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UC Davis MNRC Iodine-125 Production
- Accident Analysis
- On-site Target Transfer Process

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Associate Director, Radioisotope Sciences & Developments

NRC/UC Davis Public Meeting
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Agenda

- Introduction – Dr. Barry M. Klein, Director MNRC
- Presentation – Dr. Manuel Lagunas-Solar
- Background
  - General UC Davis MNRC Plan in the Nuclear Sciences
  - Method, Facility, and Procedures for Production of Iodine-125 (60 d)
- Accident Analysis (SAR Chapter 13)
- On-Site Target Transfer
  - Procedure
  - Portable Radiation Shield
  - Accident Analysis
- Conclusions

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Reactor Production of Iodine-125 from Enriched Xenon-124 Targets

General UC Davis/MNRC Plan in the Nuclear Sciences

- Current funded efforts by DOE and NNSA (research & education)
- Potential NSF funded Science & Technology Center (CBiNS) (Under Final Review)
- Development of Radioisotope Science Facility (RSF) at MNRC (In Progress)

  - Radioactive Material License from CDPH-Radiological Health Branch (In Progress)

  - Part 50 NRC License Amendment Application for R-130 (Under Preparation)
    - Large-scale production of Iodine-125 (New Batch Process)
    - Application, SAR, Environmental Report (In Progress)
    - Revision of MNRC Tech Specs (In Progress)

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Reactor Production of Iodine-125 from Enriched Xenon-124 Targets[1]

Method: Batch production of I-125 using the **$^{124}Xe\ (n,\gamma)^{125}Xe\ (17.1\ h) \rightarrow {}^{125}I\ (60\ d)$** thermal neutron reaction with enriched Xe-124 gas targets.

Production method uses an Al 6061 T6 thick wall (1/8-in. each) double-contained pressurized (200 psi) Xe-124 gas target for < 14 h irradiation at the existing central irradiation facility at the 2.0 MW TRIGA at UC Davis MNRC. The irradiated target with ~ 4,235 Ci of Xe-125 is then transferred to an adjacent building (see below) for processing.

Facility: A new **Radioisotope Science Facility (RSF)** adjacent to MNRC Reactor will house a dedicated laboratory and equipment to process irradiated Xe-124 targets for the production and distribution of I-125. An adjacent QA/QC laboratory will support the I-125 production effort. Other RSF laboratory facilities will be used for R&D and educational activities, pursuant to CDPH Agreement State license.

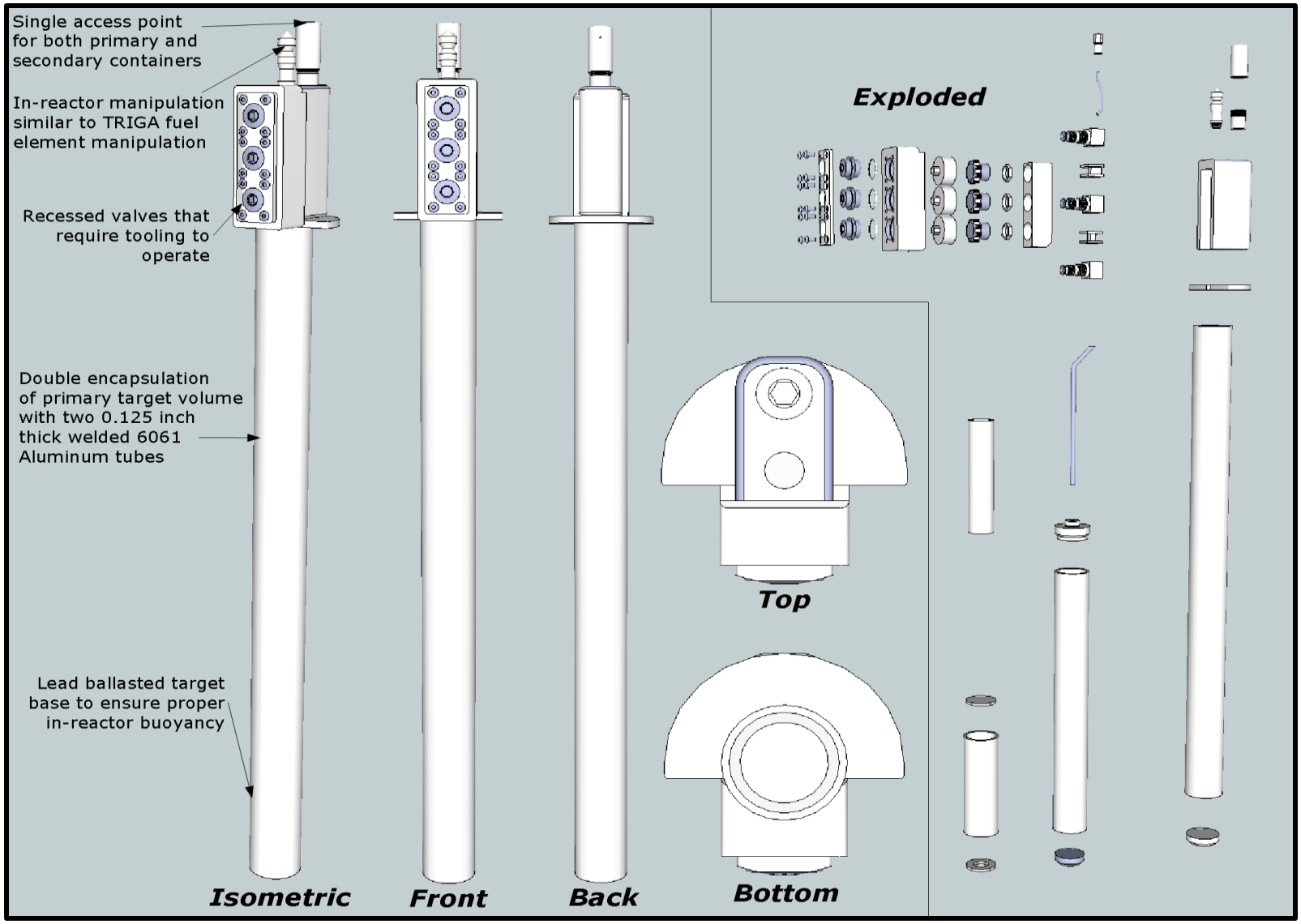
Procedures: Target handling/transfer to RSF for processing and back to Reactor building for a new irradiation cycle uses a **Portable Pb Radiation Shield**, while Xe-124 recycling and I-125 radiochemistry use an entirely robotic operation in well-shielded, vented, filtered and monitored newly-designed radioisotope boxes. The processing of Xe-124 targets is to take place in a dedicated I-125 laboratory. The whole procedure involves a 16-step process each of which has been analyzed for potential accident event scenarios (AES).

Accident Analysis: The 16-step process was analyzed and evaluated for credible accident scenarios and Maximum Hypothetical Accidents (MHA) using frequency (including quantitative probabilities) and consequence rationales and countermeasures or mitigating factors. MHAs (assumed worst-case scenarios) were identified and analyzed and used as non-credible references. It is estimated that 45 (once per week) to 90 (twice per week) I-125 batches may be produced annually.

(1) US Patent Pending

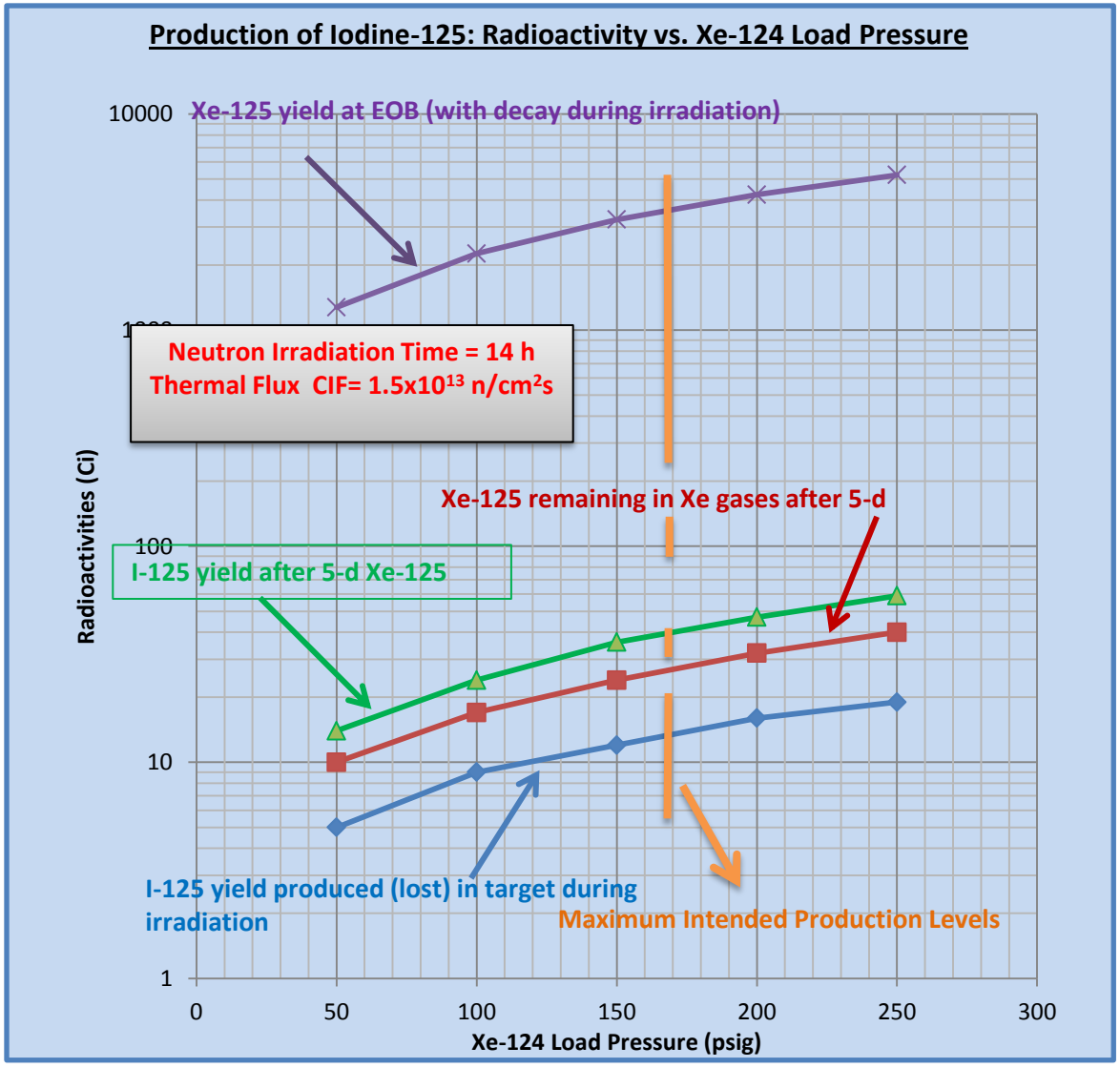
Reactor Production of Iodine-125 from Enriched Xenon-124 Targets

Reusable (<12 runs), pressurized, double containment, enriched Xe-124 gas target[1]



(1) US Patent Disclosure

Reactor Production of Iodine-125 from Enriched Xenon-124 Targets



Production Information

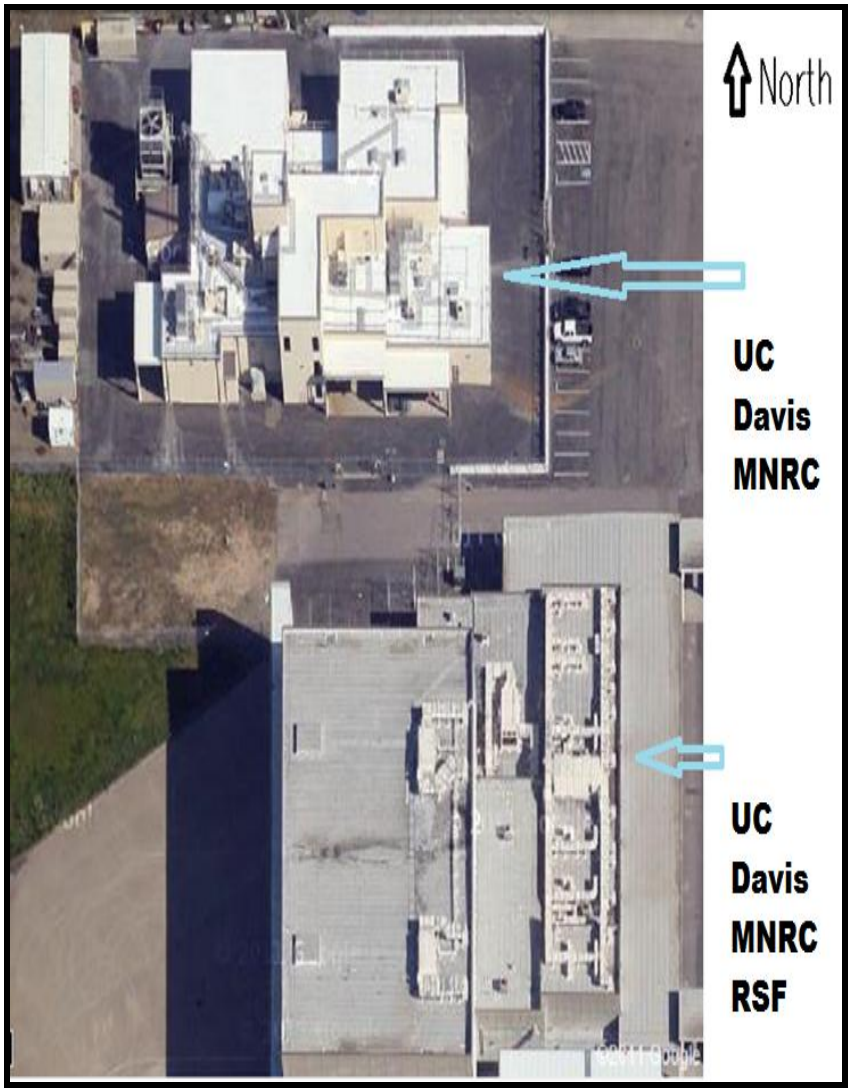
I-125 = ~ 47 Ci/batch at End-of-Processing (EOP) (in 0.1N NaOH);

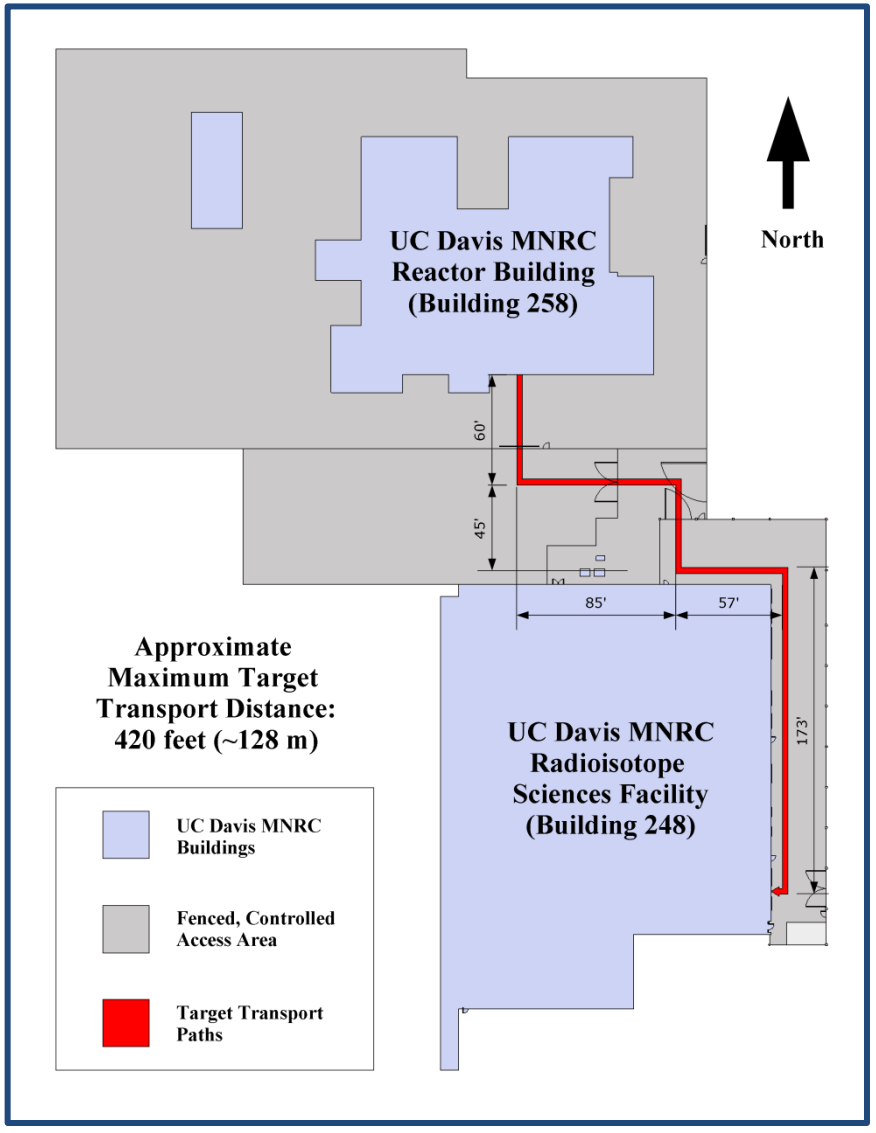
Xe-125 = ~ 4,235 Ci at End-of-Bombardment (EOB);

I-125 lost in target (Xe-125 decay during 14-h irradiation) = ~ 16 Ci;

Xe-125 after 5-d decay = ~ 32 Ci (0.6%).

The UC Davis MNRC Radioisotope Science Facility Site Overview





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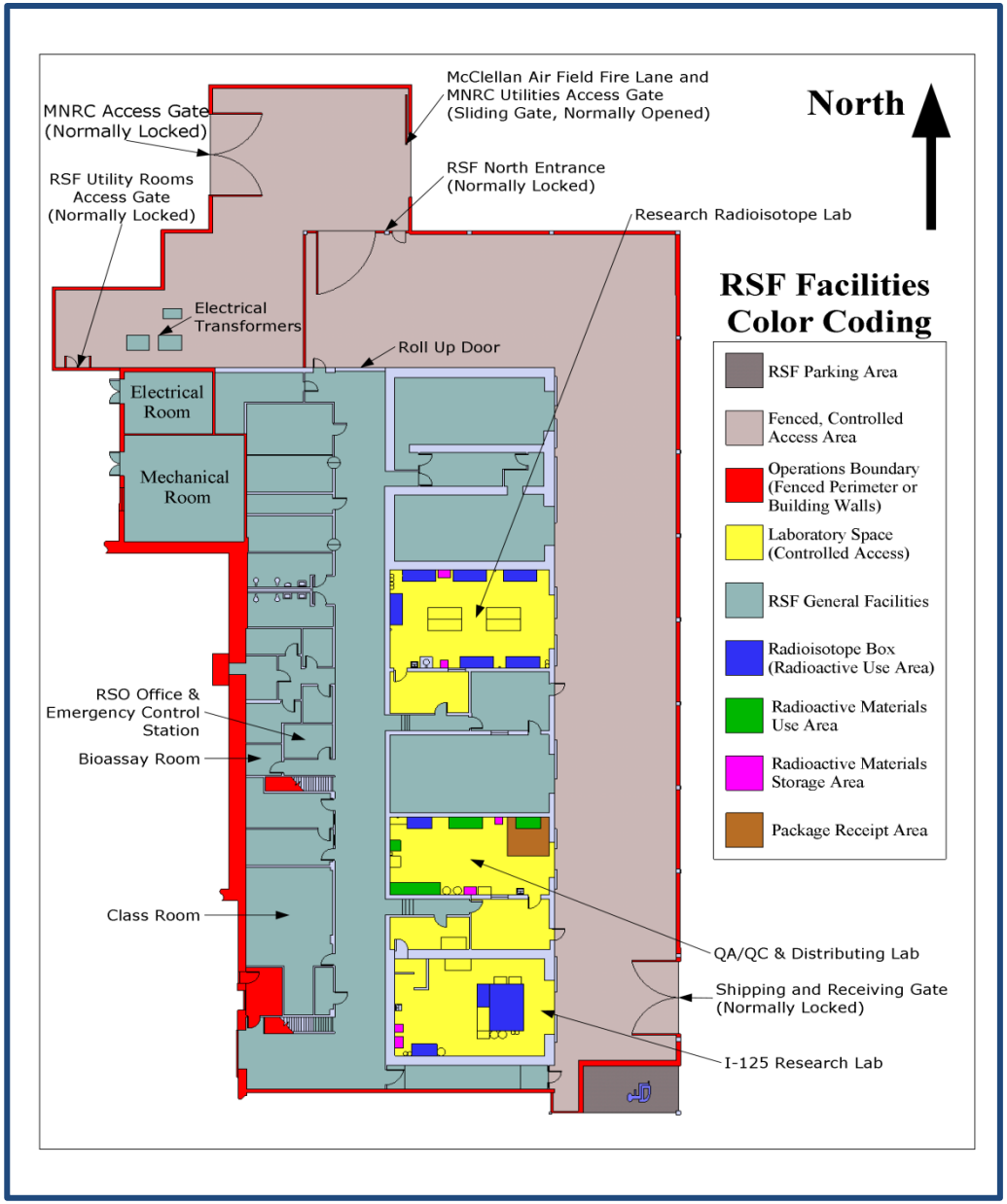
Overview of the UC Davis MNRC Radioisotope Science Facility

- The overall space available for RSF is ~ 13, 400 ft^2.
- The east side of the facility has 6 800-1,000 ft^2 laboratory spaces and 5 200-300 ft^2 support rooms.
- The west side of the facility has a class room, 9 offices, and 5 additional rooms that will be utilized as support shops (electronics, machining, etc.) and storage areas.



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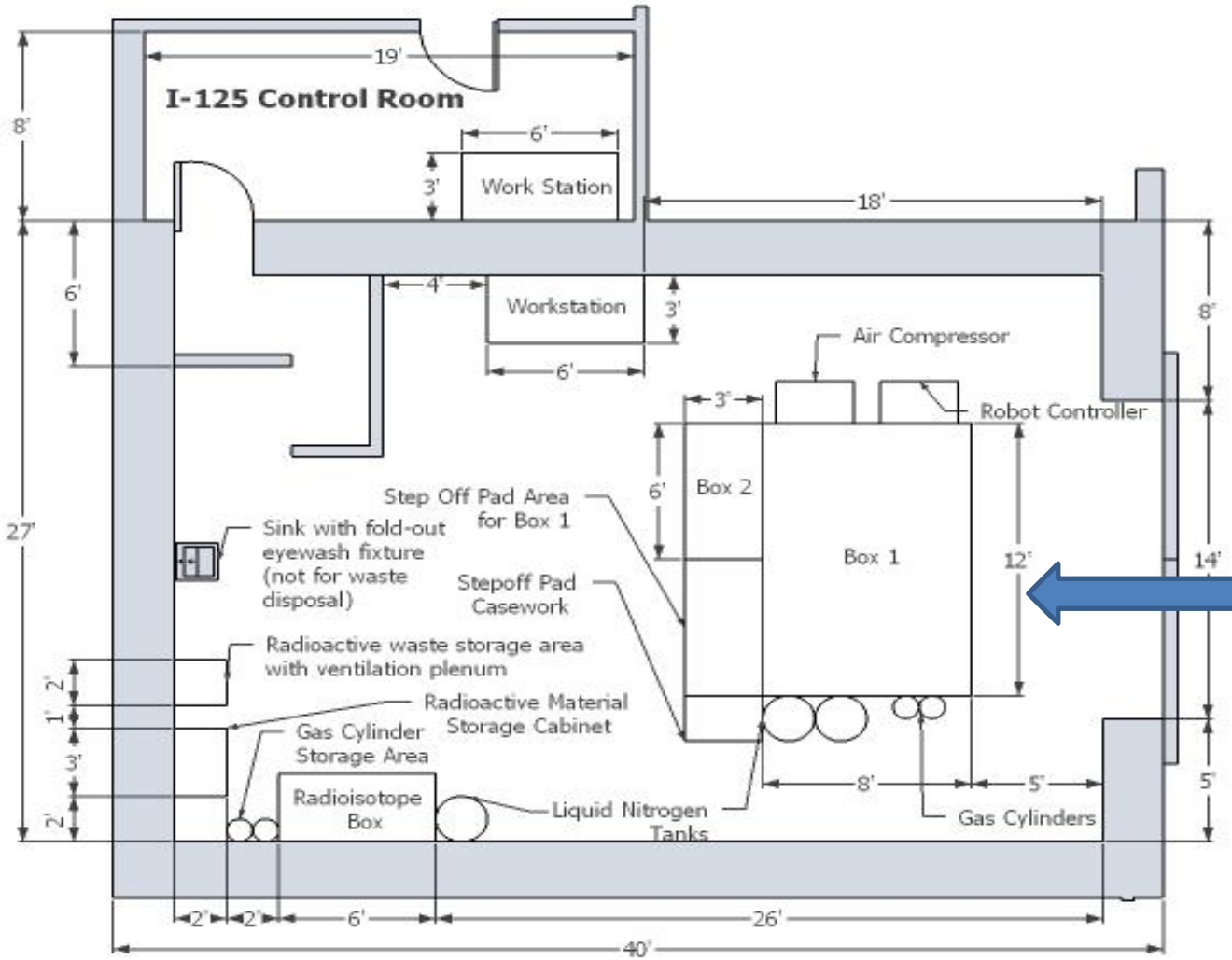
Radioisotope Science Facility
I-125 Research Laboratory



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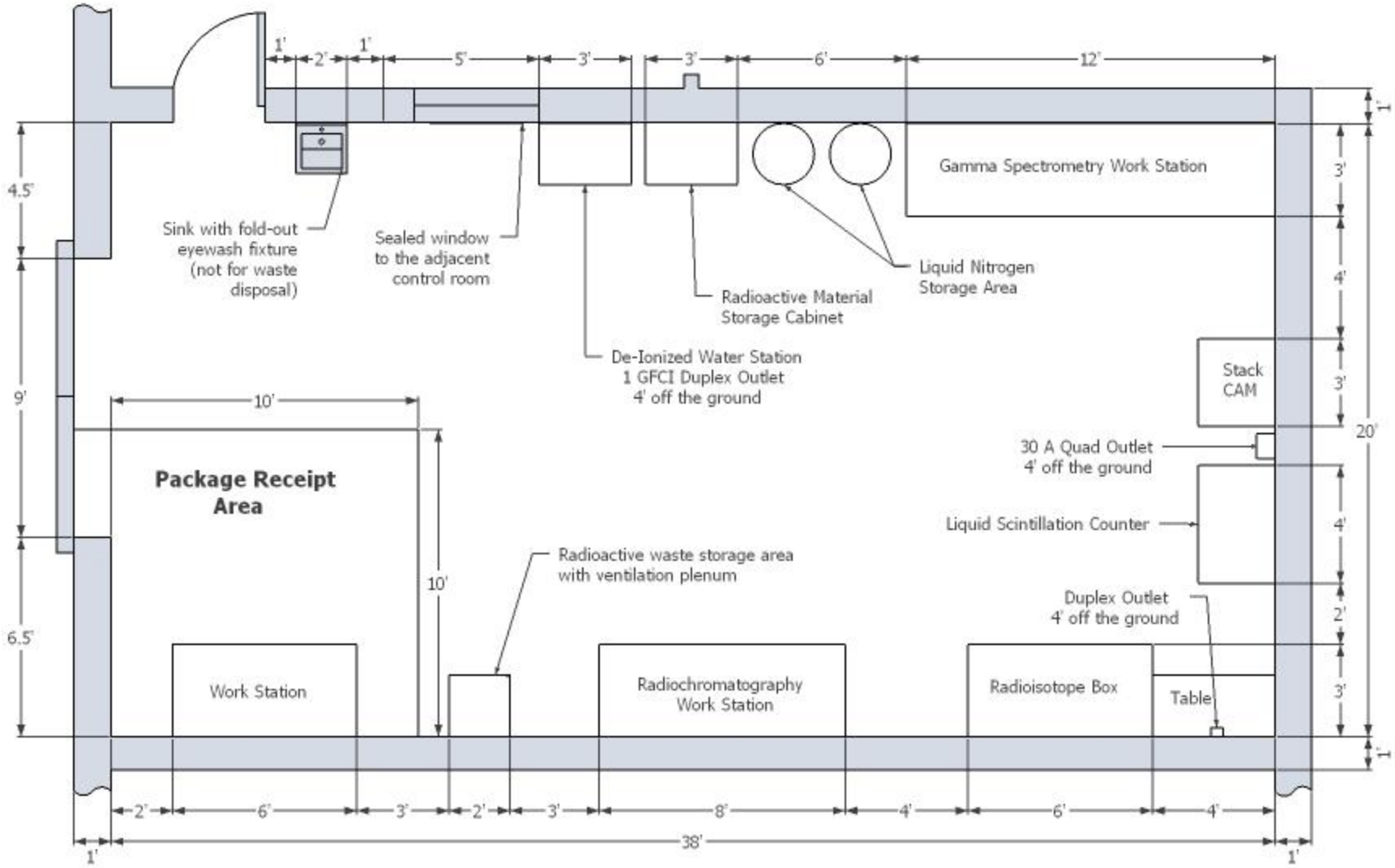
Radioisotope Science Facility
QA/QC and Distribution Laboratory



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Accident Analysis (SAR Chapter 13).
Iodine-125 Production Steps

Table 1. Iodine -125 Production Process Flow Chart (Hazard Analysis & Critical Control Points)			
Step (HACCP)	Time (day)	Location	Process Phase Description
1	-1	RSF	Xe-124 target testing. Radiochemistry system preparation and testing (6-8 h)
2	-1	MNRC	Xe-124 target transport (from RSF) and loading in Reactor (1 h)
3	1-2	MNRC	Xe-124 target irradiation to produce Xe-125 (< 14 h)
4	1-2	MNRC	Xe-124/Xe-125 target removal from reactor & loading to Pb transport shield (0.5 h)
5	1-2	MNRC & RSF	Xe-124/Xe-125 target/portable PB radiation shield transport to RSF (0.3 h) and placement into Box 1 processing system (0.2 h)
6	1-2	RSF	Xe-124/Xe-125 target connection to Box 1 processing system and connectivity assessment (Robotic operation) (< 0.1 h)
7	1-2	RSF	Robotic-controlled cryogenic transfer of Xe-125/Xe-124 gases into Decay/Storage Vessel (< 0.1 h)
8	3-5	RSF	Decay of Xe-125 to I-125 in Decay/Storage Vessel (t_{max} ~ 3.5 d).
9	3-5	RSF	Recovery of Xe-124 gas (with Xe-125) to new target/shield system for a subsequent irradiation (< 0.1 h)
10	3-5	RSF	Remote-control automatic removal (recovery) of I-125 and transfer into Box 2 processing system (< 0.1 h)
11	3-5	RSF	Formulation of I-125 into final aqueous solution and fractionation in Box 2 processing system (< 1 h)
12	3-5	RSF	QA/QC and final certification of I-125 solution for transfer to licensed users (~ 2 h)
13	4-6	RSF	Release of authorized shipments to licensed users under DOT regulations (MNRC RSO supervision) (1 h)
14	4-6	RSF	Finalize documentation of I-125 batch (0.5 h)
15	4-6	RSF	Preparation of I-125 processing system (Box 1 and Box 2) for subsequent production (include waste management) (4 h)
16	4-6	RSF	Secure storage of new Xe-124 target/shield system in Box 1 for next production run (1 h).

Reactor Production of Iodine-125 from Enriched Xenon-124 Targets

ACCIDENT ANALYSIS REPORT (AAR)
by
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Reactor Production of Iodine-125 from Enriched Xenon-124 Targets

Table 2. Criteria and Rationale for Accident Analysis (Based upon a Single Batch Production Mode)	
Accident Event (Stages)	Defines a type of failure in the I-125 production system involving an accidental release (loss of containment) of radioactivity (mostly Xe-125; I-125 and others) in the following stages (1) System Pre-Validation; (2) Target Irradiation; (3) Target Transfer; (4) Processing and (5) Distribution
Frequency (Probability)	Defines how often an accident event is anticipated (i.e. very Unlikely (1/10,000; 0.01%); remote (1/1,000; 0.1%); likely [occasional] (1/100; 1%); and frequent (1/10; 10%).
Consequences	Defines the overall effects on worker, public, and environmental health as catastrophic (non-reversible), critical; high; medium; minor; and none.
Risk Assessment	Defines overall risk level as high, medium and low based upon frequency, countermeasures, and consequence factors. Includes an accident credibility assessment as credible and non-credible (Maximum Hypothetical Accident, MHA) for every type of accident event.
Countermeasures	Indicates availability of accident controlling (mitigating) factors associated with design & engineering, material specifications; and operation features including administrative controls to react to and/or to control an accidental event. Includes MNRC Emergency Plan.

Accident Analysis Process Overview

- **Description of Accident Event Scenario**

  Accident Stage Parameters

  * Hazards
  * Material at Risk
  * Potential Causes
  * Detection Capabilities

- **Determination of Frequency and Assumed Probability**

- **Countermeasures (Mitigating Factors)**

  * Design & Engineering
  * Materials
  * Procedures (Operational Restrictions)
  * Administrative Controls

- **Analysis of Consequences**

- **Risk Assessment and Credibility**

- **AARIC Conclusions**

Reactor Production of Iodine-125 from Enriched Xenon-124 Targets

AARIC Conclusions

Summary of AARIC Analyses				
Accident Scenario	Frequency	Consequence	Risk Assessment	AARIC Voting
1. Target/System Testing	Very unlikely	Low	Low/Credible	Unanimous
2. Target Transport/Loading	Very unlikely	Low	Low/Credible	Unanimous
3. Reactor Target Irradiation	Very unlikely	Critical	Low/Credible	Unanimous
4. Target Removal/Loading	Very unlikely	Low	Low/Credible	Unanimous
5. Target Transfer Reactor to RSF	Remote	Critical	Low/Non-Credible	Unanimous
6. Target System Connection	Very Unlikely	High	Low/Credible	Unanimous
7. Target Processing	Remote	Low	Low/Credible	Unanimous
8. Xe-125/I-125 Decay Period	Very unlikely	Low	Low/Credible	Unanimous
9. Xe-124 Recovery	Remote	Low	Low/Credible	Unanimous
10. I-125 Recovery Transfer to Box 2	Remote	Low	Low/Credible	Unanimous
11. I-125 Product Formulation-Box2	Very unlikely	Low	Low/Credible	Unanimous
12. QA/QC Certification	Very unlikely	Low	Low/Credible	Unanimous
13. Release for Distribution	Very unlikely	None	Low/Non-Credible	Unanimous
14. Final Documentation	N/A	N/A	N/A	Unanimous
15. System Prep Next Run	Very unlikely	Low	Low/Non-Credible	Unanimous
16. Secure Storage Target/Pb Shield	Very unlikely	Low	Low/Non-Credible	Unanimous

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Reactor Production of Iodine-125 from Enriched Xenon-124 Targets – Target Transfer

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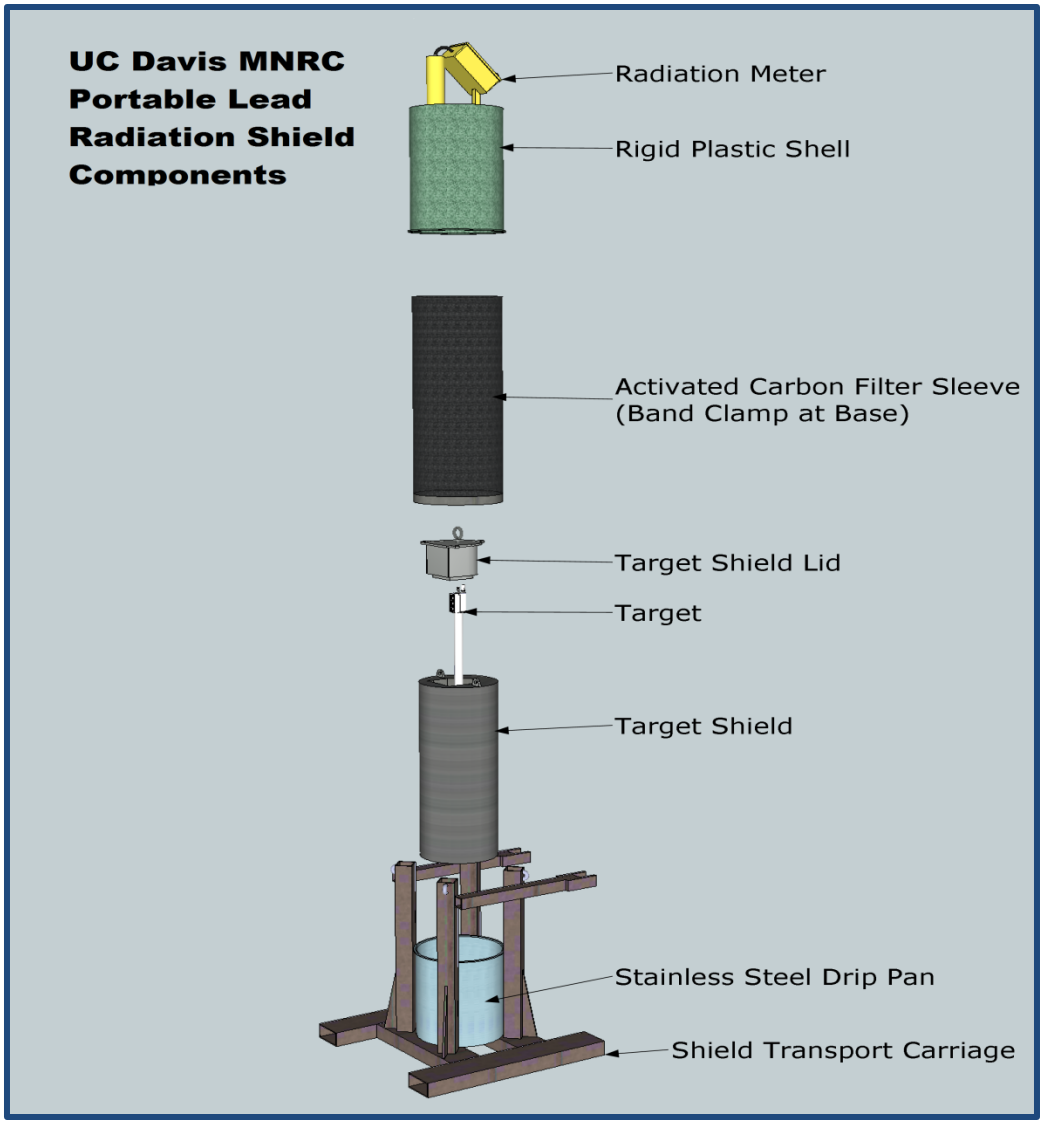
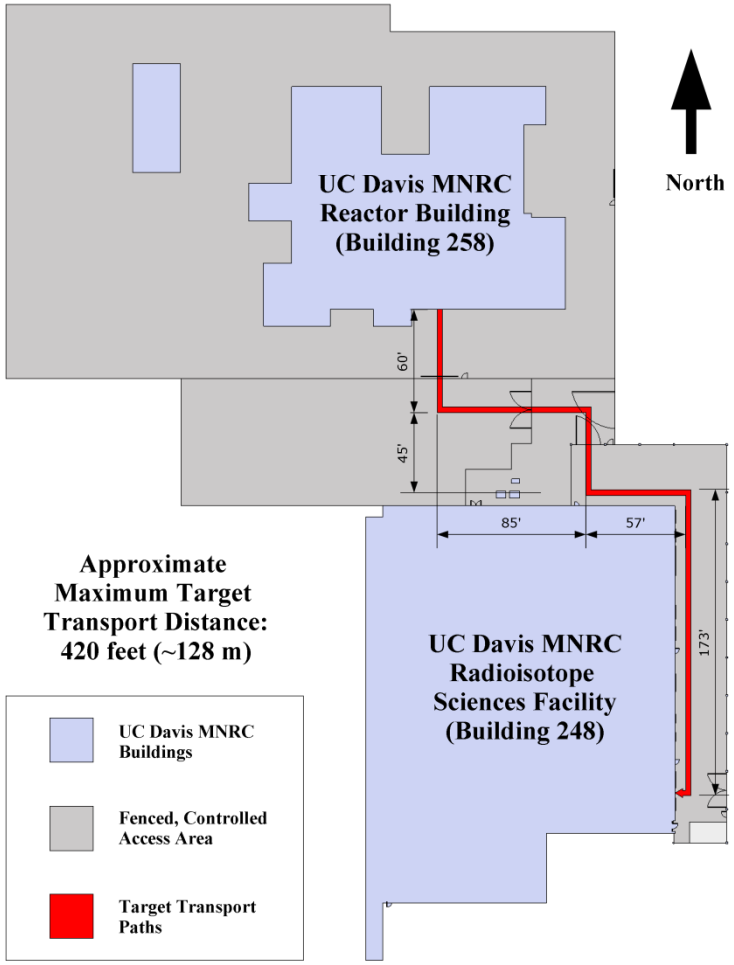
Reactor Production of Iodine-125 from Enriched Xenon-124 Targets – Target Transfer



Reactor Production of Iodine-125 from Enriched Xenon-124 Targets – Target Transfer

Target Transfer



Target Transfer Information

- Only between MNRC Reactor and MNRC RSF (RT)
- Target always inside Portable Pb Radiation Shield
- RSF-to-Reactor (Step 2) - Cold Target/Low Radiation
- Reactor-to-RSF (Step 5) – Hot Target/High Radiation
- MNRC wide transfer announcement
- Secured corridor (controlled area) fenced and concrete barriers (i.e. K-rails)
- Radiation monitoring during entire process
- Distance: 420 ft. (128 m) maximum
- Estimated transit time: 2-3 min at 2-3 miles/h (walking speed)
- Estimated transfer process time: 10-15 min
- Certified forklift operator with back up (2 person)
- Receiving area ready and secured
- Documented procedure including change in supervision from Reactor Operation to Radioisotope Staff (chain of custody) or vice versa.

Accident Event Scenario # 5					
Day 1 or 2	MNRC & RSF	Xe-124 target/shield transport to RSF (0.3 h) and placement into Box 1 Processing system (0.2 h)			

Accident Stage Parameters	
Hazards	• Accidental radiation exposure to personnel and members of the public from a Xe-125 release • (Secondary Effect). Radiation exposure to personnel and members of the public from I-125 produced in • the decay of Xe-125 • (Secondary Effect) Biological uptake of I-125 by personnel or members of the public • (Secondary Effect) I-125 contamination in uncontrolled areas
Material at Risk	• Up to 4,235 Ci Xe-125
Potential Causes of the Event	• Rupture of Pb shield exposing the irradiated target • Release of Xe-125 due to target containment failure
Detection Capabilities	• Hand-held radiation meters • Airborne radioactivity measurement system (Required for accident assessment)

Countermeasures	
Design & Engineering:	• Double encapsulation of Xe-124 inside the target during transport • Two (2) welded SS bellow valves with metallic seals • An additional cap over the target gas access point provides further access restriction to the target contents • Elastomer seals on all Pb shield openings for additional leak mitigation • Radiation shielding remains effective if target containment is compromised as long as Xe-125 is contained inside the shield cavity • SS cladding – 0.25 in. surrounding Pb shield • Pb shield weight (~ 5,000) lb, low center of gravity (~24-in above base), and Pb thickness (>7.5-in thickness >18-in outside diameter) make toppling the shield difficult • Short distance between Reactor and RSF buildings requires short transport time (< 30 min) • Fenced and secured transport corridor between Reactor and RSF buildings keeps public > 3 m away from the target
Operational Restrictions:	• All process steps will be conducted by properly certified/trained personnel under close, direct supervision • The fenced corridor between the Reactor and RSF buildings will be secured and controlled by MNRC personnel before the transfer takes place • Box 1 at the RSF building will be prepared and ready to receive the target prior to its transport to the RSF building • The transfer between buildings will not begin until the target/Pb shield is properly secured to the fork-lift at MNRC staging area • The transfer operation will be conducted using well-known, documented, and practiced procedures with the use of all prescribed countermeasures, controls, and oversight • The Reactor Operations staff (2 supervisory level personnel) will release the target/Pb shield to the supervisory level Radioisotope Staff member in the MNRC staging area only with the approval of the MNRC RSO or trained representative • The RSO or his designee will approve transfer only after all health physics operational guidelines are met and the transfer documentation is completed • A certified fork-lift operator accompanied by the supervisory level Radioisotope Staff member will drive the loaded fork-lift at a walking speed to the RSF building using the secured corridor • When the target/Pb shield reaches the RSF building, it will be placed inside Box 1

AARIC Final Vote			
Frequency:	Remote	Consequence:	Critical
Risk Assessment:	Low	Credibility:	Non-Credible

Conclusions

AARIC Recommendation: Potentially catastrophic consequences, but remote likelihood with many of the associated methods of failure considered as non-credible (such as multiple, simultaneous valve failure or complete, sudden loss of radiation shielding). Design and engineering and operational restrictions are sufficient to mitigate potential risks and operate safely and reliably.

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Maximum TEDE and CEDE Radiation Dose Estimates for Target Transfer (AES # 5)

Radiation Source (Ci)	Location	Release Fraction (%)	Total Emission (Ci)	Max TEDE (Rem) Positions (1: 1m; 2: 2m; 3: 6m)	Max CEDE-Thyroid (Rem) Positions	Observations
Xe-125						
(A) During transfer from MNRC to RSF						
4,235	MNRC to RSF	100	4,235	1. 2.52E+02 2. 2.63E+02 3. 2.41E+02	N/A	Non-Credible (MHA)
4,235	MNRC to RSF	10	424	1. 2.52E+01 2. 2.63E+01 3. 2.41E+01	N/A	Credible
4,235	MNRC to RSF	1	42.4	1. 2.52E+00 2. 2.63E+00 3. 2.41E+00	N/A	Credible
4,235	MNRC to RSF	0.1	4.24	1. 2.52E-01 2. 2.63E-01 3. 2.41E-01	N/A	Credible
4,235	MNRC to RSF	0.01	0.424	1. 2.52E-02 2. 2.63E-02 3. 2.41E-02	N/A	Credible
4,235	MNRC to RSF	0.001	0.0424	1. 2.52E-03 2. 2.63E-03 3. 2.41E-03	N/A	Credible
(A) During placement into Box 1 at RSF						
4,235	I-125 Lab	100	4,235	1. 1.10E+02	N/A	Non-Credible (MHA)
4,235	I-125 Lab	10	424	1. 1.10E+01	N/A	Credible
4,235	I-125 Lab	1	42.4	1. 1.10E+00	N/A	Credible
4,235	I-125 Lab	0.1	4.24	1. 1.10E-01	N/A	Credible
4,235	I-125 Lab	0.01	0.424	1. 1.10E-02	N/A	Credible
4,235	I-125 Lab	0.001	0.0424	1. 1.10E-03	N/A	Credible

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Maximum TEDE and CEDE Radiation Dose Estimates for Target Transfer Process (AES # 5)

Table 12. Maximum TEDE (Rem) and CEDE-Thyroid (Rem) for Accident Event Scenario # 5 (Xe-124 Target Transfer to RSF and Placement in Box 1) – Event Time 5 min

Radiation Source (Ci)	Location	Release Fraction (%)	Total Emission (Ci)	Max TEDE (Rem) Positions	Max CEDE-Thyroid (Rem) Positions	Observations
I-125						
(A) During transfer from MNRC to RSF						
26	MNRC To RSF	100	26	1. 3.80E+03 (1 m) 2. 3.23E+03 (2 m) 3. 2.27E+03 (6 m)	1. 3.80E+03 2. 3.23E+03 3. 2.26E+03	Non-Credible (MHA)
26	MNRC To RSF	10	2.6	1. 3.80E+02 2. 3.23E+02 3. 2.27E+02	1. 3.80E+02 2. 3.23E+02 3. 2.26E+02	Non-Credible
26	MNRC To RSF	1	0.26	1. 3.80E+01 2. 3.23E+01 3. 2.27E+01	1. 3.80E+01 2. 3.23E+01 3. 2.26E+01	Credible
26	MNRC To RSF	0.1	0.026	1. 3.80E+00 2. 3.23E+00 3. 2.27E+00	1. 3.80E+00 2. 3.23E+00 3. 2.26E+00	Credible
26	MNRC To RSF	0.01	0.0026	1. 3.80E-01 2. 3.23E-01 3. 2.27E-01	1. 3.80E-01 2. 3.23E-01 3. 2.26E-01	Credible
26	MNRC To RSF	0.001	0.00026	1. 3.80E-02 2. 3.23E-02 3. 2.27E-02	1. 3.80E-02 2. 3.23E-02 3. 2.26E-02	Credible
(A) During placement into Box 1 at RSF						
26	I-125 Lab	100	26	1. 1.23E+02 (1 m)	1. 1.23E+02	Non-Credible (MHA)
26	I-125 Lab	10	2.6	1. 1.23E+01	1. 1.23E+01	Non-Credible
26	I-125 Lab	1	0.26	1. 1.23E+00	1. 1.23E+00	Credible
26	I-125 Lab	0.1	0.026	1. 1.23E-01	1. 1.23E-01	Credible
26	I-125 Lab	0.01	0.0026	1. 1.23E-02	1. 1.23E-02	Credible
26	I-125 Lab	0.001	0.00026	1. 1.23E-03	1. 1.23E-03	Credible

Reactor Production of Iodine-125 from Enriched Xenon-124 Targets

CONCLUSIONS

(1) A new batch method for the production of I-125 using enriched Xe-124 gas targets will be used.

(2) Thermal neutron irradiation of a single Xe-124 target at the MNRC 2-MW Reactor will follow with a short distance (128 m) and short duration (< 15 min; < 3 min in transit) target transfer to the Radioisotope Science Facility (RSF). At RSF, newly-developed radiochemistry laboratories will be solely dedicated to processing Xe-125 radioactivity to produce I-125 in solution in a 5-6 day process. Iodine-125 is to be distributed only to properly licensed users (commercial and research).

(3) The overall process has been analyzed and evaluated for risks associated with radiological consequences (airborne releases and radiation dose) and found to be safe to operate based upon design & engineering, material specifications, procedures and administrative controls.

(4) No environmental impact is expected based on loss of containment of gaseous Xe-125 (mixed with Xe-124) due to large dispersion factors under any atmospheric conditions. Direct Iodine-125 releases are not expected because of the binding of I-125 with metal surfaces and once in solution, because of its stability in no-carrier-added radiochemical forms in strongly basic solutions.

(5) A State of California Radioactive Material License (research & education) and an amended NRC license are required for full compliance before operating RSF and producing I-125.