain doses to the public ALARA, following the guidance found in Section 9.4.3.2.1(2) of NUREG-1520 (NRC, 2002). These controls include:

- Cold traps desublime uranium hexafluoride and separate it from other gases followed by activated alumina traps to capture uranium hexafluoride in the purge vacuum (PV) and Evacuation Vacuum (EV) Systems;
- A continuous vent sampler that draws samples from the process vent using an isokinetic probe that maintains a real time indication of effluent levels; and
- Engineered local ventilation systems to capture residual uranium during maintenance activity around the centrifuges.

In general, gases are processed through cold traps to capture the uranium hexafluoride; any residual is further reduced by passing the gas through an alumina trap. Uranium hexafluoride released from cylinder connections and disconnections that reacts with humid air to create uranyl fluoride is captured by gulper systems and then passed through a roughing filter followed by a High Efficiency Particulate Air filter to collect the uranyl fluoride particulate.

These controls are expected to result in maximum air effluent releases of about 2.7 mCi per week, or about 0.14 Ci per year of total uranium, resulting in a projected maximum airborne concentration of uranium of less than 3.2x10-15 :Ci/mL, with an associated total effective dose equivalent (TEDE) of about 0.3 mrem to the Maximally Exposed Individual (MEI). Applicant calculations using the CAP88-PC model indicate that dose rate to the MEI are well below the U.S. Environmental Protection Agency (EPA) National Emissions Standards for Hazardous Air Pollutants, limit of 10 mrem/year and the NRC limit of 100 mrem/year and are generally consistent with the guidance found in Section 9.4.3.2.1(2) of NUREG-1520.

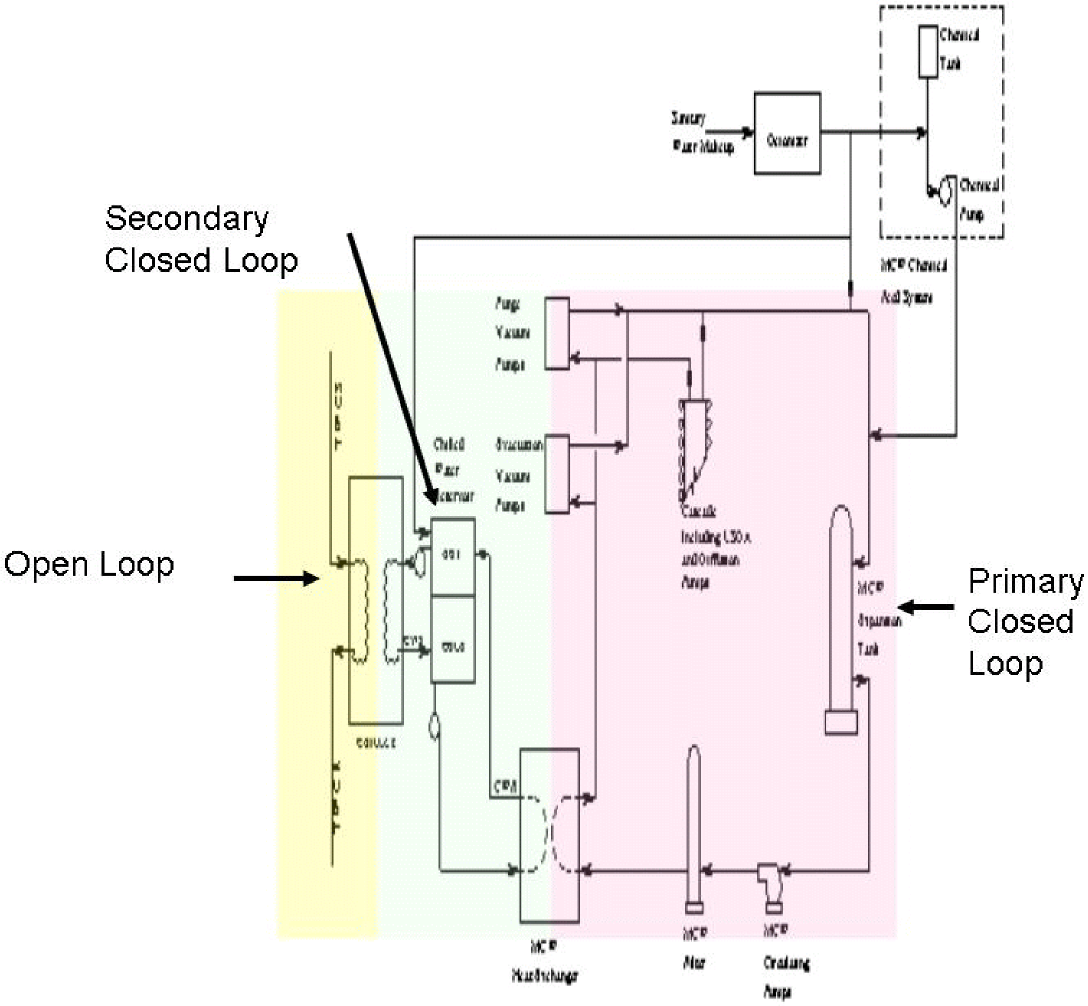
For liquid effluents, the applicant proposes an ALARA goal of 10 percent of the air effluent goal, or 0.05 mrem/year to the maximally exposed member of the public. This is equivalent to 0.05% of the 10 CFR 20.1301 limit on annual public dose. The applicant’s proposal is much less than the 10 mrem/year goal recommended in NRC Regulatory Guide 8.37, and is in general agreement with the guidance found in Section 9.4.3.2.1(2) of NUREG-1520.

The applicant indicates that the centrifuges and PV/EV vacuum pumps are to be cooled by a closed-loop Machine Cooling Water (MCW) system to minimize the amount of water potentially contaminated by uranium (Figure 4-26). Waste heat from the MCW system will be discharged via heat exchangers to the Tower Water Cooling (TWC) system. Waste heat from the cold trap refrigeration systems in the X-3346 and X-3356 buildings will also be discharged to the TWC system. The applicant proposes to use the Gaseous Diffusion Plant (GDP) Recirculating Cooling Water (RCW) system to discharge blow down water from the TWC system, as is currently done. No licensed material is expected in this location. The applicant indicated that at some time in the future, the GDP will be decommissioned. Before the GDP is decommissioned, the applicant will bypass the GDP RCW system. Instead, the effluent will be discharged directly into the RCW discharge pipeline and then into the Scioto River. This change will not have any effect because no treatment of the effluent occurs in the RCW process.

The liquid discharges to the RCW System are monitored by using an automated sampler, which collects a weekly composite sample of the liquid effluent for radiological analysis as well as samples for NPDES mandated analyses. These data are made available to the ACP as assurance that no unanticipated discharge of licensed material has occurred.

USEC proposes to collect leaks from the MCW system and incidental spills elsewhere in the ACP in the Liquid Effluent Collection (LEC) system. Water accumulated in the 550 gallon tank is sampled and pumped to either the X-6619 sewage treatment plant (STP) or containerized for disposal, depending on the results. Given the small increment in waste volumes from the MCW and existing compliance at the X-6619 STP outfall, this proposal to discharge the MCW system to this outfall is acceptable to the staff.

Figure 4-26. Machine Cooling Water (MCW) System



No changes in storm water runoff associated with installation and operation of the ACP are expected. Storm water runoff in the vicinity of the ACP is captured in either the X-2230N West Holding Pond (National Pollutant Discharge Elimination System [NPDES] outfall 012) or the X-2230M Southwest Holding Pond (NPDES outfall 013). USEC states that each holding pond contains maximum anticipated liquid discharge concentrations of 1x10-8 :Ci/mL uranium and discharges to the Scioto River.

Potential waste streams that will be generated at the ACP will include low-level radioactive waste, low-level mixed waste, hazardous waste, sanitary/industrial waste, recyclable waste, and classified/sensitive waste.

Depleted UF_6 tails will be stored in steel cylinders, within cylinder storage yards, until the cylinders are transferred to DOE or another facility for deconversion; until decommissioning; or until they are transferred to another licensee for commercial reuse. At or before the time of decommissioning, any remaining UF_6 tails will be converted to a stable oxide form and disposed of in accordance with the USEC Privatization Act. USEC has indicated a preference for using DOE as the disposition pathway for DU tails, but has kept the option open for deconversion and disposal using other licensed facilities.

Under Section 3113 of the USEC Privatization Act of 1996 (Title 42 U.S. Code 2297h), DOE, “at the request of the generator, shall accept for disposal low-level radioactive waste, including depleted uranium, if it is ultimately determined to be low-level radioactive waste, generated by any person licensed by the Nuclear Regulatory Commission to operate a uranium enrichment facility.” In addition, the generator must reimburse DOE for the disposal of depleted uranium in an amount equal to DOE’s costs, including a pro rata share of any capital costs. On January 18, 2005, the Commission issued an order stating that depleted uranium was a low-level radioactive waste. Therefore, if the applicant requests, DOE is required under the USEC Privatization Act of 1996 to accept the depleted uranium generated by the applicant.

At the request of the applicant, DOE provided a cost estimate for dispositioning depleted uranium generated by the applicant. The applicant estimated that the facility will generate 265,300 MT of DUF_6 over a nominal 30 years of operation. The applicant estimated the waste processing and disposal cost of UF_6 tails at $4.62 per kilogram of uranium (kg U). This cost is based on the total of the 4 cost components that make up the total disposition cost for DUF_6 (i.e., deconversion, disposal, and transportation).

The disposition cost was based on the estimate from DOE providing a cost for DUF_6 disposition services as calculated by a DOE contractor (DOE, 2005) and modified by the applicant to account for the amount of depleted uranium to be generated by the applicant and in 2006 dollars. To make the modifications, the applicant used the same method in developing disposition costs as used by the DOE contractor in preparing the original estimate for another uranium enrichment facility. Based on the applicant's analysis, the cost estimate for dispositioning depleted uranium in 2004 dollars would be \$2.33/kg UF_6 for deconversion, \$0.003/kg UF_6 for storage, \$0.37/kg UF_6 for byproduct disposal and transportation to the licensed disposal site, \$0.17/kg UF_6 decommissioning of the deconversion plant, and \$0.09/kg UF_6 for a Federal administrative charge. Because the deconversion was assumed to take place at Portsmouth, no transportation charge from the applicant's facility to the DOE deconversion plant would be necessary. The total amount for depleted uranium disposition would be \$2.96/kg UF_6 or \$4.38/kg U in 2004 dollars and \$3.12/kg UF_6 or \$4.62/kg U in 2006 dollars. Year 2004 costs were escalated using the Implicit Price Deflator for 2005 of 2.8 percent and the administration's June 8, 2006, estimate of inflation for 2006, as measured by a forecast of the gross national product index of 2.9 percent. The total cost in 2006 dollars for dispositioning of the 265,300 MT of UF_6 estimated to be generated over the lifetime of the ACP would be \$829 million. In addition, the applicant added a 25 percent contingency factor for a total depleted uranium dispositioning cost estimate of \$1,036 million.

Safety

On August 23, 2004, USEC Inc. (the applicant) submitted, to the U.S. Nuclear Regulatory Commission (NRC), an application requesting a license, under 10 CFR Parts 30, 40, and 70, to possess and use byproduct, source, and special nuclear material (SNM) in a gas centrifuge uranium enrichment facility. The applicant proposes that the facility be located on the U.S. Department of Energy (DOE) reservation in Piketon, Ohio, and have a nominal capacity of 3.5 million separative work units (SWUs). The facility will possess natural, depleted, and enriched uranium, and will enrich uranium up to a maximum of 10 percent uranium-235. The applicant also requested a facility clearance for classified information, under 10 CFR Part 95.

NRC staff conducted its safety review in accordance with NUREG-1520, "Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility." The staff's safeguards review involved reviews of the applicant's Fundamental Nuclear Material Control Plan (FNMCP); the Physical Security Plan, which includes transportation security; and a "Standard Practice Procedures Plan for the Protection of Classified Matter." The staff also reviewed the applicant's Quality Assurance Program Description and Emergency Plan. Where the applicant's design or procedures should be supplemented, NRC staff has identified license conditions to provide assurance of safe operation. In some areas of plant design, USEC has identified commitments to codes and standards. The actual design will be reviewed and inspected by the NRC prior to start-up of the facility or operational module.

The USEC design uses sublimation to feed the separations facility and desublimation to remove enriched product and depleted tails streams. Liquid UF_6 is limited to the two areas of product blending and cylinder sampling. Product blending liquefies feed cylinders (typically 48X 10 ton cylinders) and feeds them to product cylinders (30B, 2.5 ton cylinders) for shipment to fuel fabrication facilities. Sampling uses liquefaction of the cylinder in an autoclave, per ASTM methods. Potential accidents involving autoclaves and the blending/sampling systems were identified as high consequence events. The autoclaves are designed to numerous specifications and standards to prevent leakage of UF_6.

Staff concluded the probability of tornados striking a building were below 1E-5/yr, and, therefore, tornado hazards were not evaluated further. Seismic resistance was found to be acceptable, with a 10,000 year return basis [0.2g] for the X-3346 new addition and a 1,000 year return period [0.15g] for the other buildings.

Staff Assessment

A summary of the health effects associated with the five potential accident sequences analyzed by staff is presented in Appendix B of the SER. The accident consequences vary in magnitude, and include accidents initiated by human error and equipment failure. The most significant consequences are associated with the release of uranium hexafluoride and nuclear criticality. The proposed American Centrifuge Plant (ACP) design reduces the risk (likelihood) of the accident by identifying items relied on for safety (IROFS), and defense-in-depth features. NRC staff independently verified the accident analysis by performing confirmatory hand calculations and computer simulations. NRC staff concluded that through the combination of plant design, passive and active engineered IROFS, administrative IROFS, and defense-in-depth features, the proposed ACP will pose an acceptably low safety risk to workers, public, and the environment. As a result, the staff determined that the applicant meets the requirements to operate the proposed facility under 10 CFR Part 70.

The staff included the license conditions in the following areas for different phases of ACP operations:

- financial qualifications
- liability insurance or DOE indemnification
- funding availability for incremental construction
- contracts for plant output
- operation above 5% assay, including transportation
- classified material handling and protection

It should be noted that the license condition for criticality comes from two aspects. First, criticality safety control includes credit for moderator exclusion. However, at above approximately 7% assay (i.e., within the plant’s design envelope), a moderator is no longer needed for a critical reaction to occur, although the required mass in a low-enriched uranium system could be quite large. Second, the 30B cylinders are not approved for transporting LEU above 5% assay.

Licensing/Status The license has been issued and construction has commenced.

Self-Check Questions 4-5 ✓

1. What are the three commercial GC facilities that have undergone licensing reviews at the NRC, and who are the licensees?

2. Where are the proposed facilities located?

3. What about DU?

4. What is the current status of these facilities?

5. What was used as the basis for the GC facility license reviews?

6. What were some of the issues surrounding LES-1?

7. Discuss the conditions on the LES-2 license.

8. Discuss the conditions on the ACP license.

9. What are the planned assay limits for these facilities?

10. What are some of the issues with exceeding 5% assay?

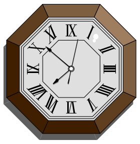
11. What are the projected routine doses associated with these facilities?

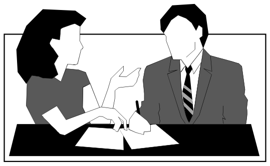
12. What are the main hazards?

13. Would liquid UF_6 be present in these facilities, and would it contribute to hazards and risks?

You have completed this section.
Please check off your progress on the tracking form.

It's time to schedule a progress meeting with your administrator. Review the progress meeting form on the next page. In Part III, As a Regulator, write your specific questions to discuss with the administrator.





Progress Review Meeting Form

Date Scheduled:________________________________**Location:**_____________________

I. The following suggested items should be discussed with the administrator as to how they pertain to your current position:

- Principle of the gas centrifuge process
- Gas centrifuge components and description
- Separative capacity
- Gas centrifuge material flow
- Feed receipt and storage
- Feed purification and vaporization
- Enrichment (stage and cascade system)
- Product and tails removal
- Piping-structure components
- Product cylinders
- Sampling analyses
- Product blending
- Product storage and shipping system
- Tails storage
- Waste confinement and management
- Sewage
- Industrial use of gas centrifuge
- Hazards and safety concerns for the gas centrifuge process
- Gas centrifuge incidents

II. Use the space below to take notes during your meeting.

III. As a Regulator:

- Since there are no operating gas centrifuge plants in the United States, what other gas centrifuge process should I be familiar with in my work?
- Is there any particular documentation that I should review regarding gas centrifuge operations?

Use the space below to write your specific questions.

IV. Further assignments? If yes, please note and complete. If no, initial completion of progress meeting on tracking form.

Ensure that you and your administrator have dated and initialed your progress on your tracking form for this module. Go to the module summary.

MODULE SUMMARY

The gas centrifuge process uses high speed, rotating cylinders (rotors) to separate isotopes, primarily by centrifugal forces. Scoops or thermal effects may be used to induce additional, secondary enrichment effects from a combined axial-radial counter-current flow within the centrifuge itself. Typical rotor sizes range from 1–2 feet diameter and 10-30 feet high. The rotors spin inside a stationary container, or stator; a vacuum is usually pulled on the stator to reduce friction and scavenge any leaks. The stator also confines GCs and debris in the event of a failure. Gas connections comprise the feed, enriched, and depleted streams; and are located on the spinning axis. Gas centrifuges operate at tens of thousands of rpm with edge speeds of hundreds of meters per second. Strong materials are needed – carbon composite materials are often used for the rotors due to superior strength to weight characteristics. GCs use UF_6 gas for uranium enrichment.

GCs produce a greater enrichment effect than gaseous diffusion. Typical alphas (enrichment per stage) are around 1.05, although up to around 1.16 may be theoretically achievable. GCs operate at relatively low pressures, usually under 0.1 psia. Consequently, while fewer GCs are needed in series to achieve a given enrichment, many are needed in parallel to achieve commercial throughput capacities. In practice, plants contain 10,000 or more GCs and are organized into several cascades, each of which can produce the intended enrichment level and consists of a few hundred to a few thousand GCs. GCs operating at the same enrichment level within the cascade are called a stage.

Environmental, safety, and health impacts of GC operations are relatively small and primarily consist of hazards associated with high speed equipment and small UF_6 and chemical leaks. However, GC plant ES&H aspects are largely determined by the operations in non-GC areas, such as feed, withdrawal, blending, and sampling. If liquid UF_6 is present in these areas, then the hazards are slightly less but similar to GDPs. However, if sublimation–desublimation is used (e.g., "cold-feeding"), then the GC plant hazards are considerably lower than GDPs. In practice, operating GC facilities are phasing out liquid UF_6 systems and replacing them with solid-vapor systems, thus avoiding liquid UF_6 hazards. New designs and proposed facilities primarily use solid-vapor systems, without liquid UF_6; only the sampling and, in one case, blending systems use liquid UF_6.

GCs are the enrichment technology of choice overseas, and large plants of one million SWU/yr or more exist in several countries. Urenco is a leading GC developer and operates three facilities with a combined output of 7.5 MSWUs/yr. France is converting its GDP to a GC facility. Domestically, no commercial GC facilities are operational. However, Urenco is planning a 3 MSWU/yr facility in New Mexico and USEC is planning a 3.8 MSWU/yr facility in Ohio. Both proposed facilities have been licensed by the NRC and initial construction has commenced. Areva has also announced its interest in constructing a GC enrichment facility in the U.S.

Congratulations! You are ready to go to the next assigned module.
