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Safe Use and Handling of Chlorine Trifluoride and Fluorine Treatment Gases During *In Situ* Chemical Treatments at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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ACRONYMS

$AlCl_3$	aluminum chloride
ATB	analytical test buggy
BrF_3	bromine trifluoride
CFR	*Code of Federal Regulations*
CIP/CUP	Cascade Improvement Program and Cascade Uprating Program
ClF_3	chlorine trifluoride
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DSA	Documented Safety Analysis
F_2	fluorine
FLM	Front Line Manager
FPDP	Fluor Federal Services, Inc., Paducah Deactivation Project
FTIR	Fourier Transform Infrared spectrometer
GDP	gaseous diffusion plant
HA	Hazard Assessment
ICT	*in situ* chemical treatment
IF_7	iodine heptafluoride
LTLT	long-term low-temperature
N_2	nitrogen
NF_3	nitrogen trifluoride
NTC	NaF trap cart
O_2F_2	dioxygen difluoride
PCTC	portable cell treatment cart
P&E	purge and evacuation
PGDP	Paducah Gaseous Diffusion Plant
PSM	Process Safety Management
PSS	Plant Shift Superintendent
R-114	dichlorotetrafluoroethane (commonly referred to as Freon)
TSR	Technical Safety Requirement
UF_6	uranium hexafluoride
UO_2F_2	uranyl fluoride

1. INTRODUCTION

The Paducah Gaseous Diffusion Plant (PGDP) ceased operation in 2013 after nearly 60 years of uranium enrichment operations. Although residual gaseous uranium hexafluoride (UF_6) and greater than safe mass fissile uranium were removed from the PGDP process cascade at shutdown, there remains significant uranium holdup within the cascade. It is estimated that as much as 30,000 lb of deposit material remains throughout the cascade equipment and piping, primarily in the form of solid uranyl fluoride (UO_2F_2). These deposits cause the process buildings (specifically, Buildings C-310, C-331, C-333, C-335, C-337, C-337-A, and C-360) to be categorized as Hazard Category 2. Hazard Category 2 facilities retain the potential for a nuclear criticality event, thus increasing the risk for harm to personnel and property. Because PGDP is being prepared for future decontamination and decommissioning (D&D), the hazard classification of the process buildings is a concern. A reduction in the hazard category reduces the risk associated with D&D and also reduces the burden of surveillance, maintenance, and protection requirements. Removal of the uranium holdup and UO_2F_2 deposits to a point at which the process buildings can be categorized as Radiological Facilities achieves a desired risk reduction.

In situ chemical treatment (ICT) is planned for deposit removal in the PGDP cascade equipment as a precursor to process building D&D. The ICT treatment chemicals are chlorine trifluoride (ClF_3) and fluorine (F_2). These chemicals are strong oxidizers and are highly hazardous. While the use of these chemicals for cascade treatment at the Oak Ridge, Portsmouth, and Paducah gaseous diffusion plants dates back to the 1950s, their use for ICT at PGDP represents a new methodology and involves much greater quantities than were used in the past. It is acknowledged that significant planning, hazard analysis, engineered controls, and personnel training are necessary before these chemicals can be used for the new ICT method at PGDP. However, the lessons learned from past uses, when combined with new controls developed for ICT, indicate that ICT can be performed safely. This paper summarizes the history and rationale for using ClF_3 and F_2 for chemical treatment, the chemistry of treatment, and the engineering and operational controls developed to assure safe treatment operations at PGDP. The following are the sections in this paper.

- Rationale for Chemical Treatment
- Conceptual Approach to ICT at PGDP
- Historical Events Considered in ICT Planning
- Handling and Storage of Treatment Gases
- Treatment Gas Transfer for Anticipated ICT Operations
- Chemistry of Treatment Reaction
- Potential Treatment Interactions
- Anticipated ICT Process and Sequence at PGDP
- NaF Cart Regeneration
- Monitoring and Controls During the ICT Process
- Safety Basis Evaluation (Risk and Mitigation)
- Training and Drills
- Conclusion

2. RATIONALE FOR CHEMICAL TREATMENT

Although gaseous ClF_3 and F_2 are highly reactive and hazardous chemicals, their hazards are well understood. Historically, they were used in off-stream cascade cell treatments since the 1940s and 1950s at the Oak Ridge, Portsmouth, and Paducah Gaseous Diffusion Plants (GDP) to fluorinate solid uranium deposits to release gaseous UF_6. While the plants were operating, cell treatments were conducted infrequently. The handling, storage, and use of these chemicals were controlled via extensive and restrictive operating procedures and safety requirements.

The evaluation of deposit removal by chemical treatment methods as a precursor to plant D&D began in the late 1980s after the Oak Ridge GDP was shut down. At that time, various options were evaluated, including one that allowed uranium to be removed at ambient temperature using ClF_3. This technique was tested in the laboratory at Oak Ridge and appeared promising. The treatment conditions included using only ClF_3 as a treatment gas; 75°F and 140°F treatment temperatures; no diluent; pressures of 1, 4, and 8 psia; and a treatment period of 35-105 days (Munday 1993a). More laboratory tests were conducted in a flow loop system, and experimental tests with ClF_3 and UO_2F_2 were run at 80°F, 120°F, and 150°F. The reaction rate at 120°F was faster than at 80°F and appeared to be faster at 120°F than at 150°F (Munday 1993a). This work formed the basis for conducting ICT at an average of 120°F. E.B. Munday further documented a preliminary design for scaling up to a size 1 converter and included trapping the UF_6 gas on sodium fluoride (NaF) (Munday 1993b).

Other alternatives considered at Oak Ridge included use of F_2, bromine trifluoride (BrF_3), iodine heptafluoride (IF_7), dioxygen difluoride (O_2F_2), and other strongly reactive fluorinating gases (Munday 1993a). Table 1 provides an evaluation of alternatives from a presentation by Dr. E. J. Barber entitled, *Comment on Gas Phase Recovery* (Barber n.d.).

Table 1. Evaluation of Treatment Gases

Treatment Gas	Evaluation Comment
F_2	Will not recover UO_2F_2 at near ambient temperature
ClF_3	Reactive
ClF_5	Kinetics less favorable than ClF_3
BrF_3	Limited vapor pressure; noxious products; better used as liquid
BrF_5	Good reactivity; noxious products
IF_7	Reactive
IF_5	Much lower fluorination potential than ClF_3

The compounds ClF_3 and IF_7 were selected for further evaluation. The conclusion was that either ClF_3 or IF_7 could be used to recover UF_6 from cascade deposits, but the recovery of the UF_6 would be simpler if ClF_3 were used. Because plant personnel had handling experience with ClF_3 and, at the time of the evaluation, IF_7 was 15 times more expensive than ClF_3, the evaluation led to the selection of ClF_3 as the best option for post-shutdown cell treatment (Barber n.d.). Ultimately, however, no post-shutdown chemical cell treatment was conducted at Oak Ridge.

Following the transition of the Portsmouth GDP to cold standby, another chemical alternative, nitrogen trifluoride (NF_3), was investigated for removal of uranium and technetium deposits. The results that NF_3 could remove both UO_2F_2 and UF_4 effectively were reported at the 2006 Waste Management Symposia (Scheele 2006). However, it was found that NF_3 is kinetically competitive with ClF_3 only at temperatures greater than 300°C (572°F).

Subsequently, two plant-scale tests of a long-term low-temperature (LTLT) treatment method were conducted at Portsmouth, as summarized in Table 2 (Riddle 1997; Riddle 2003). Later, additional LTLT treatments were conducted at Portsmouth on approximately 60% of the X-326 cells (88 out of 140 available cells) without any significant problems (Spencer 2014). The result of the full-scale use of the LTLT method was successful removal of uranium to levels below greater than safe mass. Subsequent tear down and removal of some equipment in the cells verified the equipment was free of deposits.

Table 2. Comparison of LTLT Cell Treatments at Portsmouth Gaseous Diffusion Plant

LTLT Test on X-25 Cells at Portsmouth		LTLT Test on X-27 Cells at Portsmouth	
Treatment Gas	ClF_3/F_2 mixture	Treatment Gas	ClF_3/F_2 mixture
Temperature	Ambient (70–85°F)	Temperature	Ambient (80–91°F)
Diluent	Dry nitrogen	Diluent	Dry nitrogen
Target Pressure	14.0 psia	Target Pressure	14.0 psia
Treatment Period	105 days	Treatment Period	92 days

The Portsmouth treatments were conducted on cells considerably smaller than the cells at Paducah, at lower temperatures, and for longer periods than anticipated at Paducah. Nevertheless, benchmarking visits were conducted at Portsmouth, and the LTLT lessons learned were reviewed and integrated into the Paducah ICT planning. The significant differences between the Portsmouth LTLT and the planned PGDP ICT are listed below.

- LTLT treatment was conducted at a minimum temperature of 65°F, but PGDP ICT will be conducted at an average temperature of 120°F.

- LTLT pressure was increased to near atmospheric pressure with dry nitrogen, but dry air will be used for the PGDP ICT.

- LTLT had no means to trap out UF_6 as it was being generated, but NaF trapping of the UF_6 will be used for PGDP ICT.

Based on the success at Portsmouth GDP and the improvements made to the methodology for PGDP, it is believed that ICT will be successful at PGDP. The following narrative explains the conceptual approach to ICT; the historical events that were considered; how treatment gases are handled; the chemistry of treatment; and the safety basis, controls, and personnel training required.

3. CONCEPTUAL APPROACH TO ICT AT PGDP

At PGDP, a portable cell treatment cart (PCTC) will facilitate ICT operations. The PCTC consists of two parts: a NaF trap cart (NTC) and an analytical test buggy (ATB). The NTC holds eight trap containers of NaF enclosed in an insulated oven. The ATB contains a sample manifold, a Fourier Transform Infrared spectrometer (FTIR), monitoring instrumentation, and a recirculation pump to provide motive force for treatment gas circulation through a target treatment location (an isolated cell or piping) and then through NaF traps.

In general, the ICT process is anticipated as follows. A target location (such as a cell) is isolated, the R-114 coolant is drained, and the coolant system is cut and capped off. The target location is purged and

then pressured up with dry air. Leak-tight seals are installed, and then the target location and the PCTC are connected to each other. Both are evacuated to a low pressure and leak rated to assure system integrity. Then, a treatment gas mixture of ClF_3 and F_2 is transferred from storage tanks in Building C-350 into an existing receiving volume (i.e., header) that is connected to the target location. Block valves allow operators to control the discrete amounts of treatment gas mixture allowed into the header at any given time. Under controlled conditions, a motor-operated block valve between the charged header and target location is opened, and treatment gas is admitted to the target location. The PCTC system then circulates the treatment gas mixture. The ClF_3 oxidizes and converts solid UO_2F_2 deposits to gaseous UF_6. The UF_6 is captured in the NaF traps on the PCTC. The PCTC system monitors this reaction continuously and circulates the gases until treatment has been maximized, as indicated by onboard instrumentation and analytical testing. The PCTC then is disconnected and moved either to a new treatment location or to a NaF regeneration or maintenance station, as needed.

4. HISTORICAL EVENTS CONSIDERED IN ICT PLANNING AT PGDP

As ICT was planned for PGDP, historical events were considered, and lessons learned were incorporated.

On December 13, 1962, a highly exothermic destructive reaction occurred at PGDP Building C-337 Unit 1, Cell 3 (AEC 1964). The conditions that led up to this destructive reaction are as follows.

- The cell had undergone an off-stream running hot treatment with ClF_3.
- Significant quantities of ClF_3 had been added in one continuous transfer into the cell.
- During the treatment, one or more localized reactions were initiated. Two possible causes for these reactions were (1) high temperatures induced by a malfunctioning compressor (metal-to-metal rubbing) causing a hot metal reaction between ClF_3/UF_6/reaction products and the malfunctioning compressor, or (2) ClF_3 depletion allowing free chlorine (Cl_2) to react with aluminum cell components.
- The treatment was called complete, and refrigerant R-114 was pumped to the cell coolant systems and UF_6 was added to the cell in preparation for placing the cell on-stream.
- The additional UF_6 added to the cell intensified the ongoing local reactions.
- At some point, cooler leak(s) developed that allowed R-114 to leak into the cell causing a generalized fire across the cell.
- Major R-114 inleakage developed into the cell causing over pressurization and an explosion.
- Large cell equipment was dislodged from bases and large openings occurred in the cell containment boundary. The building sprinkler system extinguished the resulting fire preventing it from igniting the roof.

The lessons learned from this event that were applied to the planning of ICT are as follows.

- The R-114 must be evacuated from the cell coolant system to prevent the inadvertent addition of R-114 during a treatment.

- A mixture of ClF_3 and F_2 must be used as the treatment gas. The F_2 prevents the formation of free Cl_2. Also, a lower limit for ClF_3 must be established to prevent depletion of this chemical and the formation of Cl_2.

- The initial charging of treatment gas to a treatment location must occur in small discrete quantities to limit the amount of gas available to support a destructive reaction in the event of high moisture or a hydrocarbon deposit.

- During the charging of treatment gas to an ICT location, an operator must observe monitoring instrumentation for reaction products that would indicate a high moisture or hydrocarbon reaction. The addition of treatment gas must be stopped, and additional actions must be taken if significant quantities of reaction products are noted.

- After a cell is charged with treatment gas, it must be pressured to between 13.0 and 14.0 psia, which will dilute the treatment gas concentration significantly. Also, by pressuring the cell to near atmosphere, wet air in-leakage will be greatly reduced.

- Rotating equipment must be shut down during ICT, which prevents the initiation of a hot metal reaction.

In addition to the lessons learned discussed above, it is noted that the current ICT operations will occur at approximately 120°F, which is significantly lower than the temperature for a running cell treatment. Also, the currently available commercial F_2 product is diluted with 80% nitrogen (N_2), and current C-350 procedures have been revised to reflect this requirement.

A second significant event occurred on July 27, 2011 (USEC 2011). A ClF_3 release occurred inside the C-350 complex. The release occurred after the cylinder valve on a full ClF_3 cylinder initially was opened to the pigtail connection to charge ClF_3 into one of the two storage tanks. A total of 18 lb of ClF_3 was released to the atmosphere from a 160-lb ClF_3 cylinder. No injuries occurred to the two operators who were present at the release location. The root cause of the release was suspected to have been contamination of the Teflon gasket inserted into the pigtail/ClF_3 cylinder connection. It is believed that the gasket contamination caused a reaction that, in turn, caused the gasket to fail. The gasket was consumed during the release, however, so the cause could not be verified. An emergency response was initiated, and the cylinder valve subsequently was closed to stop the release. No further releases have occurred at the C-350 complex since enhanced cleanliness measures were implemented.

5. HANDLING AND STORAGE OF TREATMENT GASES

The handling and storage of the treatment gases ClF_3 and F_2 always have been controlled at the Paducah Site in order to reduce hazards and mitigate risks. These controls remain in effect for the ICT project and are described below.

ClF_3 is shipped to PGDP by commercial carrier in nominal 160-lb net weight cylinders. Delivery quantities are limited by (1) the manufacturer's Process Safety Management (PSM) limit of less than 1,000 lb at the manufacturing facility, and (2) controls imposed by U.S. Department of Transportation Hazardous Material Special Permit for Hazard Zone B poisonous-by-inhalation materials. Bulk storage of ClF_3 is allowed currently at two physical locations within the PGDP boundary. The first location is C-742-B located northwest of C-745-B cylinder yard. This yard has two individual designated storage

areas separated by distance. The second location is the C-350 complex. The current administrative limit for ClF_3 is less than 1,000 lb for each designated storage area. Because the storage quantities are less than 1,000 lb, ClF_3 is not required to be controlled by the PSM program. PGDP has implemented the PSM controls voluntarily.

Handling and storage of ClF_3 at the C-350 complex are controlled by procedure CP4-OP-0442, *Handling and Storage of Chlorine Trifluoride, Fluorine, and Mixed Gases in C-350*, and CP4-OP-0437, *Chlorine Trifluoride, Fluorine, and Mixed Gas Leaks* (FPDP 2015a; FPDP 2015b). ClF_3 is very reactive and a strong irritant if released, and it can react with moisture in the air to form hydrogen fluoride (HF). Therefore, the following very extensive, safety-related requirements are employed:

- Inspection of the ClF_3 cylinder and cylinder valve for damage prior to connection of the cylinder to the C-350 charging manifold;
- Cleanliness procedures that require care to avoid contaminating the inside of the ClF_3 cylinder-to-manifold pigtail surfaces during inspection, as well as use of only clean new surgical gloves;
- Rigorous leak tightness requirements after the pigtail is connected;
- Remote manual operation of the ClF_3 cylinder valve when the valve is opened;
- Localized ventilation to exhaust any ClF_3 that might be released out the building roof; and
- An HF detection system that will detect both HF and F_2 releases and alarm locally in C-350, in C-335 Area Control Room, and in the C-300 Central Control Facility.

F_2 also is shipped to PGDP by commercial carrier in tube trailers. Each trailer can contain up to 1,975 lb of F_2 at a nominal pressure of 2,000 psig. One trailer can be located at C-410-K for off-loading and storage of F_2 into C-410-D. A second full trailer, along with an empty trailer, can be located at the C-745-A yard. The C-410-D area contains three large tanks, each of which can contain up to 240 lb of F_2. The F_2 is supplied by the manufacturer at the current commercial standard mixture of 20% F_2 and 80% N_2. Because the quantities of F_2 are above 1,000 lb, the storage, handling, and use of F_2 on plant site is controlled under the PSM program.

Handling and storage of F_2 at PGDP also are controlled by procedure CP4-OP-0429, *Operation of the C-410-D and C-410-K Fluorine Distribution Centers*. (FPDP 2015c) The partial pressure of F_2 is relatively high, thus above-atmospheric handling and storage of F_2 is necessary. The C-410-D storage tanks and F_2 header are above atmospheric pressure, with a normal operating pressure of $\leq$ 130 psia. The piping and headers downstream of the control valves have a normal operating pressure of approximately 5 psig. Given that F_2 also is very reactive and is a strong irritant, extensive safety-related requirements are employed, including the following:

- Inspection of tube trailers and manifolds for indications of leakage;
- Inspection of pigtail connection surfaces for damage;
- Cleanliness procedure steps requiring care to clean connection surfaces and gaskets using clean surgical gloves;
- Rigorous leak tightness requirements after the pigtail is connected;

- Installation of pressure regulators and rupture discs to assure that system pressure limits are not exceeded; and

- Installation of an F_2 detection system inside C-410-K and C-410-D that detects and alarms locally and in the C-300 Central Control Facility upon an F_2 release.

Pressure demand respirator protection also is used when pigtails are disconnected at C-410 because the F_2 system operates above atmospheric pressure and the truck manifold cannot be enclosed in a ventilated cabinet, as is the case in C-350.

6. TREATMENT GAS TRANSFER FOR ANTICIPATED ICT OPERATIONS

A mixture of ClF_3 and F_2 has been and will continue to be stored in two tanks at the C-350 complex and transferred to process buildings using the approved procedure CP4-OP-0442, *Handling and Storage of Chlorine Trifluoride, Fluorine, and Mixed Gases in C-350* (FPDP 2015a). F_2 is charged into the C-350 tanks from the C-410-D facility. ClF_3 then is charged into the C-350 tanks from a ClF_3 cylinder inside C-350. This mixture is rigorously controlled and contains approximately 32% ClF_3, 14% F_2, and 54% N_2. This mixture is based on optimizing cell treatments, while not allowing free chlorine (Cl_2) to exist. The tanks always are maintained at subatmospheric pressure to prevent releases. Laboratory personnel sample the tanks quarterly to ensure that the gas mixture concentrations are correct. Past sampling of the C-350 gas on a semiannual basis has shown only minor deviations from the designated concentrations.

During the anticipated ICT operations, charging of treatment gas from the C-350 facility into the isolated treatment gas receiving volume (i.e., header) is performed using two-way continuous communication between an operator located in the process building that will receive the treatment gas and an operator located in C-335 that will control C-350 operations. The process building operator is responsible for monitoring the receiving volume pressure to ensure the treatment gas is flowing correctly. The operator in C-335 monitors and controls the C-350 tank pressure using calibrated gages and controls located in C-335 to assure the correct amount of treatment gas is being charged from C-350 to the isolated receiving volume (i.e., header).

It should be noted that during the anticipated ICT operations, the frequency of charging the C-350 tanks and the handling of ClF_3 cylinders will be similar to the charging and handling that occurred during the Cascade Improvement Program and Cascade Uprating Program (CIP/CUP) that was conducted during the late 1970s and early 1980s (DOE 1985). Under the CIP/CUP, all cells were given chemical treatments after they were uprated. Discussions with PGDP operations personnel indicate that no significant reactions or ClF_3 releases occurred during the CIP/CUP operations.

7. CHEMISTRY OF TREATMENT REACTION

During ICT−which is gas phase decontamination−gaseous fluorinating agents ClF_3 and F_2 are used to fluorinate the solid uranium deposits to release gaseous UF_6. The uranium deposits in the PGDP cascade are anticipated to be in various compounds such as UF_4, UF_5, hydrates of UO_2F_2, UO_2F_2, and intermediate oxyfluorides, such as $U_2O_3F_6$ and $U_3O_5F_8$. The most prevalent compound is UO_2F_2. UO_2F_2 deposits can

be distributed fairly evenly across a stage as particles; can exist as more localized deposits such as in a seal cavity; or can be built up as on a gas cooler.

UO_2F_2 deposits resulted from the reaction of UF_6 and water (H_2O) vapor from wet air in-leakage into process equipment while it was operating at below atmospheric pressure. As shown in the reaction equation below, a solid product, UO_2F_2, forms and remains in the cell while the HF gas continues through the process cascade. Because UF_6 is in excess, other intermediate uranium oxyfluorides beside UO_2F_2 also may be formed. Uranium deposits in the form of UF_4 and UF_5 are formed from reaction with metals surfaces (corrosion). The surfaces of the equipment also are covered with a monolayer of absorbed UF_6.

$$UF_6(g) + H_2O(g) \rightarrow UO_2F_2(s) + 2HF(g)$$

ClF_3 reacts with UO_2F_2, UF_4, and UF_5 to produce UF_6. However, ClF_3 will not remove the absorbed UF_6 layer. The reaction for ClF_3 and UO_2F_2 is complex, and the following is the main chemical equation.

$$UO_2F_2(s) + 2ClF_3(g) \rightarrow ClO_2F(g) + ClF(g) + UF_6(g)$$

The reaction of UO_2F_2 is exothermic and generates heat. Deposit particles that are distributed across a large area should dissipate the heat of reaction more easily. The localized deposits possibly could generate more heat from the reaction. However, the effectiveness of the reaction also is dependent on the age of the deposit, the surface area-to-mass ratio or how finely divided the material is formed, and the total deposit mass.

An additional chemical equation of a potential UO_2F_2/ClF_3 reaction, which generates free Cl_2, is shown below (Ellis 1960).

$$2\ UO_2F_2 + 4ClF_3 \rightarrow 2\ UF_6 + Cl_2 + ClF + ClO_2F + O_2 + F_2$$

The Cl_2 gas can form aluminum chloride ($AlCl_3$), which can react in the fluorinating environment and generate hot metal reactions. The added F_2 can react with Cl_2 and ClF to form ClF_3, thus reducing the amount of Cl_2.

The Paducah hazard analysis CP2-NS-3014, *Hazard Analysis for In-Situ Chemical Treatment Activities*, Rev. 0, Section 4.3.1.1, gives a worst case example for ICT activity, which adds 350 lb of ClF_3 and 61.8 lb of F_2 to a cell (FPDP 2015d). If only the 350 pounds of ClF_3 is used and sufficient UO_2F_2 is available for complete reaction, then 666 lb of UF_6 would be generated. The F_2 and ClF react to produce ClF_3 and produce an additional 286 lb of UF_6 for a total of 952 lb of UF_6. Even if a release occurs in this bounding worst case, it will not be outside the documented analyzed safety basis for the ICT operation. This amount of UF_6 gas is not expected in a typical cell. After operators gain experience conducting ICT, there may be opportunities to optimize the amount of ClF_3/F_2 to minimize the amount of residual remnant gases to be disposed when cell treatment is completed.

The complete reaction of all ClF_3 and/or F_2 with UO_2F_2 is expected to affect the pressure of the cell or piping system. For a '000' cell at 120°F, adding 350 lb of ClF_3, 61.8 lb of F_2, and 181.9 lb of N_2 would increase the pressure by 2.95 psia. After complete reaction of these fluorinating gases in a normal reaction with UO_2F_2 without any temperature change, the pressure would increase by 0.94 psia to 3.89 psia. Any initial pressure would need to be added to this pressure. Therefore, complete reaction of ClF_3 and F_2 with uranium oxyfluorides in normal reactions would increase the '000' cell pressure by only approximately 1.0 psia (Pro2Serve 2015).

8. POTENTIAL TREATMENT INTERACTIONS

ClF_3 and F_2 present several risks if they encounter other substances in uncontrolled conditions, as follows. Appropriate controls have been evaluated for these conditions.

- ClF_3 and F_2 and the process coolant R-114 can form explosive mixtures. If a mixture is not controlled and is exposed to an ignition source, a reaction can occur. A mixture of oxidant (ClF_3 and F_2) and R-114 possibly could occur if a coolant system leak developed during ICT unless the source of R-114 is eliminated. To control this situation, the R-114 system will be drained and purged before cell treatment begins. Also, the cell R-114 system will be isolated physically by cutting and capping from the process building's R-114 distribution system before ICT begins. An explosive mixture also could occur during evacuation of the cell contents at the conclusion of ICT if the purge and evacuation (P&E) pump develops a coolant leak. To control this situation, the Technical Safety Requirement (TSR) concentration limit for ClF_3 and F_2 where R-114 could be present is 8% total oxidant at 14.7 psia (Union Carbide 1980b; FPDP 2015e). Although the FTIR on the ATB in the PCTC system can measure ClF_3 concentration, the Analytical Lab must sample the cell and measure the ClF_3 and F_2 concentrations to ensure the 8% total oxidant limit is met before the cell contents are evacuated.
- ClF_3 and F_2 react violently with organics and, depending on the amounts of hydrocarbons present, a fire or explosion can occur (Farrar 1979a). Rigorous cleanliness standards must be followed and passivation must be conducted on new equipment to be used for ICT. All gaskets and hose connections will be cleaned thoroughly by personnel wearing nonpowdered surgical latex gloves. Cascade cells and equipment that operated in a fluorinating environment prior to plant shutdown are expected to be free of organic compounds if no maintenance activities have occurred that resulted in a breach of the process system. However, the amount of treatment gas initially admitted to a target location will be limited during ICT as a further control. Additionally, FTIR scans on the PCTC can detect the breakdown products of reactions with organic compounds such as CF_4.
- ClF_3 reacts vigorously with water to form significant amounts of HF. The following chemical equation is for the reaction of excess ClF_3 with water (Farrar 1979b).

  $$2ClF_3 + 2H_2O \rightarrow ClO_2F + ClF + 4HF$$

  In-service cascade cells that were in a fluorinating environment prior to plant shutdown have been pressured up to approximately atmospheric pressure with dry air and should not contain significant amounts of water. If excess water is present or the UO_2F_2 is hydrated during an ICT evolution, some ClO_3F is formed, as indicated by the following chemical equation (Barber 1994).

  $$ClF_3 + UO_2F_2{*}xH_2O \rightarrow UF_6 + ClF + ClO_2F + HF + ClO_3F$$

  The chemical equation is unbalanced because the amount of H_2O is variable. Detection of ClO_3F by FTIR analysis would indicate the presence of H_2O in the treatment system.

  If significant amounts of water were evenly dispersed throughout the treatment location and the total amount of ClF_3 reacted, the pressure in the cell would increase. The worst case pressure rise from the 350 lb of ClF_3 and H_2O was calculated using the ideal gas equations for the gas moles generated. For a '000' cell at 120°F, adding 350 lb of ClF_3, 61.8 lb of F_2 and 181.9 lb of N_2 would increase the pressure by 2.95 psia. After complete reaction of these fluorinating gases, a normal reaction with H_2O without any temperature change would increase the pressure by 3.54 psia, giving a total pressure of 6.49 psia. Any initial pressure would need to be added to this pressure. Complete reaction of the fluorinating gases would require 74.8 lb of water. Therefore, complete reaction of ClF_3 and F_2 with

H_2O in normal reactions would only increase the '000' cell pressure by approximately 3.54 psia (Pro2Serve 2015).

Prior to ICT operations, if water is suspected to be present in a cell, an evaluation will be performed to determine the extent of condition and recovery options. In general, a drying operation would be performed before ClF_3 is introduced to the cell. The drying operation consists of dry air purging and/or a fluorine-only treatment.

- A potential UO_2F_2/ClF_3 reaction can occur in which free Cl_2 is generated, as described by the following equation (Ellis 1960).

$$2UO_2F_2 + 4ClF_3 \rightarrow 2\ UF_6 + Cl_2 + ClF + ClO_2F + O_2 + F_2$$

The Cl_2 gas can form aluminum chloride ($AlCl_3$), which can react in the fluorinating environment generating hot metal reactions. However, "…$AlCl_3$ has been shown not to form in significant amounts in the presence of F_2 or ClF_3; therefore, a deficiency of fluorinating agents in the presence of Cl_2 must be avoided" (Union Carbide 1982a). The added F_2 can react with Cl_2 and ClF to form ClF_3 reducing the amount of Cl_2. The main purpose for using a ClF_3/F_2 mix is safety; therefore, ICT is using a mixture of 70% ClF_3/30% F_2 by volume (Union Carbide 1982b).

It is noted that during the anticipated ICT operations, the amount of treatment gas initially admitted to a target location will be limited and increased only after verification of the normal expected gas concentrations, chemical compositions, and reaction rates. Reactions with large, finely divided UO_2F_2 deposits will generate UF_6 and heat in the localized area. This information was considered during evaluation of the 1962 incident at C-337 Unit 1 Cell 3. The investigative report of that incident states, regarding deposits in the barrier, "…it is concluded that a destructive reaction between UO_2F_2 and ClF_3 is unlikely." However, "…large accumulations in cooler heads could be hazardous if treated with ClF_3" (AEC 1964). It should be noted that at the time of the incident, the Unit 1 cells were A-B cooled. During the equipment upgrades under the CIP/CUP in the 1970s/1980s, the configuration was changed to A-line cooling, thus putting the barrier before the cooler and reducing the likelihood of a large uranium deposit on the cooler. During the anticipated ICT operations, the concentration of ClF_3 and F_2 in the initial charging volume will be high, and the total pressure will be low (before pressuring up to 13.5 psia). If an unexpected increase or decrease in stage pressure or an unexpected increase in temperature occurs, the treatment will be stopped for evaluation. If a substantial and extremely reactive UO_2F_2 deposit existed in a cascade cell, FTIR analysis would indicate higher UF_6 concentrations in a particular stage.

A destructive reaction is considered to be extremely unlikely during the ICT project. With no R-114 present and no rotating equipment as an ignition source, an explosion inside the ICT location is not credible. If a destructive reaction were to occur, the cell pressure will be maintained stable to help prevent the transfer of a reaction to another location inside the cell. Also, all cell block valves will be closed, thus encapsulating a reaction to a single cell. The cell block valves, piping, and equipment shells all are constructed of thick, nickel-plated steel. The one exception would be the pipe expansion joints. In the event of a burn-through of the cell containment boundary, no significant lube oil will be present to support an external fire. The area surrounding a cell is constructed of concrete, steel, and transite, which would not support an expansive fire. The building roof is combustible; however, the building fire protection system will be in place to quickly douse a fire if one were to occur. The ICT location cell housing will be in place, which will present a barrier to the spread of a fire or reaction products. Finally, only the inter-cell piping directly connects one cell to another. For a destructive reaction in one cell to reach another cell, it would have to burn through two separate valves, each with heavy double discs. This event would be extremely unlikely.

9. ANTICIPATED ICT PROCESS AND SEQUENCE AT PGDP

ICT is planned for all size cells and associated piping at PGDP. Treatment will begin in the C-337 facility that contains '000' size cells. The '000' size (over 10 times the volume of the X-27 size cell treated at Portsmouth) requires method changes to enhance the treatment as compared to the Portsmouth method. Table 3 compares the conditions of the Portsmouth LTLT and the Paducah ICT.

Table 3. Comparison of Portsmouth LTLT to Paducah ICT

Condition	LTLT on X-27 Size Cells at Portsmouth	ICT on 2X, '00', '000' Size Cells at Paducah
Oxidant	ClF_3/F_2 mixture	ClF_3/F_2 mixtures
Temperature	Ambient (80-91°F with no external heat sources)	~120°F with external heaters blowing into cell housing
Diluent	Dry nitrogen	Dry air
Pressure	14.0 psia target	~13.5 psia target
Gas mixing	Recirculation for samples	Continuous recirculation for samples and pumps for recirculation from 1st stage to last stage.
Gas trapping	None	UF_6 removal on NaF trap cart
Duration	92 days	Estimated 35 days

The oxidant gases are the same, and the total treatment pressures are similar for both Portsmouth and Paducah treatments. The Paducah ICT pressure target is only 0.5 psia lower. The LTLT method used dry nitrogen as a diluent, but the ICT method uses dry air. Dry air previously was used as a diluent in running cell treatments at Paducah. Other technical documentation also indicated that dry air is nearly as effective as nitrogen as a diluent (Union Carbide 1980a). The temperature for the ICT is increased to approximately 120°F to enhance the rate of reaction greatly and reduce the duration to achieve the same degree of deposit removal. The ICT also recirculates the gas from the first stage to the last stage to improve the distribution of the treatment gases and enhance the ClF_3 and UO_2F_2 reaction. The ICT also has the ability to remove the UF_6 gas from the recirculation stream by trapping the UF_6 on NaF traps on the PCTC. By removing UF_6 from the system, the reaction is driven to produce more UF_6 product. The continual removal of UF_6 also reduces a potential reactant in a hot metal reaction. The estimated ICT duration is 35 days, which is less than half the duration of the LTLT.

Per TSR and procedure requirements, several conditions must be met before the initial transfer of treatment gas to the ICT location (FPDP 2015e).

- The R-114 refrigerant in the cell coolant system must be drained and an R-114 negative obtained. The R-114 lines at the cell's R-114 drain valves and other connecting lines must be cut and capped to isolate the cell R-114 system physically from the building R-114 distribution system and from adjacent cells. The removal of R-114 from the ICT target location will eliminate R-114 as a potential contributor to a destructive reaction.
- Rotating equipment that might serve as an ignition source for a destructive reaction at a target location will be shut down.
- A target treatment location temperature will be adjusted to approximately 120°F. Performing ICT at 120°F instead of ambient temperature improves the chemical reaction rate. Performing ICT at this relatively low temperature also significantly reduces the possibility of a destructive reaction.

- The coolant system will be pressured with dry air to a nominal 5 psig to minimize the potential for treatment gas to enter the coolant system.
- The ICT target location must be evacuated to a low starting treatment pressure and leak rated to assure system integrity (the TSR requirement is ≤ 2 psia, and the operations procedure requirement is ≤ 1 psia).
- A surge volume must be established. The ICT target location always should be maintained below atmospheric pressure, but the surge volume is established to relieve the ICT target location pressure if it exceeds atmospheric pressure for any reason.
- Personnel and vehicular traffic must be restricted at the ICT location on both the cell and ground floors.
- The receiving volume (i.e., header) must be isolated, evacuated, and leak rated before the first treatment gas transfer from C-350.

Per TSR requirements, the treatment gas will be transferred from C-350 into an isolated treatment gas receiving volume (i.e., header) first before an ICT target location is charged with the treatment gas. Procedural requirements limit the amount of treatment gas transferred into the receiving volume (i.e., header) to less than one half of the amount allowed for a cell by the TSR to reduce further the material at risk. This approach will limit the material at risk for any one transfer operation.

After the receiving volume is charged with treatment gas, the treatment gas is transferred into the ICT target location (i.e., a cell with PCTC connected) by remotely opening a single motor operated block valve, which allows treatment gas to flow by pressure differential into the ICT target location. During the charging of treatment gas to the ICT target location, an operator continuously monitors the pressure in the cell to assure that the treatment gas is in fact going to the correct location and that an adverse reaction is not occurring (as indicated by a rapid increase in pressure).

The initial charges of treatment gas into each target location will occur in small discrete quantities from the receiving volume. These discrete quantities will add about 0.1 to 0.2 psi partial pressure of treatment gas to the target location at a time. The intent of this charging method is that in the very unlikely event hydrocarbon material or high moisture does exist in the target location, only a very limited amount of ClF_3/F_2 will be available to support a destructive reaction.

After the treatment gas has been added to a cell, it will be pressured with dry air, typically to between 13.0 and 14.0 psia, which will dilute the treatment gas concentration to approximately 8%. Dilution of the treatment gas with dry air reduces the pressure differential between atmosphere and the cell pressure, which will minimize wet air inleakage into the cell. After the cell is pressurized, it is anticipated that it will take approximately 35 days to complete the treatment. During this time, the FTIR automatically will take frequent samples of the treatment gas for trending. Also, an operator will monitor the ICT target location at least twice per shift to assure the PCTC system components are working correctly and to monitor cell temperatures, pressure, and treatment gas concentrations/break down products to assure no abnormal conditions exist. Cell temperatures and pressure can be monitored 24/7 via the cascade ADP system.

A UF_6 negative is required before the ICT operating mode is exited, per the TSR. Thus, after ICT is declared complete at a specific target location, a UF_6 negative will be obtained from that location. The UF_6 negative is obtained through the evacuation and purging of the ICT location using P&E centrifugal pumps and/or the Normetex pumps. As the treatment gas is evacuated with P&E pumps or the Normetex pumps, the gas will be routed to one or both of the existing C-310 NaF trap banks. The NaF traps will trap out the residual UF_6 that remains in the treatment gas to acceptable levels. Then the gas is discharged out

the C-310 Building 200-ft stack. The flow rate through the traps can be adjusted to ensure stack permit limits are not exceeded. The permit limits address uranium and fluoride emissions.

10. NAF CART REGENERATION

After several evolutions of ICT, a NaF cart becomes full of UF_6. The NaF cart will be regenerated to release the UF_6 from the NaF in the same manner that the plant's existing stationary NaF trap system performed during PGDP operations. The NaF cart regeneration process consists of heating the NaF traps to between 600°F and 650°F and flowing a 10 slpm mixture of 10% F_2 and 90% N_2 through the traps to release the UF_6 from the NaF. Two NaF carts may be regenerated simultaneously for a total flow of 20 slpm. The discharge flow from the NaF carts (containing F_2, N_2, and UF_6) then is routed to the C-335 Separation System. At the Separation System, cold traps will trap out the UF_6. The discharge flow from the cold traps containing F_2 and N_2 and residual amounts of UF_6, then will pass through a set of stationary NaF traps and Alumina traps to trap out the remaining UF_6 prior to discharge out the C-310 Building 200-ft stack.

The cold traps are cooled by a chiller unit to about -30°F. The chiller unit contains refrigeration compressors that use both R-404A and R-508B refrigerants. The refrigerants, in turn, cool a glycol mixture that is pumped to external cooling jackets on the cold traps to cool the cold traps. As noted earlier, F_2 can react with refrigerant to form an explosive/ignitable mixture. Thus, the possibility of contact between the residual F_2 in the discharge flow and the refrigerants was considered. It is noted that the cold traps are made from Schedule 40 Monel. The Monel alloy is very corrosion resistant, even under fluorinated conditions. Thus, the F_2 inside the cold traps is separated from the chiller refrigerants by a Schedule 40 Monel trap shell and a glycol loop. It is considered to be extremely unlikely for the chiller refrigerants to gain access to the inside of the cold traps and react with the F_2.

11. MONITORING AND CONTROLS DURING THE ICT PROCESS

Before any ICT evolution occurs, there are controls in place at the C-350 and C-410 facilities. The control of hydrocarbons in the C-350 and C-410 complex is accomplished by rigorous inspection and clean handling techniques per procedural requirements. Procedural requirements for the connection of hoses/pigtails between the PCTCs and cells also require rigorous inspection and clean handling techniques. All PCTC carts and hoses/pigtails will be passivated with F_2 prior to first use in the field, which will eliminate the potential for hydrocarbon materials in this equipment.

As treatment gas is added to a cell, samples from a FTIR on the PCTC will be obtained across the cell to assure that the treatment gas is being diffused across all of the stages. Per procedure, during the charging of ClF_3/F_2 to the ICT target location, operators will monitor FTIR sample results closely for CF_4 and ClO_3F. CF_4 would be a result of a ClF_3/F_2 and hydrocarbon material reaction, and ClO_3F would be a result of a ClF_3/F_2 and moisture reaction. If significant quantities of CF_4 or ClO_3F are noted, then the addition of treatment gas to the target location will be stopped, and cell temperatures and pressures will be closely monitored to determine if additional actions per procedure are necessary. It should be noted that the vast majority of all ICT target locations were in UF_6 service prior to plant shutdown, and no unreacted organic deposits should be present in these locations.

A destructive reaction may be indicated by any of the following:

- An abrupt increase in cell temperature is observed at any stage;
- An abrupt increase or decrease in cell pressure is observed;
- A localized detonation is heard or felt by workers near the ICT cell; or
- Outgassing of cell contents is observed.

In the event that a destructive reaction is suspected, the addition of treatment gas will be stopped immediately. Additionally, the Plant Shift Superintendent (PSS) and Front Line Manager (FLM) will be notified, access controls will remain in place to prevent personnel from entering the affected area, cell pressure and temperatures will be monitored remotely to determine cell condition, and the cell pressure will not be disturbed. Personnel in entry gear can locally isolate the PCTC system from the cell if required. Leaving the cell pressure as is will minimize the potential of spreading a reaction to other locations within the cell. Cell temperatures and pressure can be monitored 24/7 via the cascade ADP system.

Controls also are implemented when the ICT is complete at a target location. The P&E pumps use R-114 as a coolant. In order to prevent a potential destructive reaction should coolant leak from the P&E coolers into the process system while the P&E pumps are operating, the treatment gas ClF_3/F_2 concentration will be limited to 8 mole percent. The ClF_3/F_2 concentration will be determined via laboratory analysis of the treatment gas at the ICT location prior to use of the P&E pumps. This limit assures that, even if R-114 is present, a destructive reaction is not credible.

A hot metal reaction also is not considered credible during P&E pump operation because of the low UF_6 concentration in the treatment gas. This is because the UF_6 generated in an ICT target location will be trapped in NaF traps as it is being generated.

The P&E pump's discharge temperature, pressure, and vibration levels will be monitored closely. High discharge temperature will cause an alarm in the building control room. A hardwire trip of a P&E pump will occur if undesirable vibration occurs or if the discharge pressure approaches atmosphere.

Finally, the vast majority of ICT target locations were in UF_6 service prior to plant shutdown. No unreacted hydrocarbon deposits are expected in these locations. However, some locations that have been shut down for an extended period of time may require significant maintenance activities to reassemble necessary equipment to support ICT. Preplanned special treatment sequences likely will be required. For instance, those locations suspected of containing high moisture concentrations may require extended dry air purging and/or pretreatment with dilute F_2.

12. SAFETY BASIS EVALUATION (RISK AND MITIGATION)

The ICT process was evaluated in CP2-NS-3014, *Hazard Analysis (HA) for In-Situ Chemical Treatment Activities* (FPDP 2015d). The unmitigated consequence of accidents for the ICT process results in a high consequence due to chemical exposure to workers and the public. In response to that, controls were developed to mitigate the risk of an accident, as documented in CP1-NS-3000, *Documented Safety Analysis (DSA) for the Department of Energy Paducah Site Deactivation Project*, and CP1-NS-3001, *Technical Safety Requirements for the Department of Energy Paducah Site Deactivation Project* (FPDP 2015e; FPDP 2015f; FPDP 2015g).

The HA Appendix A, *ICT Hazard Identification*, provides the detailed listing of potential hazard events identified and considered. The HA Appendix D, *Hazard Evaluation Table*, provides an extensive summary of the postulated events, unmitigated risk, preventive features, mitigative features, and the mitigated risk. The events that were identified with potential "high" unmitigated consequences to the worker, co-located worker, or off-site were fires, deflagrations, loss of containment (exposure to HF), criticality, and natural phenomena. The controls developed in the HA, and documented in the DSA and TSR, reduced most of the unmitigated consequences such that the mitigated risks could be considered either low or moderate. There was one exception−deflagration. The residual risk of deflagration has a frequency of "extremely unlikely" because of the implemented controls. However, the consequence to the worker for exposure to hazardous chemicals remains "high" due to limited evacuation time.

To address the remaining "high" consequence, the charge limit for treatment gas is restricted to 350 lb of ClF_3 and 61.8 lb of F_2 per cell. The DSA assumes that a maximum of eight target locations can be treated simultaneously in a process building. The treatment gas mass limits, along with the engineered and administrative controls, mitigate the consequence of potential accidents. The following are the TSR Safety Significant engineered controls for cell treatment.

- High pressure fire water system and the fire protection systems in the process buildings and Building C-310
- PCTC and UF_6 primary system integrity
- PCTC pressure indication instrumentation
- R-114 coolant system isolation by cut and cap

13. TRAINING AND DRILLS

Training is conducted per DOE Order 426.2, *Personnel Selection, Training, Qualification, and Certification Requirements for DOE Nuclear Sites*, (DOE 2010) and plant procedure, CP2-TR-0100, *Training Program* (FPDP 2015h). Nuclear Facility Managers (NMFs), Facility Operations Supervisors and Operators, Surveillance and Maintenance technicians, Emergency Responders, and support groups are trained in a graded approach depending on their involvement in the ICT process. Lessons learned from operating experience with chemical handling and cell treatments at Portsmouth and Oak Ridge have been incorporated into training.

The NFMs who will conduct the ICT operations are trained in accordance with CP3-OP-1118, *Facility Management* (FPDP 2015i). This training ensures that the NFMs have competencies in the areas listed below.

- Roles, Responsibilities, Authorities, and Accountabilities
- Nuclear Criticality Safety Compliance
- DSA/TSR
- Unreviewed Safety Question Determination
- Work Planning and Control
- Conduct of Operations

- Integrated Safety Management
- Security
- Component Configuration Management Processes
- Regulatory Compliance/Safety Management program
- Emergency Response/Management
- Oversight/Assessments
- Facility Specifics

Their training also ensures that the NFMs are prepared to make decisions about the ICT process including mode changes, operability calls, and decisions in response to abnormal conditions that may arise during the ICT process.

Facility Operations Supervisors and Operators are trained for their normal operations duties and specifically on the ICT process. Their ICT training includes the following topics.

- TSRs
- Handling fissile material
- F_2 and ClF_3 distribution systems
- F_2 and ClF_3 overview and chemical safety
- ICT processes
- Operation of the C-410-D & K facilities
- Operation of the PCTC System
- Operation of the FTIR
- Operation of the lube oil skid
- Operation of the dual-speed pumps in C-337
- Operation of the C-310 NaF trap system
- Operation of the C-310 Jet Station
- C-350 process safety

Training, as listed below, also is provided to Supervisors and Operators for the regeneration and withdrawal phase of the ICT project in which the C-335 Separation System is used to regenerate NaF trap media in the PCTC system.

- Replacement of PCTC NaF trap media
- Operation of the C-335 Separation System
- C-310 operational overview
- C-310 product withdrawal
- UF_6 cylinder handling
- Use of the C-310 Matrix floor scale
- Use of UF_6 pigtails
- Operation of Winslow sales

In addition to their normal emergency training, the Emergency Response personnel are trained on F_2 and ClF_3 overview and chemical safety, emergency response actions at C-350 and C-410-D, and overview of the ICT process and PCTC operations.

Support personnel are trained in their respective support job tasks and in an overview of the ICT process.

Emergency management drills are conducted per DOE Order 151.1C, *Comprehensive Emergency Management System*, (DOE 2005) and plant procedure CP3-EP-1017, *Emergency Response Drills* (FPDP 2015j). Field emergency response drills are conducted for the Emergency Operations Center, PSS, fire services, E-Squad, and local building personnel. Elements tested include hazard recognition, emergency notification, immediate protective actions, local personnel assembly and accountability, response dispatch, emergency classification, equipment staging, hazmat response, hazmat mitigation, and confirmed mitigation.

Evaluated operations drills are conducted for NFMs, Facility Operations Supervisors, and Facility Operators to test their knowledge, skills, and abilities related to the ICT process, operation of the PCTCs, process support systems, response to upset conditions, and the TSRs.

14. CONCLUSION

Both ClF_3 and F_2 are highly reactive and hazardous chemicals. While the Paducah, Portsmouth, and Oak Ridge plants have had many decades of experience handling these chemicals, their use at Paducah for ICT represents new methodology. While the hazards of the ICT treatment gases ClF_3 and F_2 are well understood, a significant initiative still was undertaken to develop and document the safety basis, hazard analysis, engineered controls, and administrative controls to perform ICT safely.

The lessons learned from previous use of treatment gases were incorporated into the development of controls for the ICT process at PGDP. Only one evaluated risk from ICT remains with a “high” consequence, and that is deflagration. It is noted that deflagration is not an anticipated risk during steady-state ICT operations. It is considered credible only during initiation and conclusion of an ICT evolution. The process controls enacted for ICT reduce the frequency of this risk to “extremely unlikely,” but the consequence to a nearby worker remains high because of the worker’s inability to evacuate quickly enough should a breach occur in the ICT primary boundary. Several mitigations are enacted to address this consequence, including limiting personnel access to the ICT work areas, physically isolating the R-114 coolant system from a cell, ensuring leak tightness of all systems prior to initiating ICT, and controlling the rate of addition of treatment gases to ICT locations and restricting the total quantities.

By incorporation of the lessons learned from past cell treatments at other gaseous diffusion plants to the new controls implemented at PGDP, the risks from ICT operations have been mitigated, and ICT can be performed safely.

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