MIRION Connect 26 AMERICAS

Annual Users' Conference

ADVANCING RADIATION SAFETY. EMPOWERING PROGRESS.

M Resort, Henderson, NV | June 15 – June 18

MIRION TECHNOLOGIES

Innovations in NDA Waste Characterization: What's New

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Mirion Connect | Annual Users' Conference 2026

Henderson, NV

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Contents

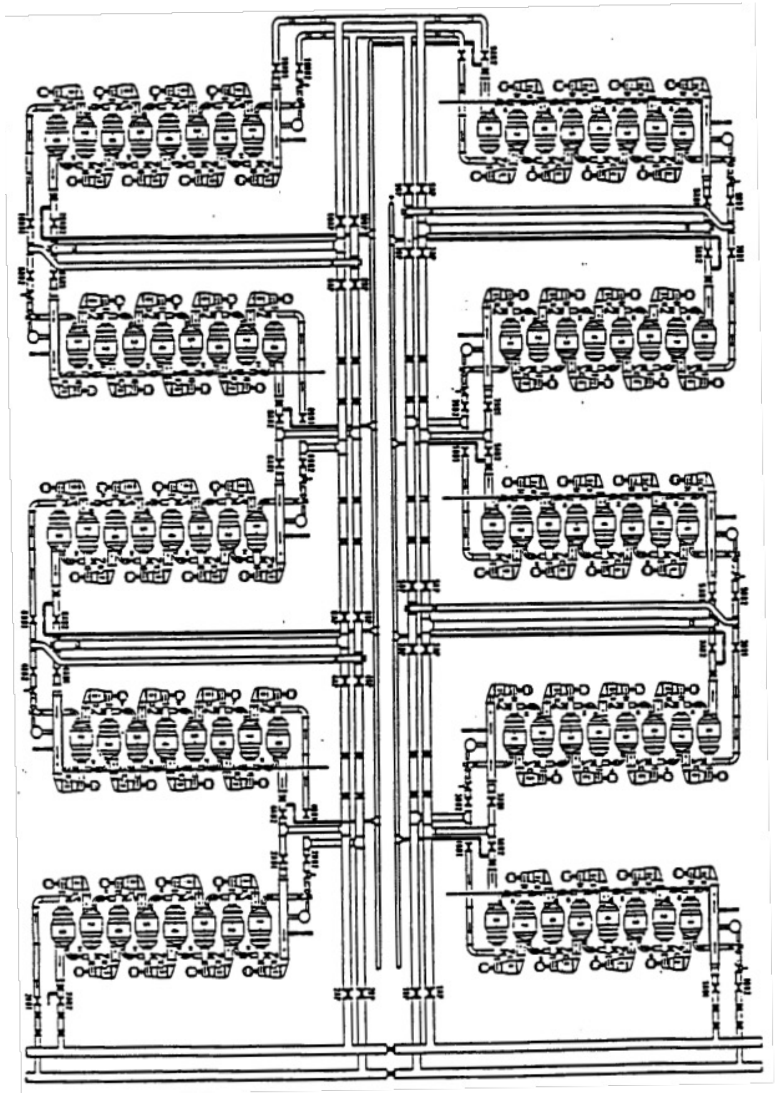
Remote in situ Screening for Converters and Compressors (RISCC)

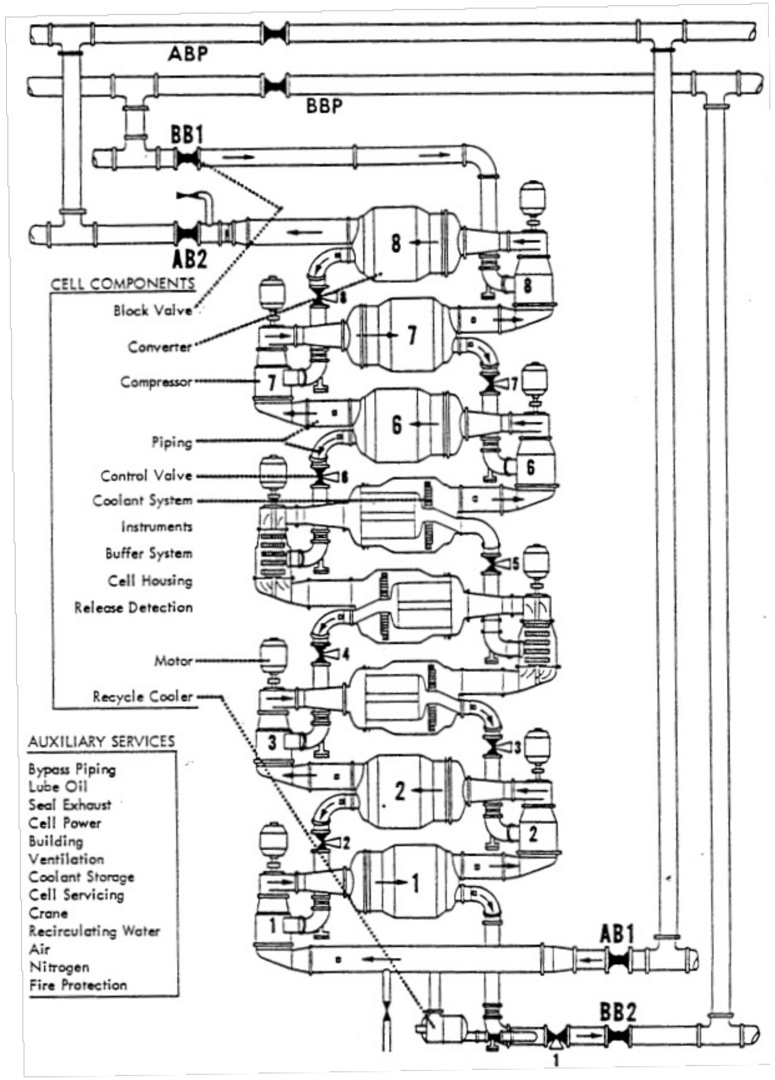
RISCC

Challenge

- *Remove 000 converters and compressors from buildings 333 and 337 for U holdup characterization within the LINAS.*
- *Each 000 converter must meet NCS limits for fissile (U-235) prior to being removed from the cell/building.*
- *Gamma activity is present, but the attenuation paths are impossible to determine.*
- *The holdup generates (alpha, n) neutrons but there are sources of neutrons everywhere, including those of cosmic ray origin, i.e., spallation and (n,2n).*
- *Many unknowns such as the location of the holdup and how significant the holdup may be.*
- *Very limited space to work with.*

RISCC/Challenge/Cells





- *Buildings 333 and 337 at PGDP contain 100's of cells.*
- *Each cell consists of 8 stages where the expected main sources of holdup are the 000 converters and compressors.*
- *The physical size of the 000 converters and compressors are several feet and weigh thousands of pounds.*
- *The cosmic ray induced neutrons are considered as interference (considerable).*

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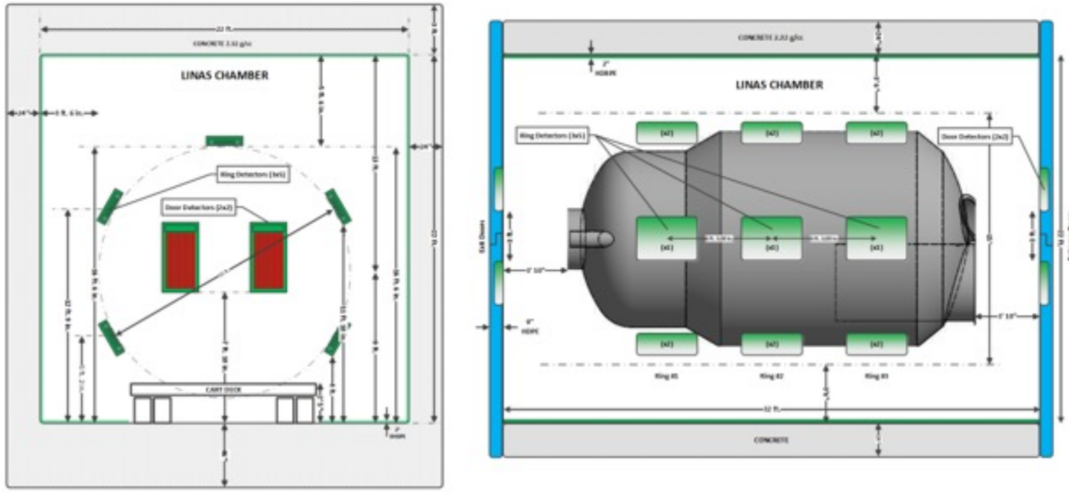

Fig. 3 Front view (left) and top view (right) of the LINAS chamber. The top view incudes the 000 bulged converter which is the maximum diameter object (plant equipment).

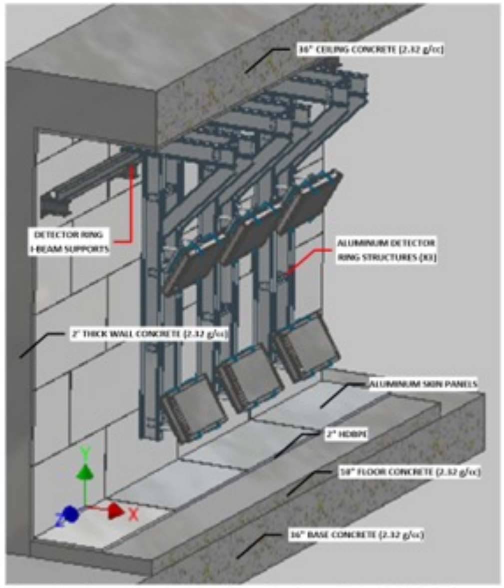

Fig. 4 Cross-section (z-plane) of the LINAS chamber (doors not shown).

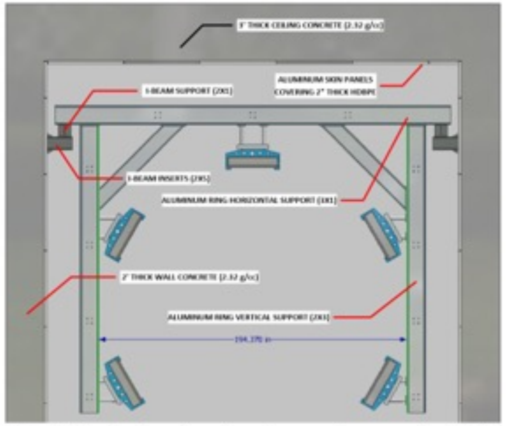

Fig. 5 Detector ring structure and support within the LINAS chamber.

- *The Large Item Neutron Assay System (LINAS) is the beneficiary of the RISCC method.*

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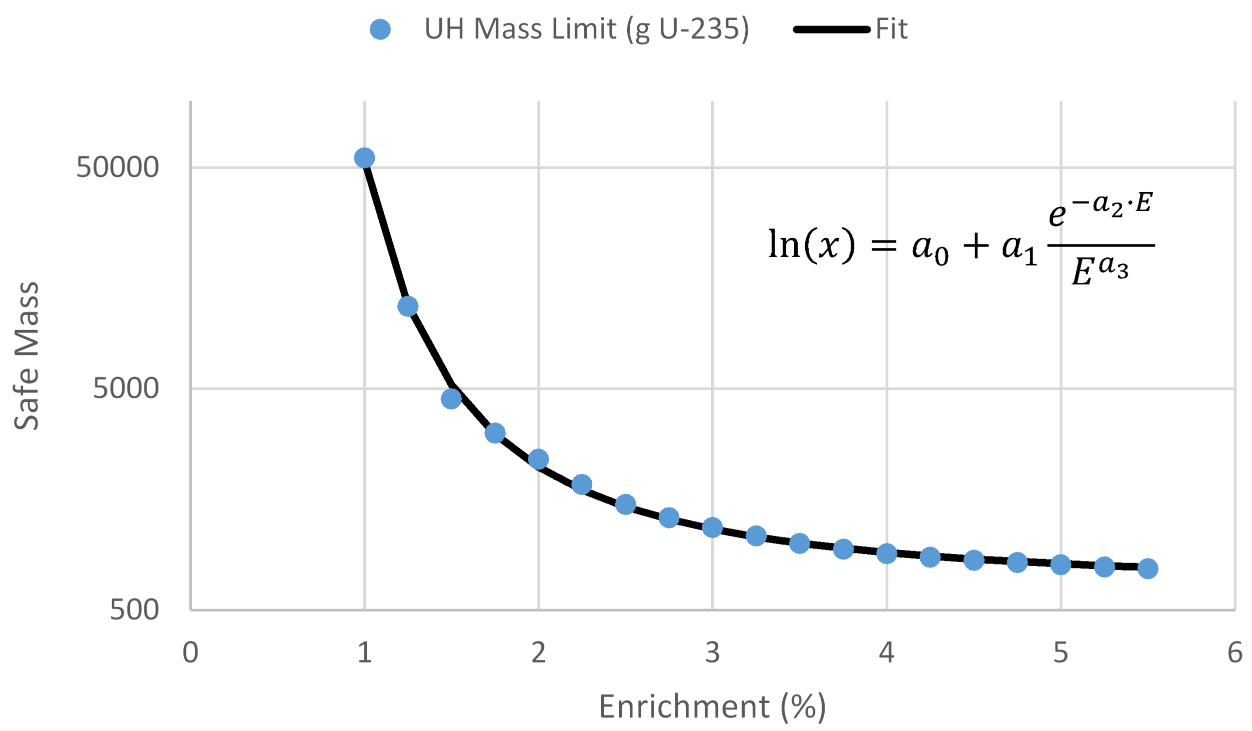
RISCC/Challenge/Safe Mass



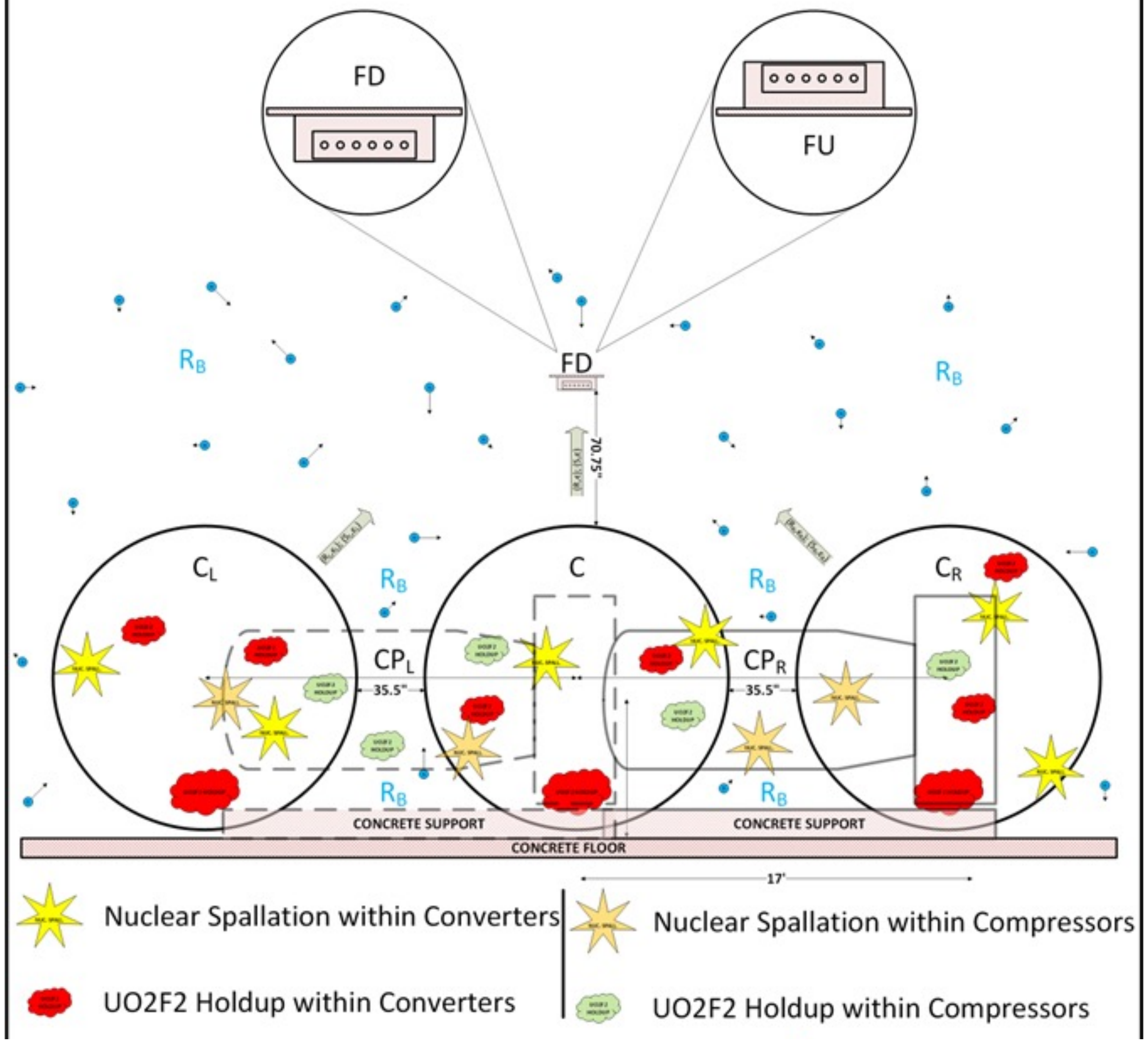
- *Safe mass limit is non-linear with enrichment.*
- *Safe mass is very high for less than 1%-2% enrichment (building 333).*
- *Safe mass is reasonably high for 2%-3.0% enrichment (building 337).*
- *Safe mass is more difficult to achieve for > 2.5% enrichment.*
- *Plant maximum is ~ 4.5% enrichment.*

RISCC

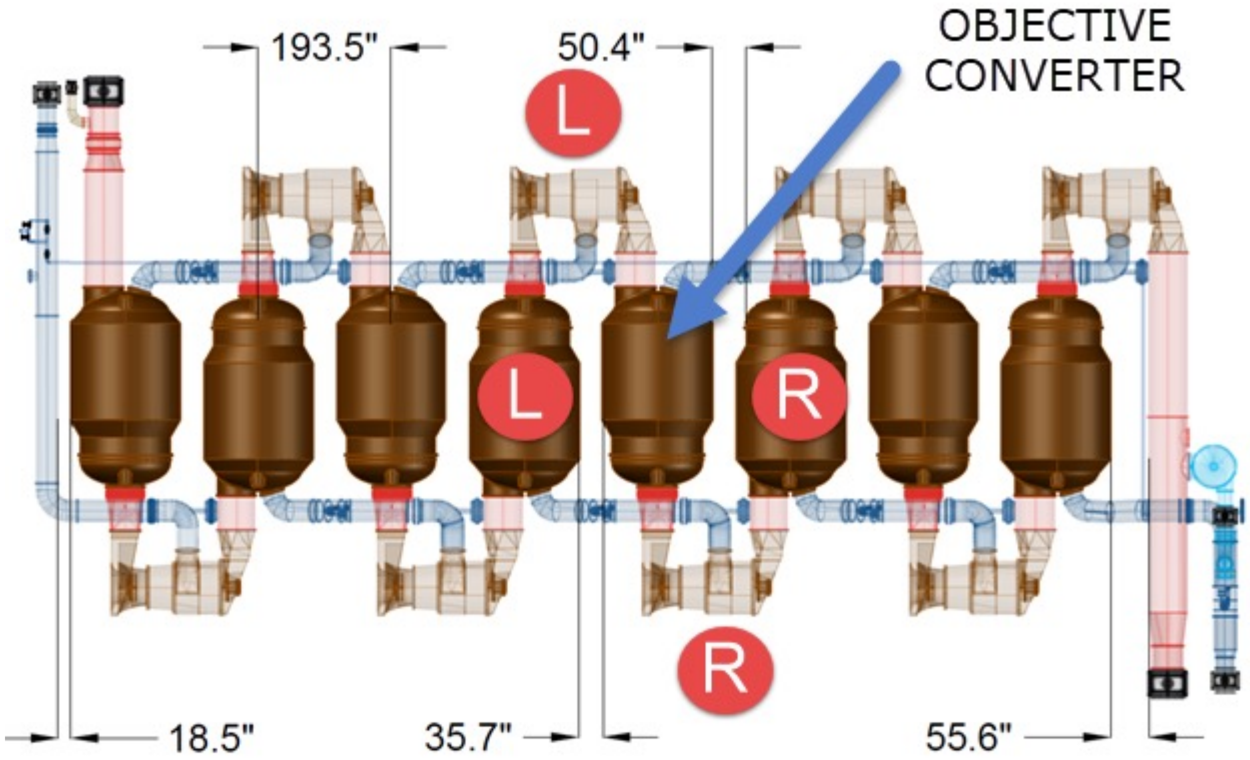
Solution

- *Devised a safe mass limit approach with increasing levels of accuracy to address NCS limits for higher enrichments.*
- *Utilize neutron measurements via existing neutron slabs with an additional borated background shield.*
- *Make two basic neutron slab measurements for converters and compressors in the cell: facing towards and facing away.*
- *Create a model-based technique to subtract the facing away response from the facing towards response including the cosmic ray affects.*
- *Utilize the knowledge gained from the LINAS and 6-GGUN projects which includes the parametrization of cosmic ray induced neutrons.*

RISCC/Solution/Measurements



- *Measure all 8 stages of a cell.*
- *The measurement utilizes multiple (3) neutron slabs for the Facing Down (FD) and Facing Up (FU) over the objective converter*



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RISCC

Method/1

- The contribution of neutrons yields two basic equations; facing up (FU) and facing down (FD).
- The two equations involve FD/FU ratios for VWA (Volume Weighted Average) computed with MCNP.
- The two equations are subtracted and the net rate for the objective converter is computed.
- The resultant net rate is subjected to a conservative counting efficiency to compute the efficiency corrected cps.
- Along with the computed nSA (neutron Specific Activity) for the known enrichment and other cascade information, the safe mass value for grams of U-235 is computed.

Method/2

RISCC

- *A four (4) Level approach to attack more challenging cells with higher enrichment*
- *Level 1 (L1) only the cosmic ray induced neutrons for the nearest neighbors are considered.*
- *Level 2 (L2), assumes L1 plus holdup considerations from neighboring converters but not holdup from neighboring compressors. FD/FU ratios for the conservative efficiency come into play at this level.*
- *Level 3 (L3) assumes L2 plus the measured compressor holdup.*
- *Level 4 (L4) assumes L3 but includes gamma spectroscopy to determine if a less conservative neutron detector efficiency may be utilized.*

RISCC/Method/System of Equations

$$R_{CU_{ik}} = \frac{R_{FD_{ik}} - f \cdot R_{FU_{ik}} - \left(1 - \frac{f}{r_{C_{ik}}}\right) \cdot R_{CSP_{ik}}}{1 - \frac{f}{r_{C_{ik}}}} - \frac{\sum_{j \neq k}^{8} \left[\left(1 - \frac{f}{r_{C_{ij}}}\right) \cdot \left(R_{CU_{ij}} + R_{CSP_{ij}}\right) + \left(1 - \frac{f}{r_{CP_{ij}}}\right) \cdot \left(R_{CPU_{ij}} + R_{CPSP_{ij}}\right) \right]}{1 - \frac{f}{r_{C_{ik}}}} \quad \textbf{Eq. 6}$$

$$R_{CU_{ik}} = \frac{R_{FD_{ik}} - f \cdot R_{FU_{ik}} - \left(1 - \frac{f}{r_{C_{ik}}}\right) \cdot R_{CSP_i} - \sum_{j \neq k}^{L,R} \left[\left(1 - \frac{f}{r_{C_{ij}}}\right) \cdot \left(R_{CSP_{ij}}\right) + \left(1 - \frac{f}{r_{CP_{ij}}}\right) \cdot \left(R_{CPSP_{ij}}\right) \right]}{1 - \frac{f}{r_{C_{ik}}}} \quad \textbf{Eq. 7}$$

The summed response, for the kth (stage) converter is then,

$$R_{CU_k} = \sum_{i=1}^{N} R_{CU_{ik}} \quad \textbf{Eq. 8}$$

- R_{FD}= *summed response (cps) as measured in the neutron detector slabs facing down.*
- $f \cdot R_B$= *fraction of the cell environmental background neutrons,* R_B, *not shielded, or enhanced, by the converters and compressors below.*
- R_{C_U} = *UO2F2 response (cps) from the converter immediately below (objective converter).*
- $R_{C_{SP}}$= *CRS response for the objective converter.*
- R_{CL_U}= *UO2F2 response (cps) from the converter immediately to the left of the objective converter.*
- $R_{CL_{SP}}$= *CRS response from the converter immediately to the left of the objective converter.*
- R_{CR_U}= *UO2F2 response (cps) from the converter immediately to the right of the objective converter.*
- $R_{CR_{SP}}$= *CRS response from the converter immediately to the right of the objective converter*
- R_{CPL_U}= *UO2F2 response (cps) from the compressor immediately to the left of the objective converter.*
- $R_{CPL_{SP}}$= *CRS response from the compressor immediately to the left of the objective converter.*
- R_{CPR_U}= *UO2F2 response (cps) from the compressor immediately to the right of the objective converter.*
- $R_{CPR_{SP}}$= *CRS response from the compressor immediately to the right of the objective converter*

RISCC/Method/Models

Table 1 MCNP VWA efficiencies for the objective converter immediately below the three detectors for 2", 1" and 0" to exemplify the FD/FU ratio $(r_{c_{ik}})$.

Detector Position†	Back-Shield Depth (inches)	MCNP Efficiency (%) Model 00 T4A, T1A Face-Down FD	Unc.	Face-Up FU	Unc.	FD/FU $(r_{c_{ik}})$	Unc.
1	2	9.989E-03	0.73%	6.730E-04	2.82%	14.84	
2	2	1.698E-02	0.56%	1.223E-03	2.04%	13.89	
3	2	1.267E-02	0.65%	9.060E-04	2.43%	13.99	
	SUM	3.964E-02	1.13%	2.802E-03	4.25%	14.15	4.39%
1	1	9.976E-03	0.73%	1.445E-03	1.94%	6.90	
2	1	1.699E-02	0.50%	2.620E-03	1.41%	6.49	
3	1	1.268E-02	0.65%	1.891E-03	1.64%	6.71	
	SUM	3.965E-02	1.10%	5.956E-03	2.90%	6.66	3.10%
1	0	1.008E-02	0.73%	3.033E-03	1.29%	3.32	
2	0	1.705E-02	0.56%	5.548E-03	0.97%	3.07	
3	0	1.275E-02	0.65%	4.055E-03	1.13%	3.14	
	SUM	3.988E-02	1.13%	1.264E-02	1.97%	3.16	2.27%

†1=outlet; 2=middle; 3=inlet;

- *Results for VWA MCNP modeling are shown for the objective converter below.*
- *The models for no BHDPE back-shield and 2 thicknesses of BHDPE, 1" and 2".*
- *The factor of FD/FU of 6.66 for the 1" BHDPE was adequate for the back-shield thickness.*
- *The face down (FD) efficiencies are basically unaffected by the back-shield.*

RISCC/Method/Models/Adjacent

Table 2 MCNP VWA efficiencies for the adjacent converters with the objective converter immediately below the three detectors for 2", 1" and 0" to exemplify the FD/FU ratio $\left(r_{c_{ij}}\right)$.

Detector Position†	Back-Shield Depth (inches)	MCNP Efficiency (%) Model 01 T4A,T1A Face-Down FD	Unc.	Face-Up FU	Unc.	FD/FU $\left(r_{c_{ij}}\right)$	Unc.	Model 00 Ratio
1	2	4.435E-03	0.90%	2.713E-04	3.58%	16.35		2.25
2	2	5.526E-03	0.80%	3.347E-04	3.17%	16.51		3.07
3	2	4.201E-03	0.93%	2.448E-04	3.84%	17.16		3.02
SUM		1.416E-02	1.52%	8.508E-04	6.13%	16.65	6.31%	2.80
1	1	4.475E-03	0.89%	5.600E-04	2.48%	7.99		2.23
2	1	5.594E-03	0.80%	7.390E-04	2.17%	7.57		3.04
3	1	4.239E-03	0.92%	5.375E-04	2.49%	7.89		2.99
SUM		1.431E-02	1.51%	1.837E-03	4.13%	7.79	4.40%	2.77
1	0	4.586E-03	0.87%	1.308E-03	1.61%	3.51		2.20
2	0	5.695E-03	0.79%	1.668E-03	1.44%	3.41		2.99
3	0	4.354E-03	0.90%	1.210E-03	1.65%	3.60		2.93
SUM		1.464E-02	1.48%	4.186E-03	2.72%	3.50	3.09%	2.72

†1=outlet; 2=middle; 3=inlet;

- *Results for VWA MCNP modeling are shown for the adjacent converters.*

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RISCC/Method/Models/Compressor

Table 3 MCNP VWA efficiencies for the adjacent compressors with the objective converter immediately below the three detectors for 2", 1" and 0" to exemplify the FD/FU ratio $\left(r_{c_{ij}}\right)$

Detector Position†	Back-Shield Depth (inches)	MCNP Efficiency (%) Model 02 T4A,T1A Face-Down FD	Unc.	Face-Up FU	Unc.	FD/FU $\left(r_{cp_{ij}}\right)$	Unc.	Model 00 Ratio
1	2	9.571E-04	1.48%	6.346E-05	5.63%	15.08		10.44
2	2	2.233E-03	0.98%	1.191E-04	4.11%	18.75		7.60
3	2	4.803E-03	0.66%	2.009E-04	3.25%	23.91		2.64
SUM		7.993E-03	1.89%	3.834E-04	7.69%	20.85	7.92%	4.96
1	1	9.688E-04	1.47%	1.058E-04	4.43%	9.16		10.30
2	1	2.235E-03	0.97%	2.268E-04	3.07%	9.85		7.60
3	1	4.823E-03	0.66%	4.066E-04	2.25%	11.86		2.63
SUM		8.027E-03	1.88%	7.392E-04	5.84%	10.86	6.14%	4.94
1	1	9.856E-04	1.45%	2.442E-04	2.90%	4.04		10.22
2	1	2.291E-03	0.96%	4.877E-04	2.03%	4.70		7.44
3	1	4.890E-03	0.65%	1.044E-03	1.41%	4.68		2.61
SUM		8.167E-03	1.86%	1.776E-03	3.81%	4.60	4.24%	4.88

†1=outlet; 2=middle; 3=inlet;

- *Results for VWA MCNP modeling are shown for the adjacent compressors.*

RISCC

Results

- *Several cells were measured in the 1.4% to 2.4% enrichment range.*
- *In general, less than 2.0% enrichment, most, if not all stages passed the safe mass limit using L1 method.*
- *L2 method showed improvement where many more cells could be extracted.*

RISCC/Results

Table 10 Cell results for all 8 stages of C-337 U5C3 2.1% assay using RISCC Method #1.

Objective Converter															
f	R_{CU}	%Err	m_{CU} (g U23	TMU	Safe Mass Limit (g U-235)	Safe Mass?	k	β (mb^{-1})	ΔP (mb)	σ_{RSP} (cps)	σ_{RB} (cps)	L_0 (counts)	MDA (g U-235)	R_B (FD)	R_B (FU)
1.05	0.579376	2.12%	1745	29.03%	2100	No	1.645	5.906E-03	5.000	0.011	0.002	300	1005	4.226	4.305
1.05	0.59338	2.08%	1787	29.03%	2100	No	1.645	5.906E-03	5.000	0.015	0.003	306	1025	3.973	4.368
1.05	1.116698	2.06%	3363	29.03%	2100	No	1.645	5.906E-03	5.000	0.015	0.004	304	1017	3.760	4.199
1.05	1.255938	2.00%	3783	29.03%	2100	No	1.645	5.906E-03	5.000	0.015	0.004	313	1049	3.921	4.458
1.05	1.071253	2.04%	3226	29.03%	2100	No	1.645	5.906E-03	5.000	0.015	0.004	308	1030	3.670	4.292
1.05	1.226784	2.00%	3695	29.03%	2100	No	1.645	5.906E-03	5.000	0.015	0.004	313	1047	4.032	4.462
1.05	0.749043	2.09%	2256	29.03%	2100	No	1.645	5.906E-03	5.000	0.015	0.003	303	1013	3.856	4.236
1.05	0.419756	2.12%	1264	29.03%	2100	Yes	1.645	5.906E-03	5.000	0.011	0.002	302	1012	4.174	4.387
													AVERAGE:	3.951	4.338
													%RSD:	4.86%	2.24%

Table 11 Cell results for all 8 stages of C-337 U5C3 2.1% assay using RISCC Method #1 and the iterative approach (26 iterations).

Objective Converter															
f	R_{CU}	%Err	m_{CU} (g U23	TMU	Safe Mass Limit (g U-235)	Safe Mass?	k	β (mb^{-1})	ΔP (mb)	σ_{RSP} (cps)	σ_{RB} (cps)	L_0 (counts)	MDA (g U-235)	R_B (FD)	R_B (FU)
1.05	0.53991	2.12%	1626	29.03%	2100	No	1.645	5.960E-03	5.000	0.023	0.004	306	1024	4.431	4.337
1.05	0.106375	2.08%	320	29.03%	2100	Yes	1.645	5.960E-03	5.000	0.024	0.004	312	1042	4.568	4.462
1.05	0.773685	2.06%	2330	29.03%	2100	No	1.645	5.960E-03	5.000	0.024	0.004	309	1034	4.404	4.300
1.05	0.818726	2.00%	2466	29.03%	2100	No	1.645	5.960E-03	5.000	0.024	0.004	318	1066	4.684	4.578
1.05	0.405489	2.04%	1221	29.03%	2100	Yes	1.645	5.960E-03	5.000	0.024	0.004	313	1047	4.540	4.429
1.05	0.977017	2.00%	2943	29.03%	2100	No	1.645	5.960E-03	5.000	0.024	0.005	318	1064	4.664	4.562
1.05	0.268055	2.09%	807	29.03%	2100	Yes	1.645	5.960E-03	5.000	0.024	0.004	308	1031	4.434	4.327
1.05	0.320354	2.12%	965	29.03%	2100	Yes	1.645	5.960E-03	5.000	0.017	0.003	305	1020	4.434	4.428
													AVERAGE:	4.520	4.428
													%RSD:	2.46%	2.36%

Table 12 Cell results for all 8 stages of C-337 U5C3 2.1% assay using RISCC Method #1 and the MS Excel Solver [5] approach.

Objective Converter															
f	R_{CU}	%Err	m_{CU} (g U23	TMU	Safe Mass Limit (g U-235)	Safe Mass?	k	β (mb^{-1})	ΔP (mb)	σ_{RSP} (cps)	σ_{RB} (cps)	L_0 (counts)	MDA (g U-235)	R_B (FD)	R_B (FU)
1.05	0.579376	2.18%	1745	29.03%	2100	No	1.645	5.906E-03	5.000	0.022	0.004	306	1024	4.354	4.325
1.05	0.222135	2.14%	669	29.03%	2100	Yes	1.645	5.906E-03	5.000	0.024	0.004	311	1042	4.427	4.439
1.05	0.82431	2.12%	2483	29.03%	2100	No	1.645	5.906E-03	5.000	0.024	0.004	309	1034	4.287	4.282
1.05	0.90299	2.06%	2720	29.03%	2100	No	1.645	5.906E-03	5.000	0.024	0.005	318	1065	4.556	4.558
1.05	0.494239	2.10%	1489	29.03%	2100	No	1.645	5.906E-03	5.000	0.024	0.004	313	1046	4.410	4.409
1.05	1.025571	2.06%	3089	29.03%	2100	No	1.645	5.906E-03	5.000	0.024	0.005	318	1063	4.543	4.543
1.05	0.397557	2.15%	1197	29.03%	2100	Yes	1.645	5.906E-03	5.000	0.024	0.004	308	1030	4.307	4.307
1.05	0.2807	2.18%	845	29.03%	2100	Yes	1.645	5.906E-03	5.000	0.017	0.003	305	1020	4.427	4.427
													AVERAGE:	4.414	4.411
													%RSD:	2.24%	2.35%

- *Safe mass results for various methods.*
- *2.1% enrichment so challenging.*
- *L1 is in the first table – only one converter passed the safe mass limit.*
- *L2 is shown in the last two tables where 3 or 4 converters pass the safe mass limit.*
- *L3 will surely release more but the response for the 000 compressors is required.*

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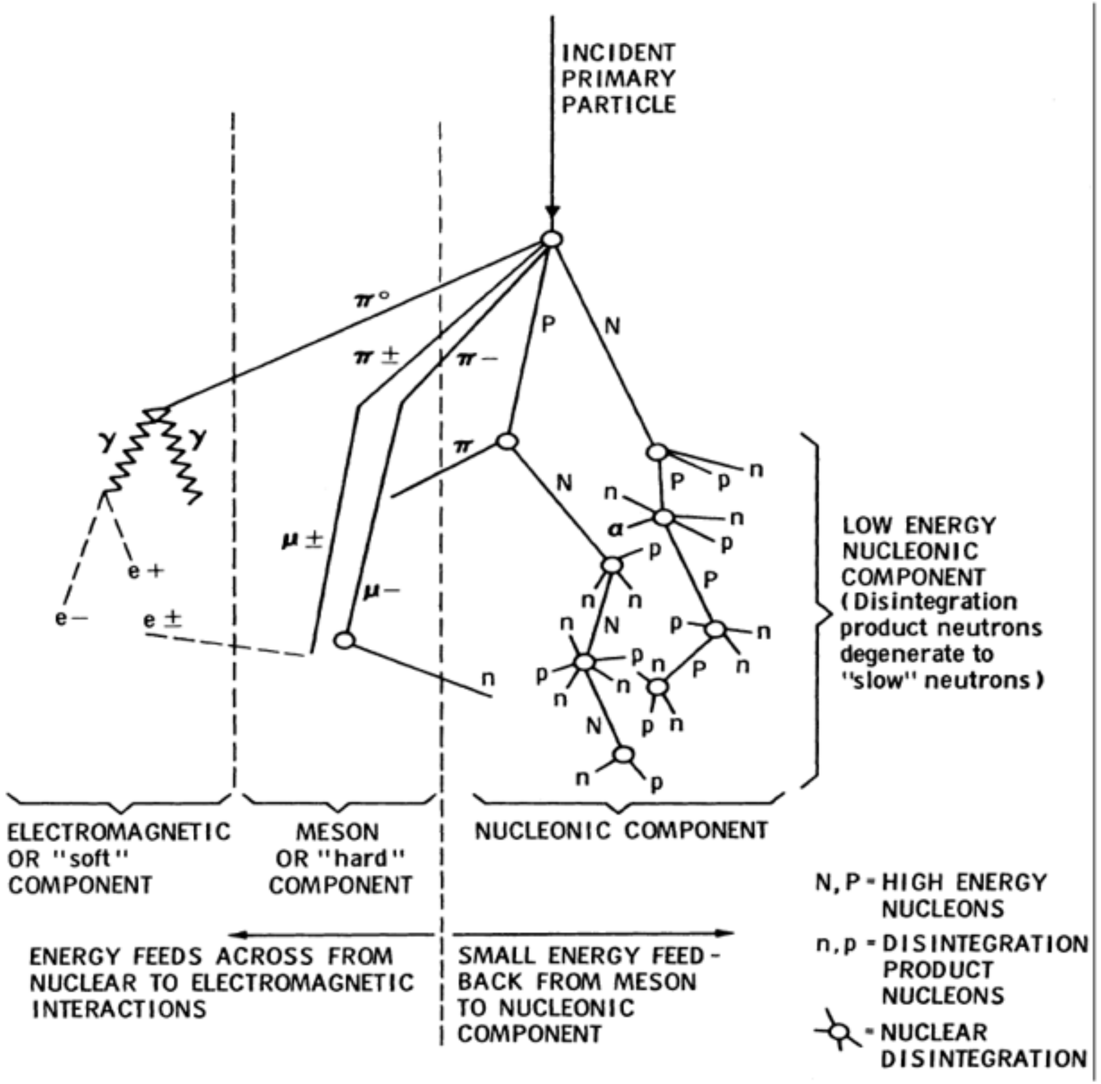
RISCC Targets Completed

- *Successfully completed NQA-1 compliant RISCC method (L1, L2) for removing 000 converters for 1%-2% enrichment (Q3 2025).*
- *FRNP made a slight improvement by measuring the 000 compressor efficiency which is L3 (Q4 2025).*
- *Have successfully screened numerous 000 converters (2026).*

What’s New

- *MCNP model for cosmic-ray(CR) induced nuclear spallation.*
- *Improved MCNP model for the 000 Compressor*
- *Introduced Gamma Spectroscopy for hold-up localization (L4).*

MCNP Model for Cosmic-Ray (CR) Induced Spallation



- *Model assumes a single incident proton of solar (GeV) and galactic (TeV) origin.*
- *As these high energy protons penetrate downwards, they interact with the atoms in the atmosphere, creating secondary particles.*
- *As these secondary particles continue downwards deeper into the atmosphere, they initiate complex cascades of other particles.*
- *What eventually reaches the earth's surface is a mixture of several particle species.*
- *Of particular interest for predicting the cosmogenic background count rate in a neutron counter are the neutrons, protons, and muons that reach the surface (nucleonic component).*
- *To estimate the background count rate in the LINAS system due to cosmogenic flux, a two-step approach was taken, utilizing the MCNP6 physics modeling code. Very briefly, this approach was*

  1. Model the cosmic protons striking the upper atmosphere and track the cascades and interactions throughout a slab of simulated atmosphere. Tally the flux of particles (neutrons, protons, and muons) that reach the ground.

  2. Using the particle fluxes from the previous step (i.e. the energy spectrum, absolute flux value, and angular distribution), define a separate surface source and launch this ground-level flux downwards into the LINAS model under various configurations.
- *Modelled a single cell in building 337 and successfully predicted the observed ~ 3 cps (~ 1 cps outside).*
- *New RISCC method will use this CR model. Presenting at INMM 2026.*

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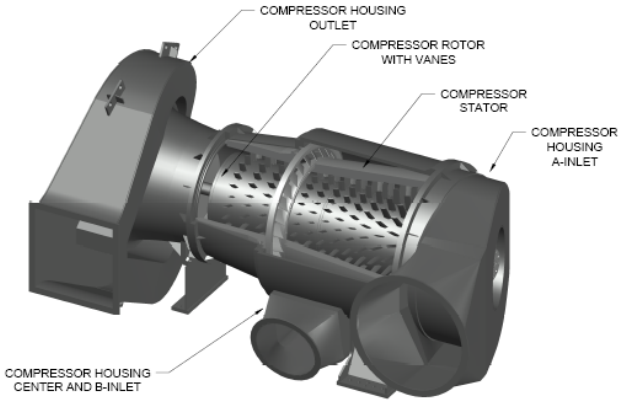
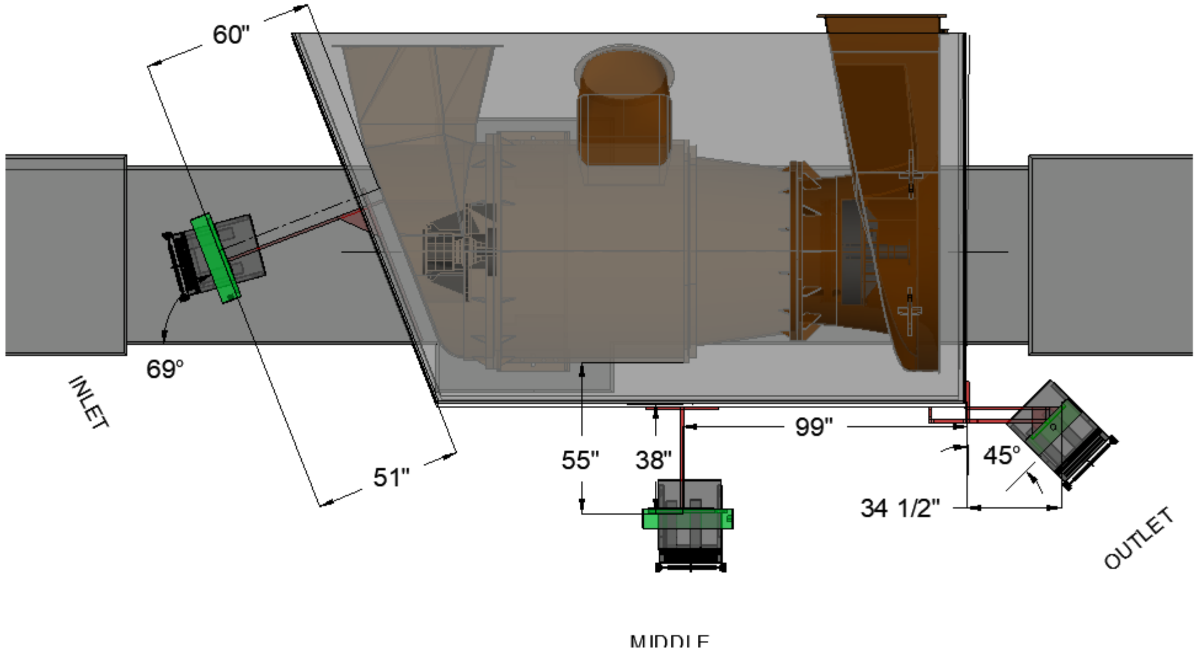
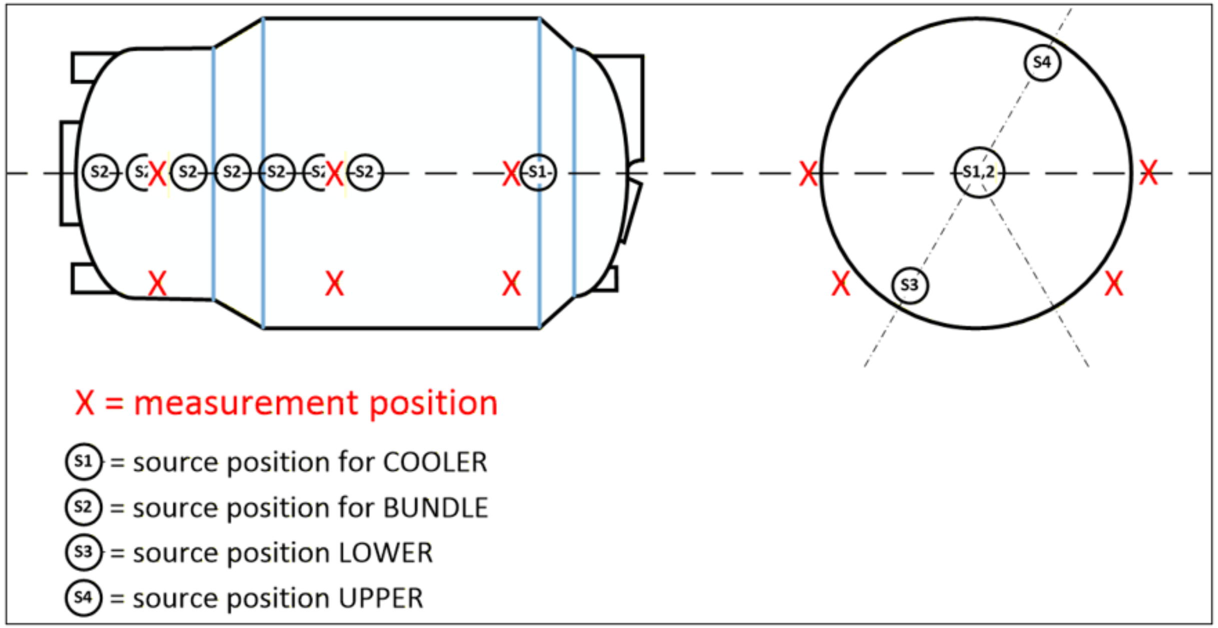
000 Compressor MCNP Model





- *FRNP has supplied detailed drawings of the 000 compressor – mostly CSTEEL and Aluminum.*
- *Will run new MCNP CR model to better determine the CR-induced nuclear spallation yield.*
- *From an efficiency perspective, model the neutron slabs as positioned in the figure to the left.*
- *Overall accuracy improvement to the RISCC methods developed in 2025.*

RISCC Gamma Introduction (L4)



- *Measure (gamma/Aegis) the converter (1" stand-off) at the six (X) positions on each side so 12 measurements in total.*
- *Sensitivity to:*
  - *Converter "belly".*
  - *Bundle (diffusion membrane/UF6 entrance).*
  - *Cooler (UF6 exit)*
- *Exploiting differential peak analysis (186 keV/1001 keV) and known cascade enrichment, localize the deposit (if any).*
- *Correct the MCNP efficiency model for that deposit.*
- *Significantly lowers the TMU in addition to improved accuracy.*
- *For method validation, we are currently measuring at S1, S2 and S3 source positions using Normal and 4% enrichment WRM's using a 00 surrogate.*
- *Discovered much Pa-233 (Np-237) introduced many moons ago as reactor refeed from Idaho, presumably EBR-II.*
- *It appears the Np-237 (24 kg through the whole system) has plated – we can use this plated hypothesis to see if the Uranium is plated or not (passivation layer).*

Advancing Radiation Safety.
Empowering Progress.

Thank you