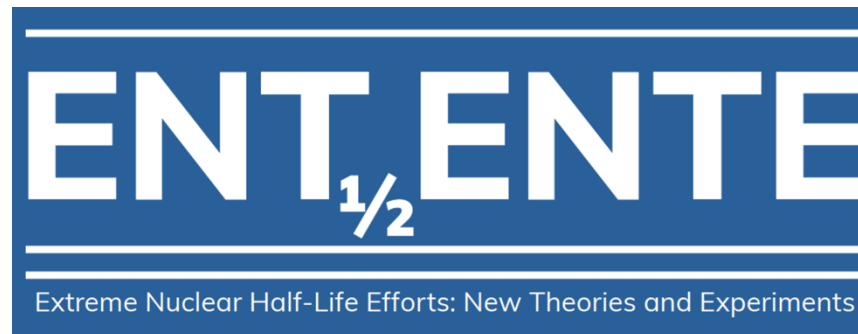


Opportunities with Tellurium

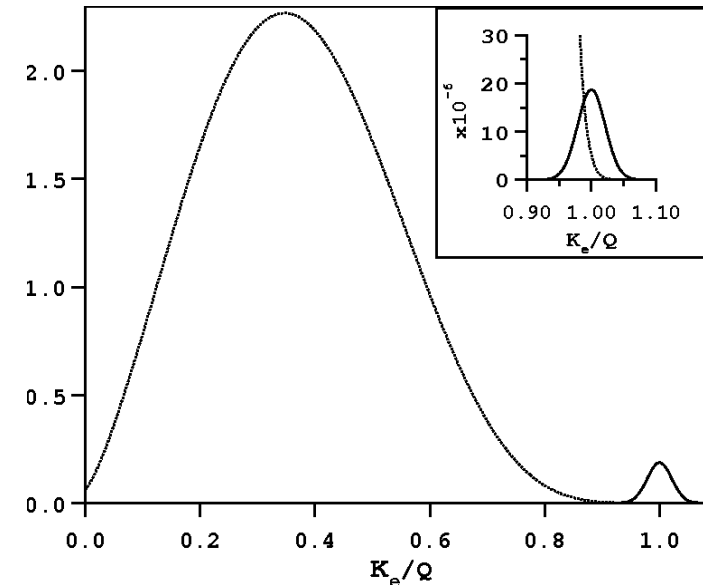
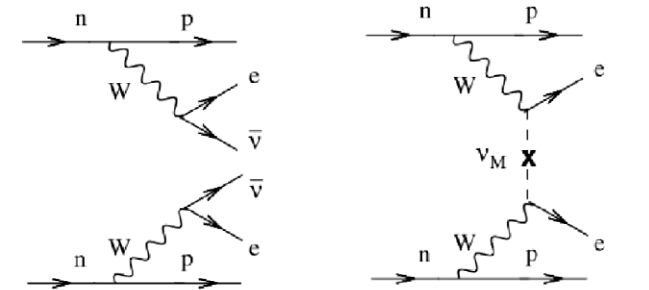


Szymon Manecki, September 30th, 2025

Double Beta Decay

- Are neutrinos their own anti-particles?
- $2\nu\beta\beta$ (Dirac)
 $(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$
 $\sim 10^{18}-10^{21}$ years
- $0\nu\beta\beta$ (Majorana)
 $(A, Z) \rightarrow (A, Z + 2) + 2e^-$
 $> 10^{25}$ years
- We measure:

$$\frac{1}{T_{1/2}} = \underbrace{G}_{\text{Phase space factor}} \underbrace{g_A^4 \mathcal{M}^2 \left(\frac{m_{\beta\beta}}{m_e} \right)^2}_{\text{Nuclear matrix element}}$$



Double Beta Decay

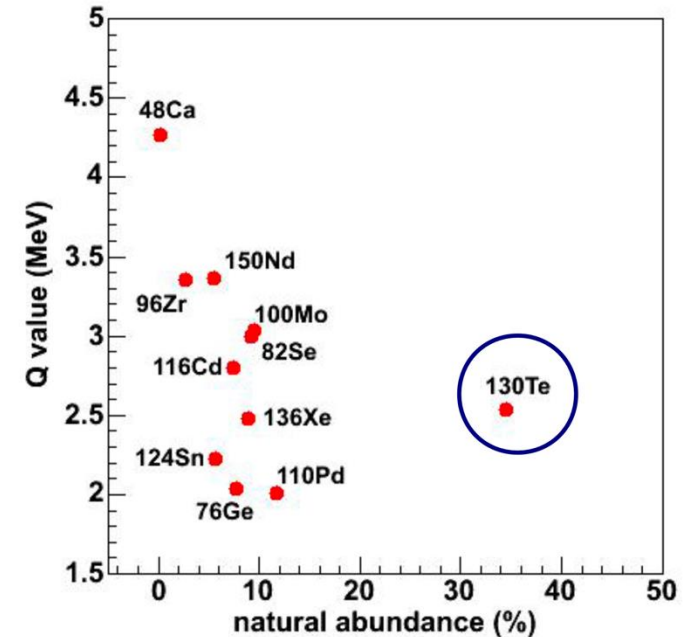
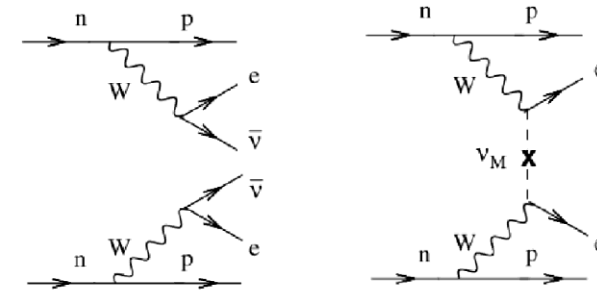
- Are neutrinos their own anti-particles?

- $2\nu\beta\beta$ (Dirac)
 $(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$
 $\sim 10^{18}-10^{21}$ years

- $0\nu\beta\beta$ (Majorana)
 $(A, Z) \rightarrow (A, Z + 2) + 2e^-$
 $> 10^{25}$ years

- We measure:

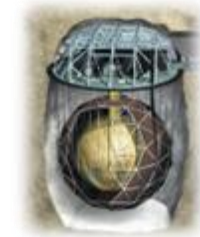
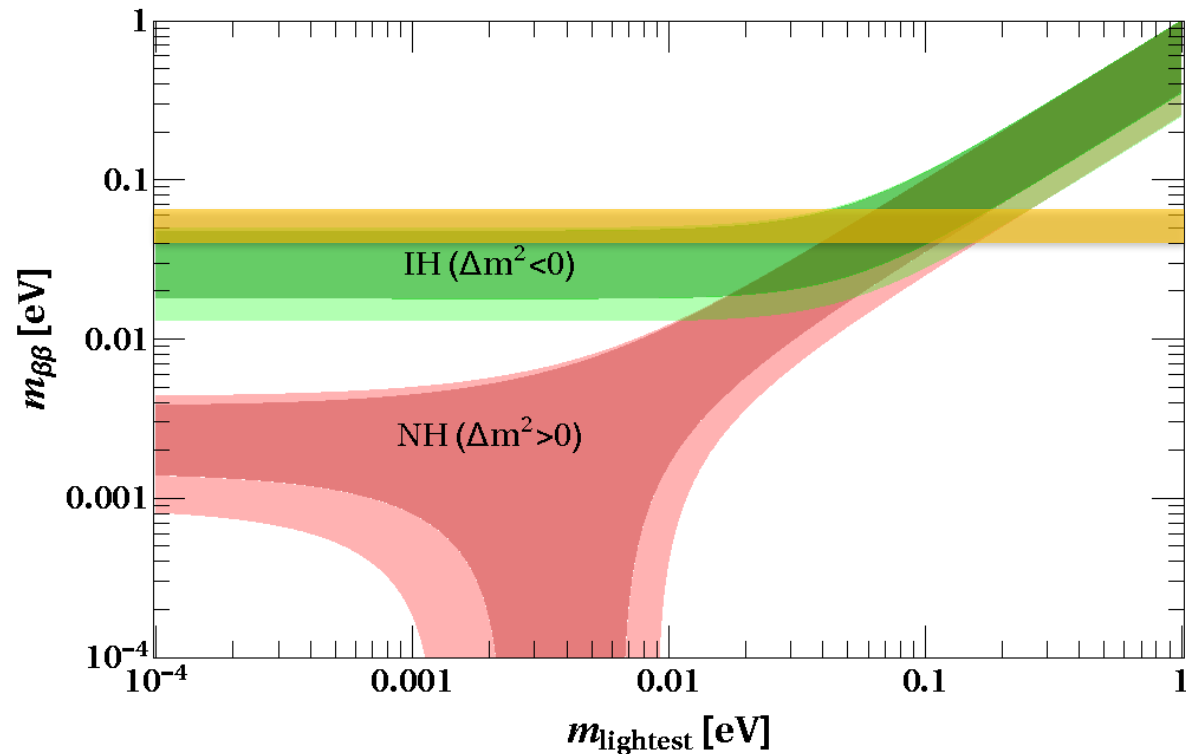
$$\frac{1}{T_{1/2}} = \underbrace{G}_{\text{Phase space factor}} \underbrace{g_A^4 \mathcal{M}^2 \left(\frac{m_{\beta\beta}}{m_e} \right)^2}_{\text{Nuclear matrix element}}$$





Future Scale of Tellurium Detectors

- Towards the bottom of Normal Hierarchy

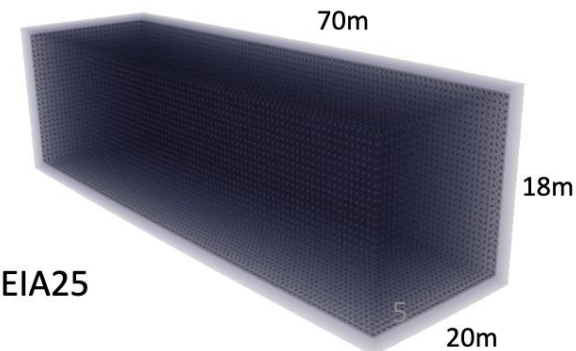


Ref: Chin. Phys. C 41 (2017) 053001

SNO+

JUNO-II

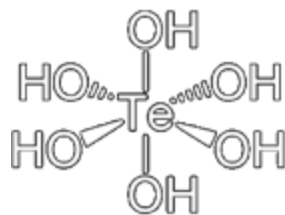
THEIA



THEIA25

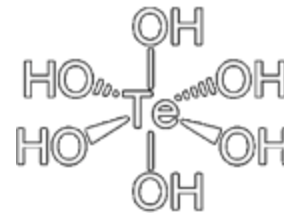
Tellurium

- Telluric Acid crystal



Tellurium

- Telluric Acid crystal



1 1A																	18 VIIA																	
1 H Hydrogen 1.008																	18 He Helium 4.003																	
2 IIA																																		
3 Li Lithium 6.941	4 Be Beryllium 9.012															19 K Potassium 39.098																		
5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180											20 Ca Calcium 40.078																		
11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.69	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.63	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.8									
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium [98]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.32	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.91	54 Xe Xenon 131.29	55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [277]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [271]	112 Cn Copernicium [285]	114 Nh Nihonium [286]	115 Mc Moscovium [288]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]																			
107 Lr Lawrencium [260]	108 Ac Actinium [227]	109 Th Thorium [232]	110 Pa Protactinium [231]	111 U Uranium [238]	112 Np Neptunium [237]	113 Pu Plutonium [244]	114 Am Americium [243]	115 Cm Curium [247]	116 Bk Berkelium [247]	117 Cf Californium [251]	118 Es Einsteinium [252]	119 Fm Fermium [257]	120 Md Mendelevium [258]	121 No Nobelium [259]	122 Lr Lawrencium [262]																			

isotope	Cosmogenic Counts in Year 1 (no purification)
²² Na	7.04×10^{-3}
²⁶ Al	9.67×10^{-2}
⁴² K	6.55×10^{-2}
⁴⁴ Sc	8.41×10^{-1}
⁴⁶ Sc	5.21×10^{-2}
⁵⁶ Co	1.02×10^{-3}
⁵⁸ Co	2.50×10^{-3}
⁶⁰ Co	6.62×10^{-3}
⁶⁸ Ga	6.20×10^{-2}
⁸² Rb	5.15×10^{-16}
⁸⁴ Rb	8.88×10^{-12}
⁸⁸ Y	2.23×10^{-1}
⁹⁰ Y	5.05×10^{-2}
¹⁰² Rh	1.33×10^{-3}
^{102m} Rh	9.54×10^{-4}
¹⁰⁶ Rh	8.59×10^{-1}
^{110m} Ag	7.96×10^{-2}
¹¹⁰ Ag	1.07×10^{-1}
¹²⁴ Sb	1.77×10^{-2}
^{126m} Sb	3.06
¹²⁶ Sb	2.92×10^{-35}



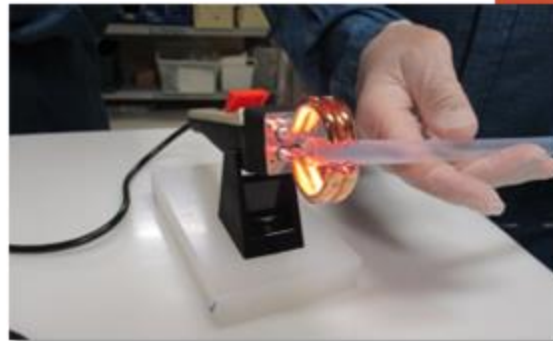
Process Systems

- Ultra-clean PFA Teflon
 - Every wet process line and vessel constructed with plastic to suppress metals leaching
- Polypropylene vessels (mostly cost savings)
- PFA piping
- Not a good radon barrier



Process Systems

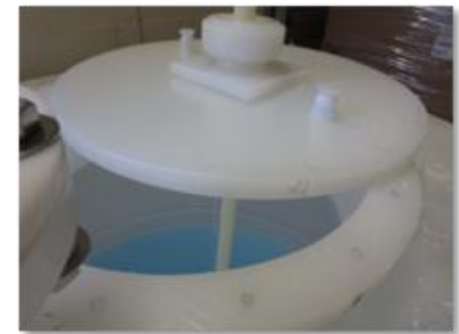
- Ultra-clean PFA Teflon
 - Every wet process line and vessel constructed with plastic to suppress metals leaching
 - Polypropylene vessels (mostly cost savings)
 - PFA piping
 - Not a good radon barrier



Process Systems

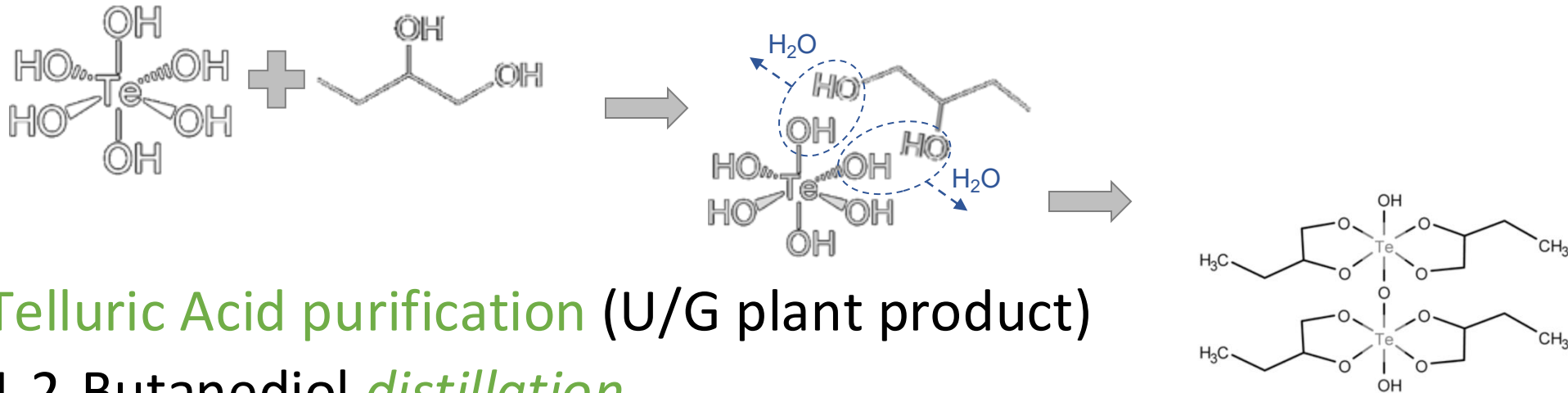
- Ultra-clean PFA Teflon
 - Every wet process line and vessel constructed with plastic to suppress metals leaching
 - Polypropylene vessels (mostly cost)
 - PFA piping
 - Not a good radon barrier

	Soak 1 (2 days)		Soak 2 (4 days)		Soak 3 (4 days)	
	RXT	TRXT	RXT	TRXT	RXT	TRXT
U	1	0.2	<0.05	<0.05	<0.05	<0.05
Th	5	1	1.1	<0.1	<0.1	<0.1
Ca	2700	2000	380	180	<20	<20
Fe	5600	5000	220	170	17	37



Loading method

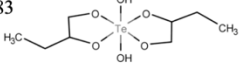
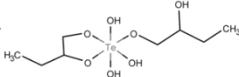
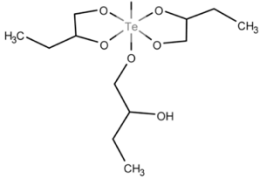
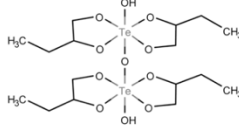
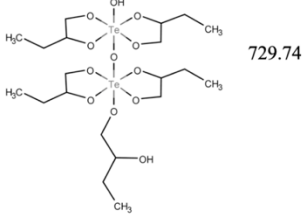
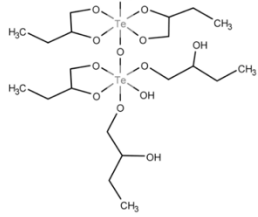
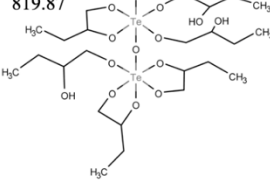
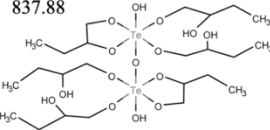
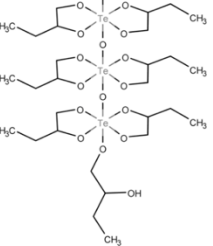
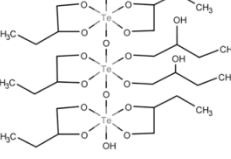
- (In the case of SNO+) **LAB-soluble Tellurium-Diol** complexes are formed in condensation and further oligomerization reactions of Telluric Acid with 1,2-Butanediol



- Telluric Acid purification** (U/G plant product)
- 1,2-Butanediol *distillation*
- DDA *distillation*

Loading method

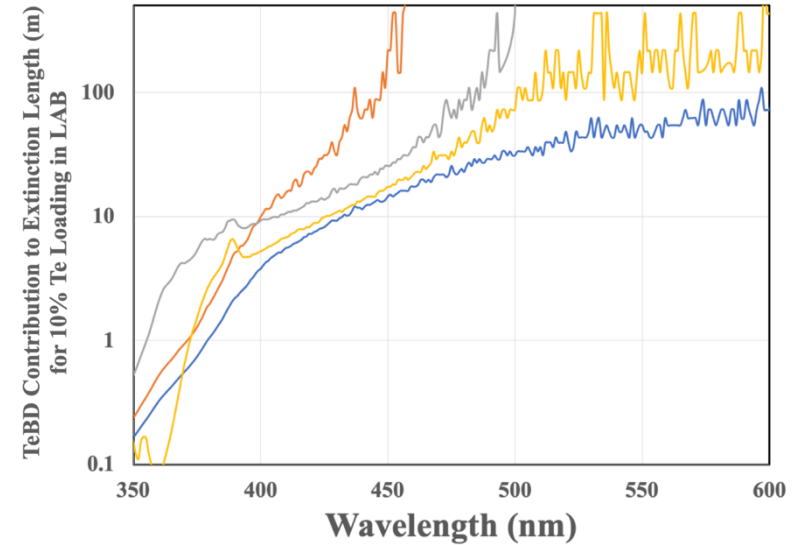
- (In the case of SNO+) **LAB-soluble Tellurium-Diol** complexes are formed in condensation and further oligomerization reactions

a	b	c
<p>337.83</p>  <p>355.84</p> 	<p>409.93</p> 	<p>657.64</p> 
d	e	f
<p>729.74</p>  <p>747.76</p> 	<p>819.87</p>  <p>837.88</p> 	<p>1049.56</p>  <p>1067.57</p> 

Loading method

- Other, **critical considerations**

- Long term chemical stability
- Long term optical stability
- Chemical compatibility

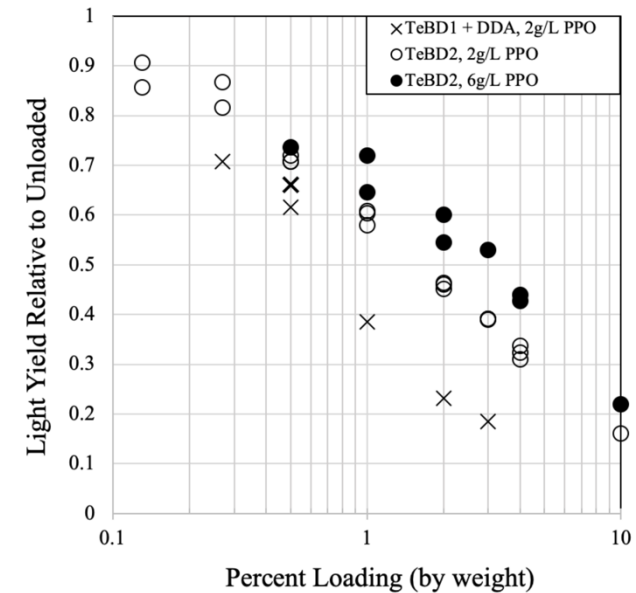


- These are critical R&D efforts that must be initiated as early as possible to establish sufficient confidence in the approach down the road
 - Analytical methods, chemical reaction models, material selection, reagents procurement

Loading method

- Other, **critical considerations**

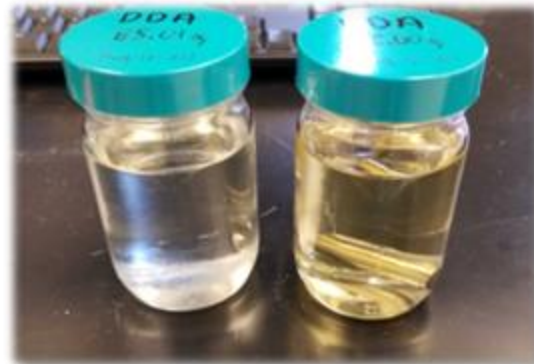
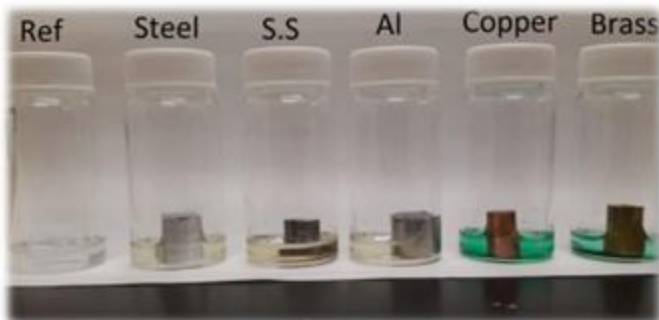
- Long term chemical stability
- Long term optical stability
- Chemical compatibility

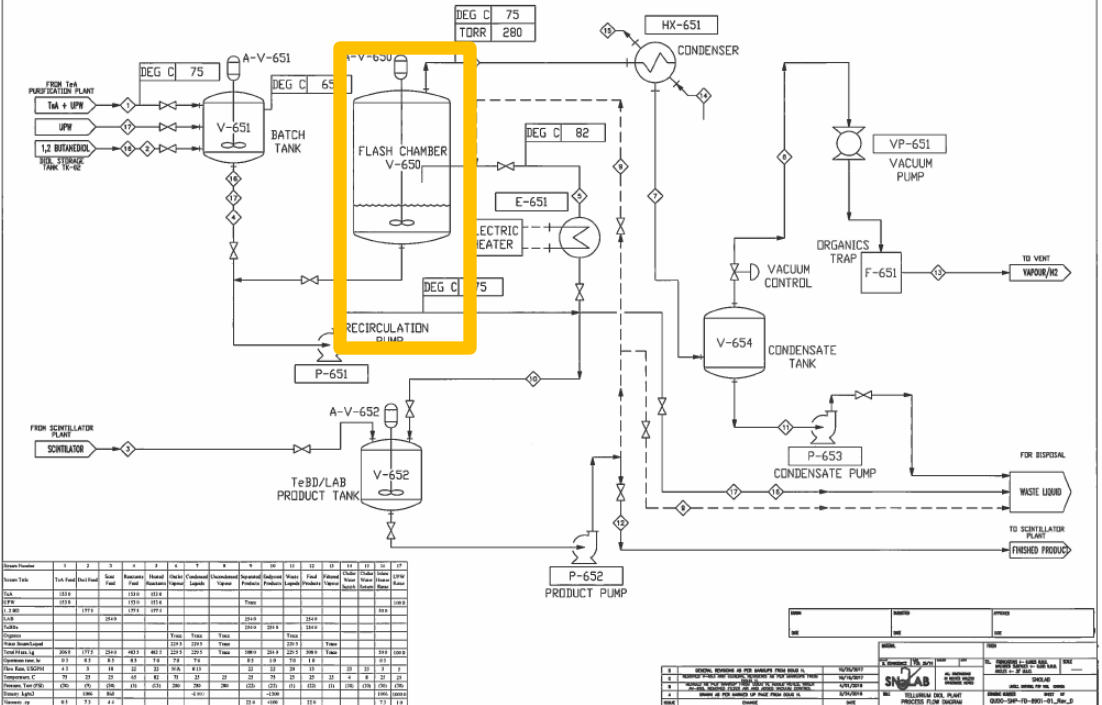


- These are critical R&D efforts that must be initiated as early as possible to establish sufficient confidence in the approach down the road
 - Analytical methods, chemical reaction models, material selection, reagents procurement

Loading method

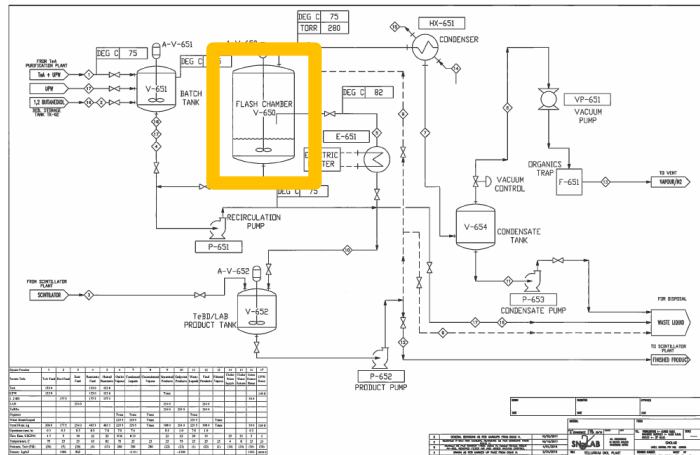
- Long term compatibility testing, e.g.:





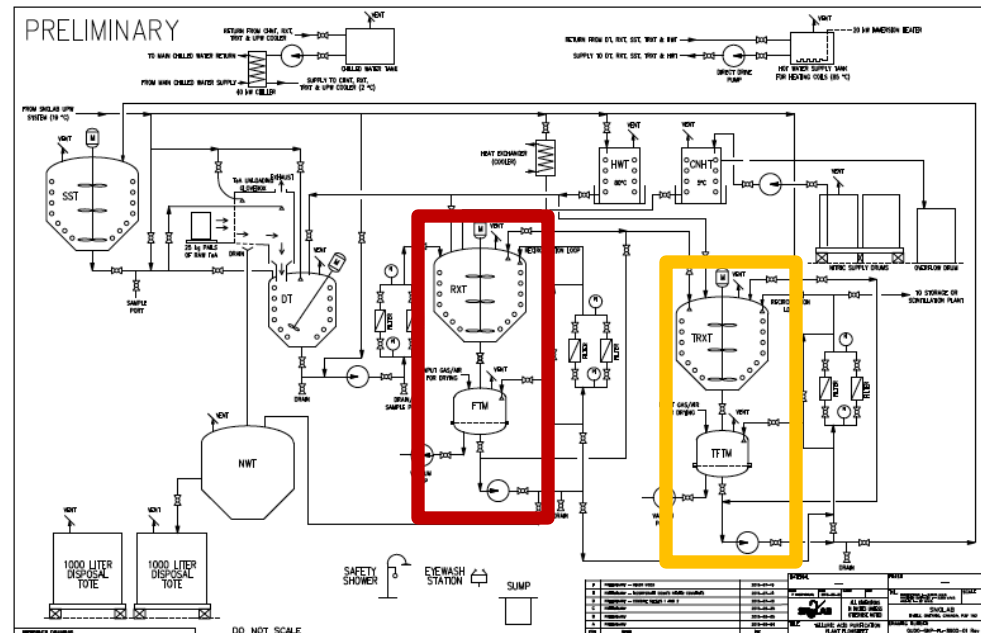
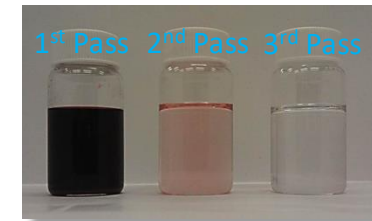
Loading method


- Scaling of chemical processes is not 'straight forward' – a factor of 100 will carry risk.

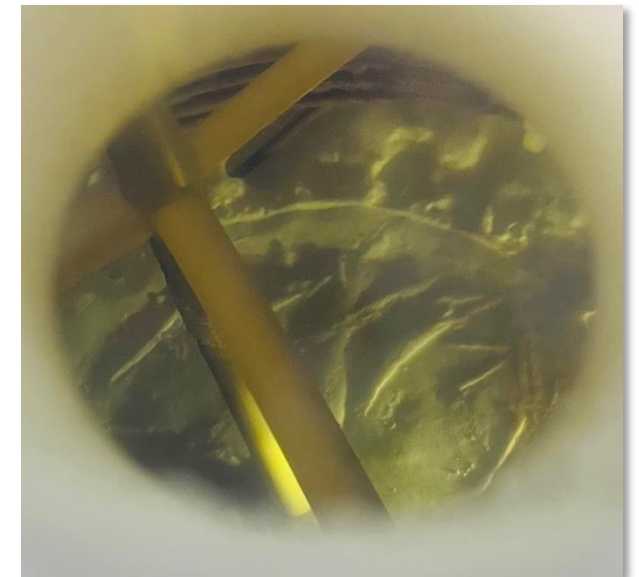
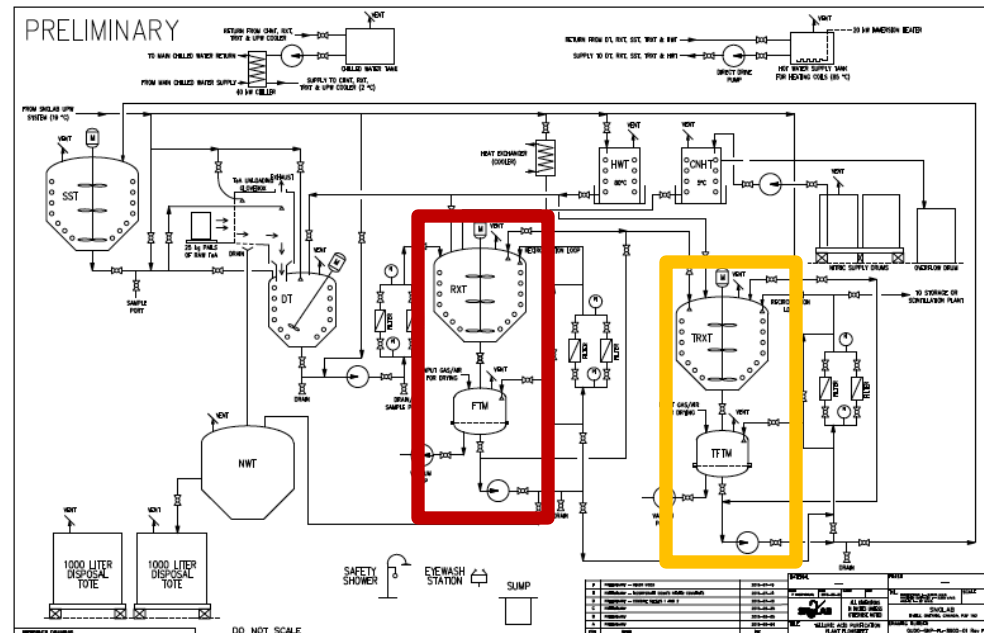


Tellurium Purification

- Relies on recrystallization and requires the use of nitric acid
 - Filter out insoluble impurities in water
 - Dissolve the rest and drain away after telluric acid is recrystallized



- 

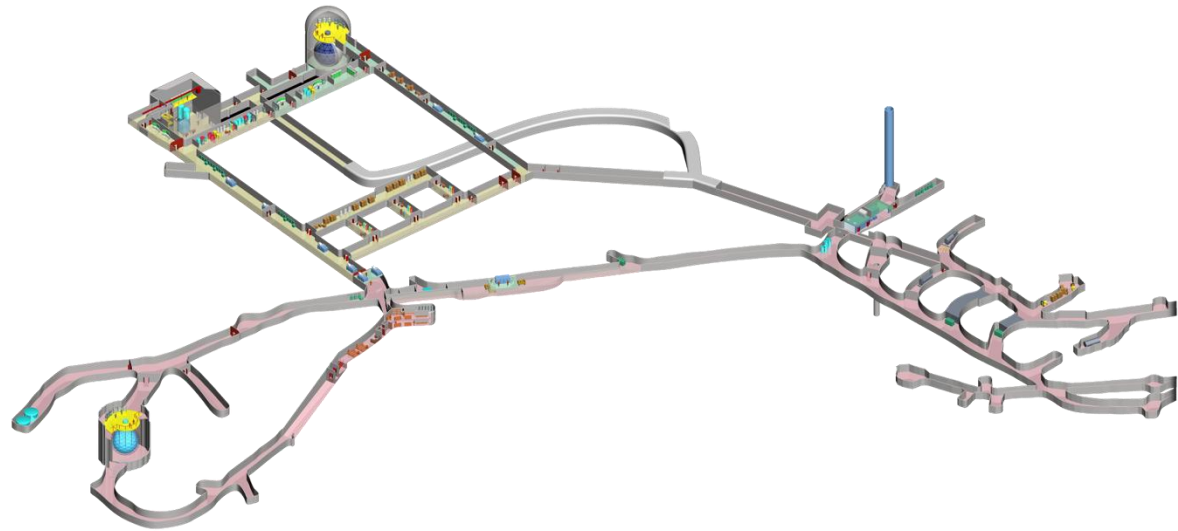


Tellurium Purification

- Relies on recrystallization and requires the use of nitric acid
 - Filter out insoluble impurities in water
 - Dissolve the rest and drain away after telluric acid is recrystallized
- Sufficient optimization and continues operations could give
 - 500 kg of telluric acid per week (~250 kg of tellurium)
- Bottlenecks
 - Logistics: Nitric acid deliveries and waste disposal

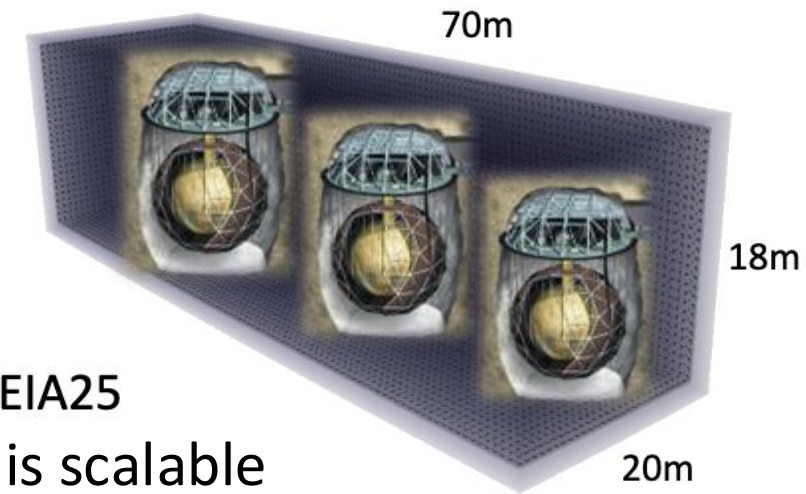
Tellurium Purification

- Underground facilities in the future
 - Tellurium purification
 - Nitric acid purification
 - Filtration
 - Scavengers
 - Distillation
- In the process of tellurium purification, 70% nitric acid transitions to ~40% nitric, contaminated with 'percentage levels of tellurium' and trace metal impurities



Conclusions

- Achieving normal hierarchy sensitivity requires a 100-tonne scale tellurium loading in LS
- **Te in LS is a feasible method**
 - Cost of isotope (high isotopic abundance)
 - Synthesis from water-soluble to scintillator-soluble is scalable
 - Purification of tellurium is now being demonstrated with SNO+
 - Scaling of the purification method has room for improvement
 - Optimization of the process and improved logistics for reagents and waste
- Future detector technology needs more refined simulations and engineering work – e.g., acrylic vessel vs nylon balloon(s)





Backup