Uranium-233 Characteristics, Inventories, Uses, and Disposal

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Outline

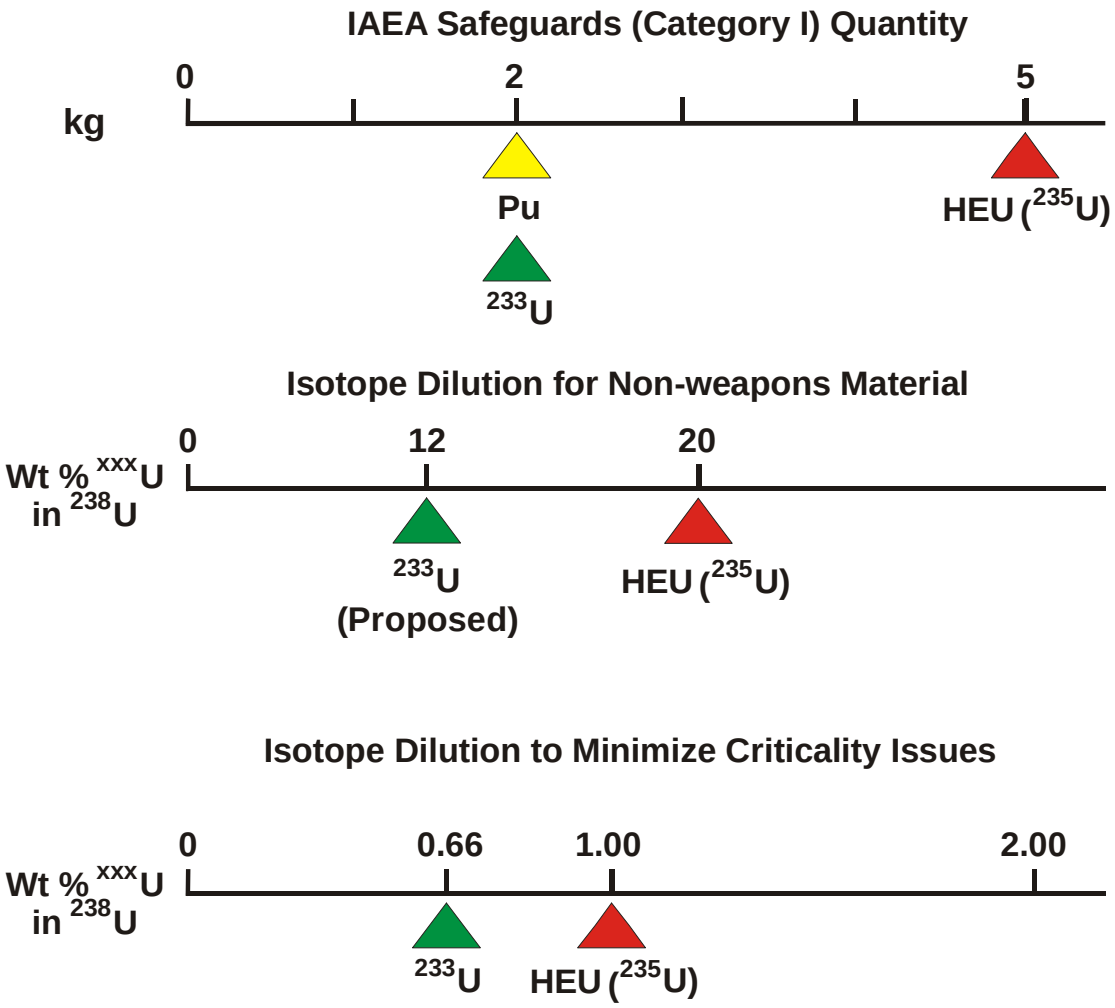
- History
- Properties of ^{233}U
- Inventories
- Medical Applications
- Disposal Options
- DNFSB Recommendation 97-1
- Request for Proposals
- Conclusions

History of ^{233}U At ORNL

- **Developed methods to recover ^{233}U from spent nuclear fuels (1950s-1960s)**
- **Developed ^{233}U fuels (1960s-1970s)**
- **Storage (1950's-today)**
- **Disposition program (1995-2000)**
- **DNFSB Recommendation (1997)**

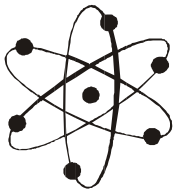
Properties of ^{233}U

Nuclear Characteristics of the Three Fissile Materials That Can Be Produced in Large Quantities

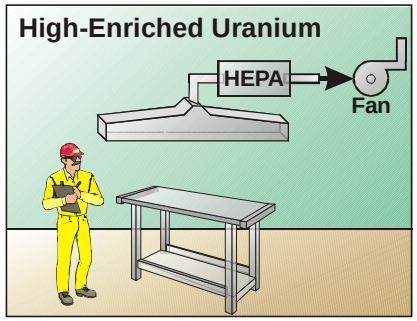


HIGH SECURITY

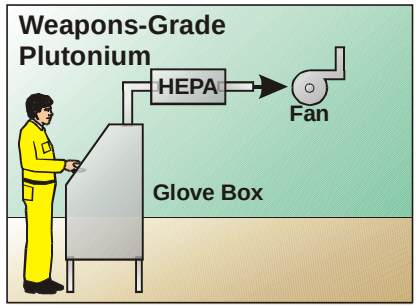
CRITICALITY SAFETY



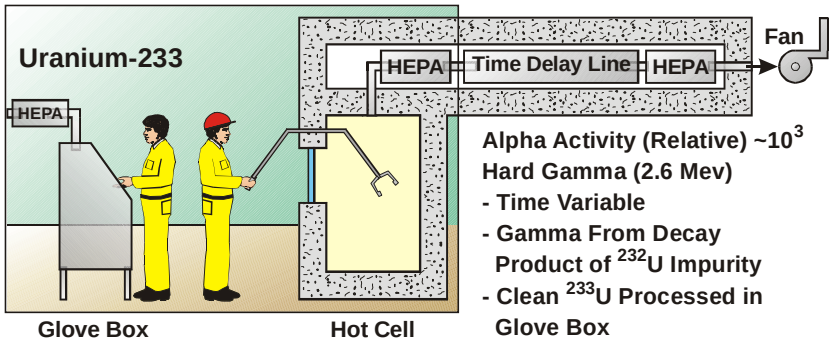
Uranium-233 Has Fundamentally Different Handling Requirements Than ^{239}Pu and ^{235}U



Alpha Activity (Relative) = 1
No Significant Gamma

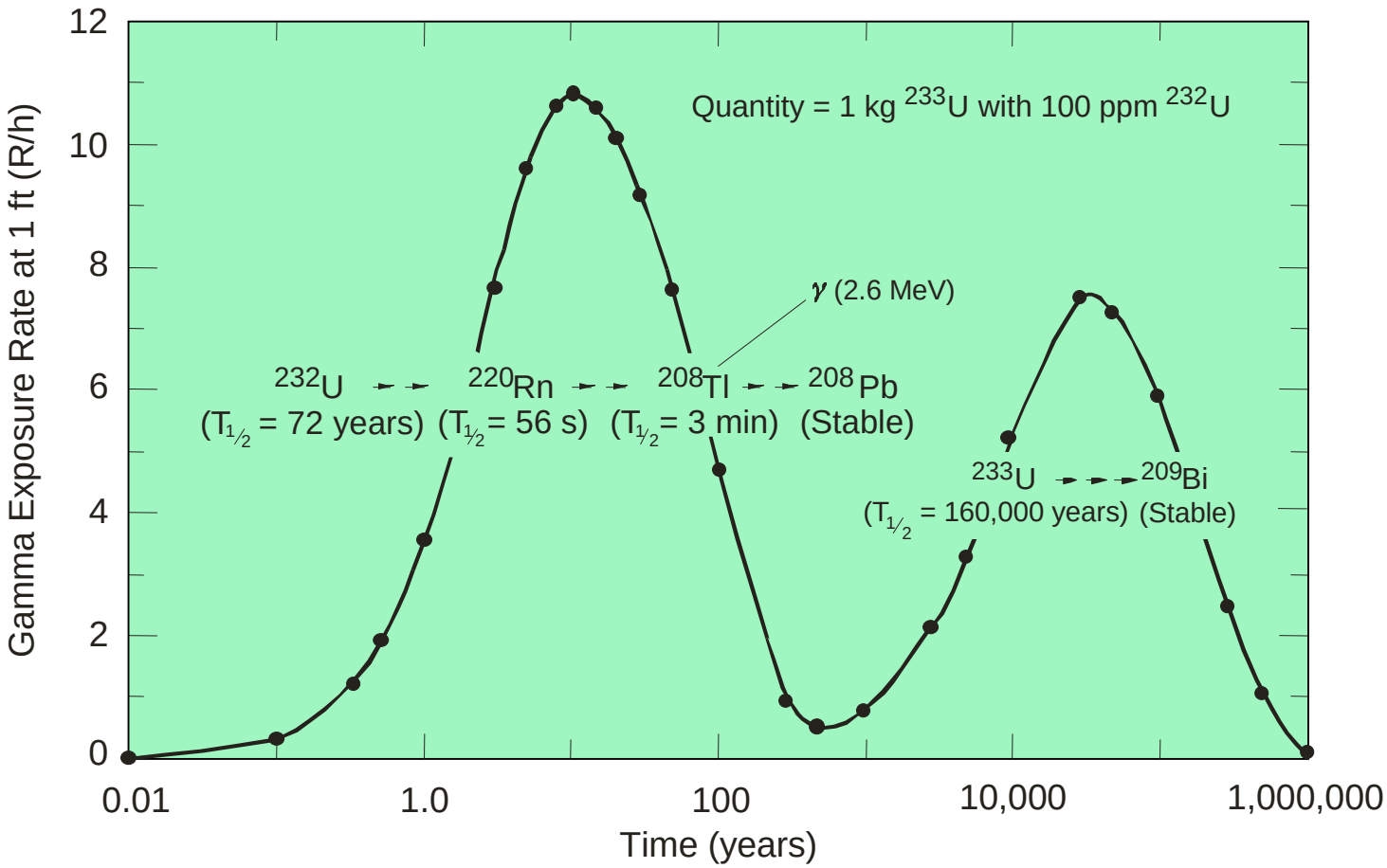


Alpha Activity (Relative) ~10^4
Soft Gamma
- Minimal Shielding
- Leaded Gloves Acceptable



Alpha Activity (Relative) ~10^3
Hard Gamma (2.6 Mev)
- Time Variable
- Gamma From Decay Product of ^{232}U Impurity
- Clean ^{233}U Processed in Glove Box

Uranium-233 with Significant Quantities (100 ppm) of ^{232}U Is a Significant Gamma Radiation Hazard



Inventories

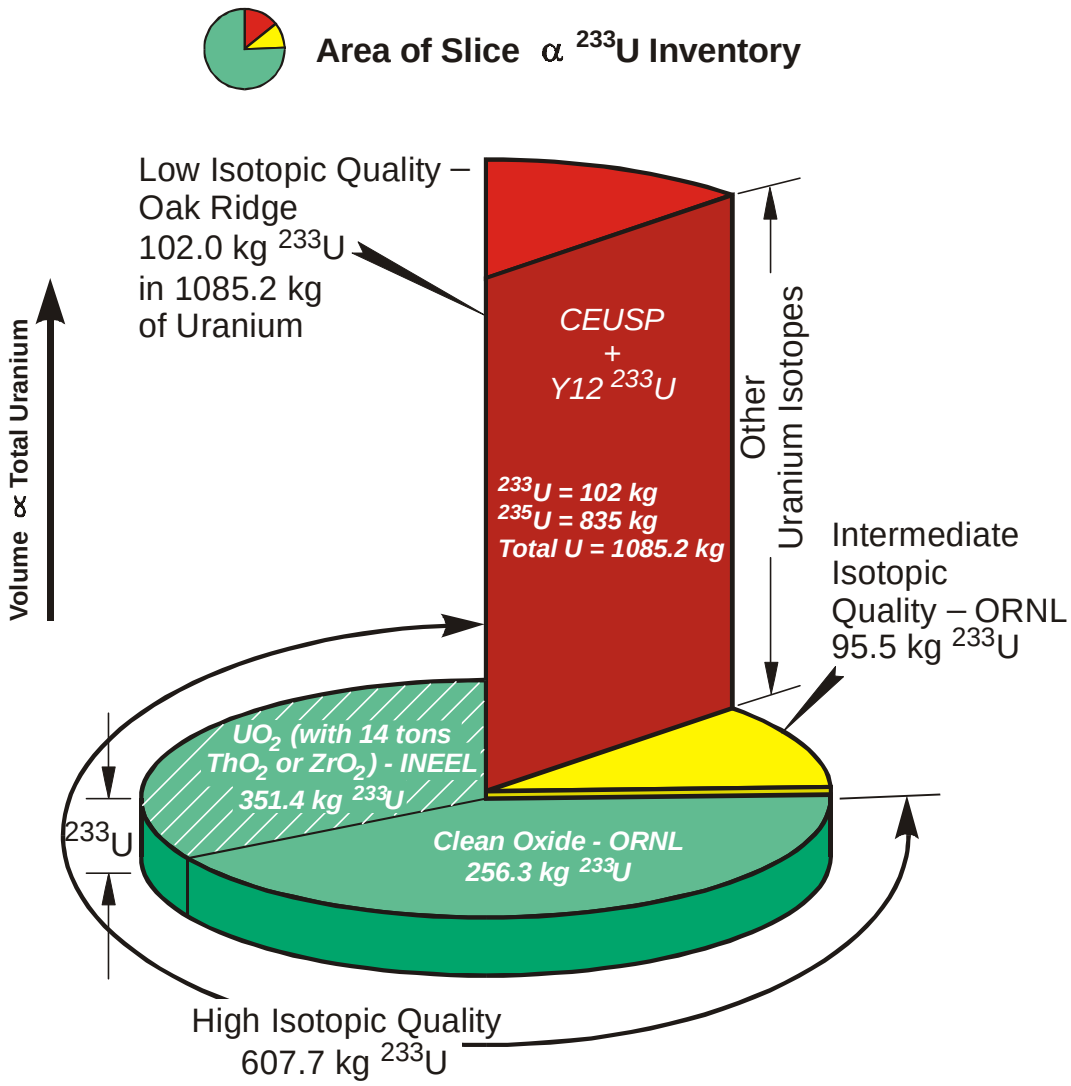
The Existing Separated ^{233}U Inventory Can Be Divided into Three Major Categories

- **High-Isotopic-Quality ^{233}U**
  - **Greater than 95% ^{233}U**
  - **Low ^{232}U content with relatively low gamma-radiation levels**

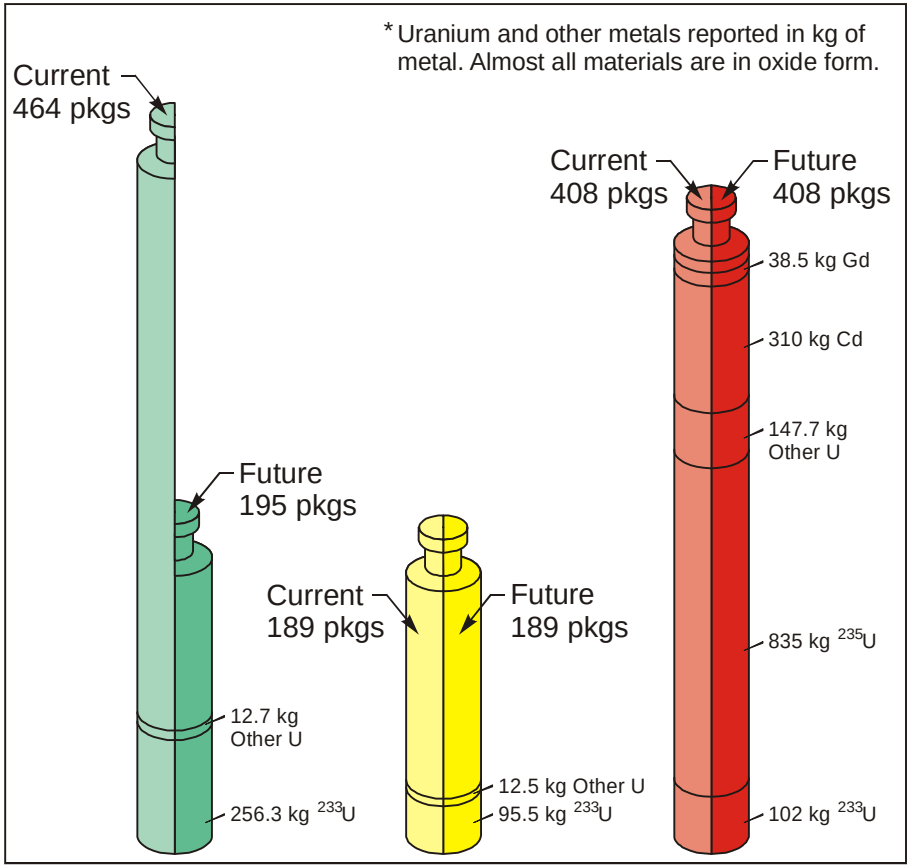
- **Intermediate-Isotopic-Quality ^{233}U**
  - **Greater than 95% ^{233}U**
  - **High ^{232}U (>15 ppm) content with high gamma-radiation levels**

- **Low-Isotopic-Quality ^{233}U**
  - **Less than 50% ^{233}U**

U.S. Separated ^{233}U Inventory



Current and Future Inventory of Separated ^{233}U in Oak Ridge



High Quality (<15 ppm ^{232}U)

Intermediate Quality (>15 ppm ^{232}U)

Low Quality (High Average ^{232}U Content)

Medical Applications

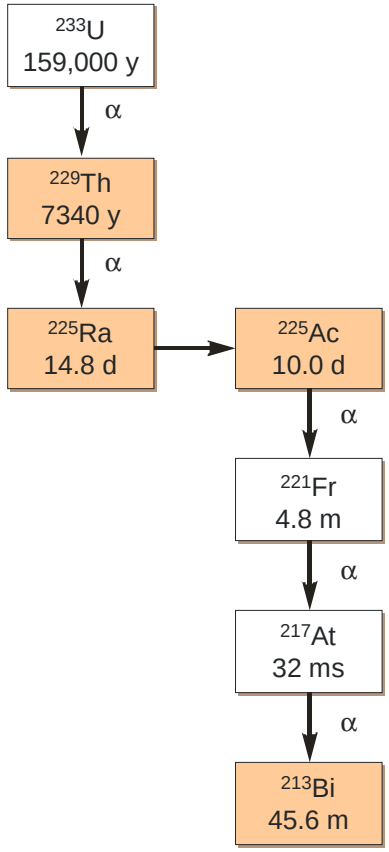
Medical Isotopes Are Being Recovered From ^{233}U For Clinical Trials

- **Near-term need for limited quantities of ^{213}B for cancer clinical trials**
- **Uranium-233 is the only current source of this isotope**
- **If clinical trials are fully successful, much larger quantities will be required**
- **Other methods to produce the medical isotopes have been proposed but the technology is not yet developed**

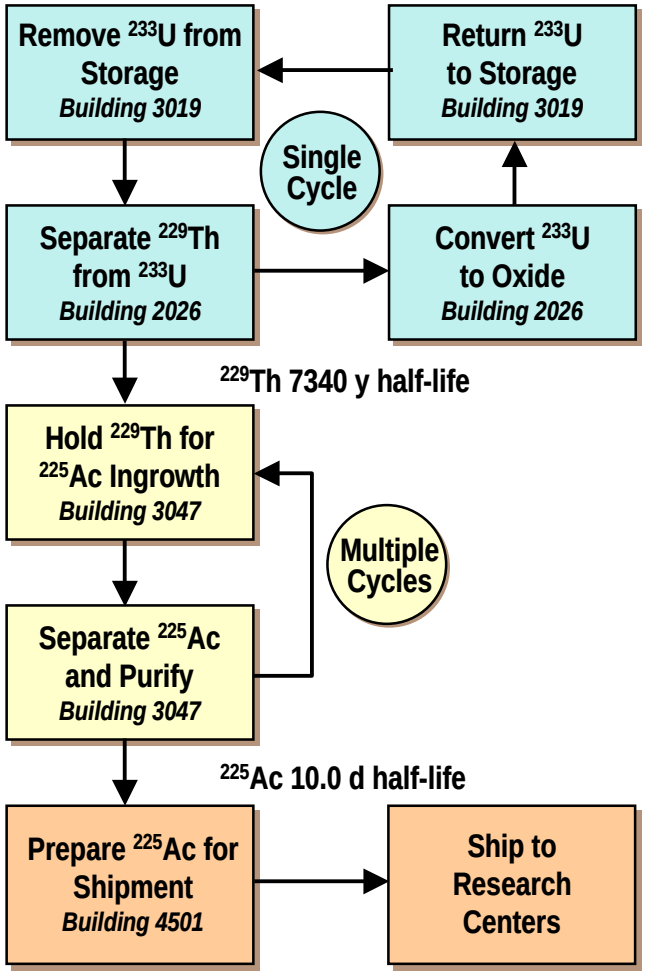
Clinical Trials on Humans and Animals are Underway To Investigate the Use of Bismuth-213 (A Decay Product Of ^{233}U) for Treatment of Cancer

Institutions	*Cancer*
Memorial Sloan-Kettering Cancer Center (New York)	Leukemia (Clinical Trials) Prostate
Fred Hutchinson Cancer Center (Seattle)	Large Tumor
Oak Ridge National Laboratory	Lung
St. George (New Zealand)	Skin
National Institute of Health	Breast
University of Idaho	
Other	

Thorium-229 is Recovered from ^{233}U and Then Decays to ^{213}Bi (Desired Isotope)



ORNL Recovers ^{225}Ac from $^{233}U/^{229}Th$ in a Multi-Step Process



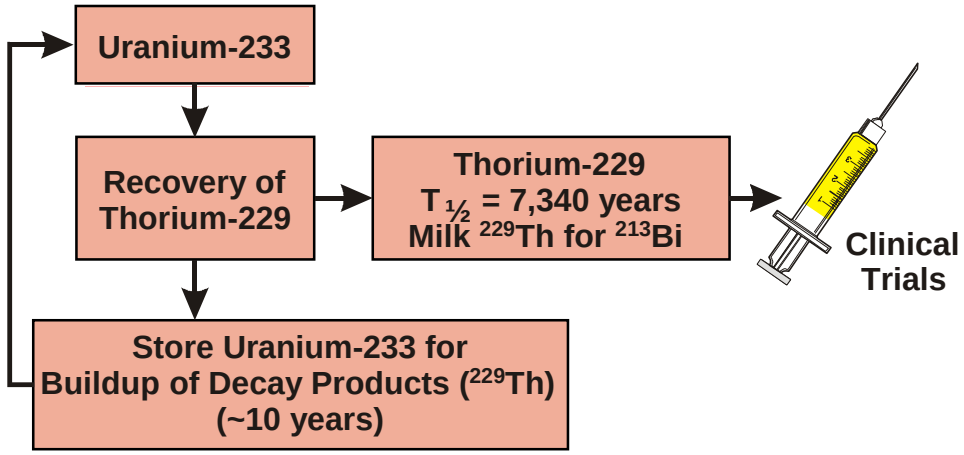
Radiochemical Development Facility Building 3019

Radioactive Materials Analytical Laboratory Building 2026

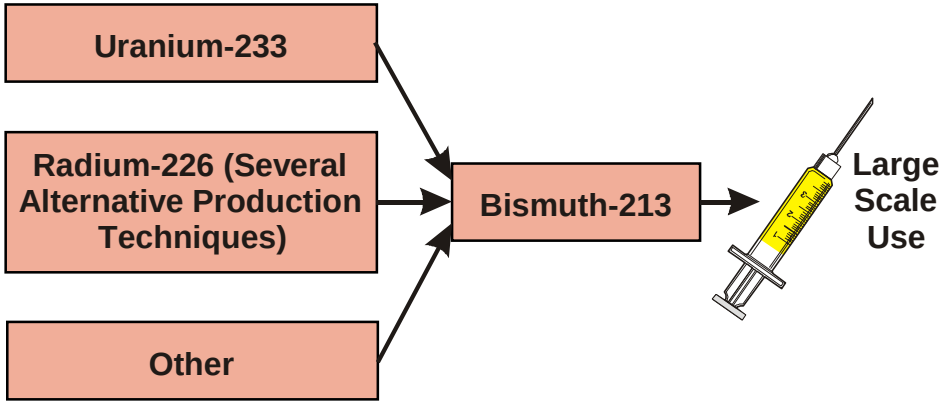
Radiochemical Development Laboratory Building 3047

Clear Near-term Need For ^{233}U Derived Isotopes: Long-term Need Is Unclear

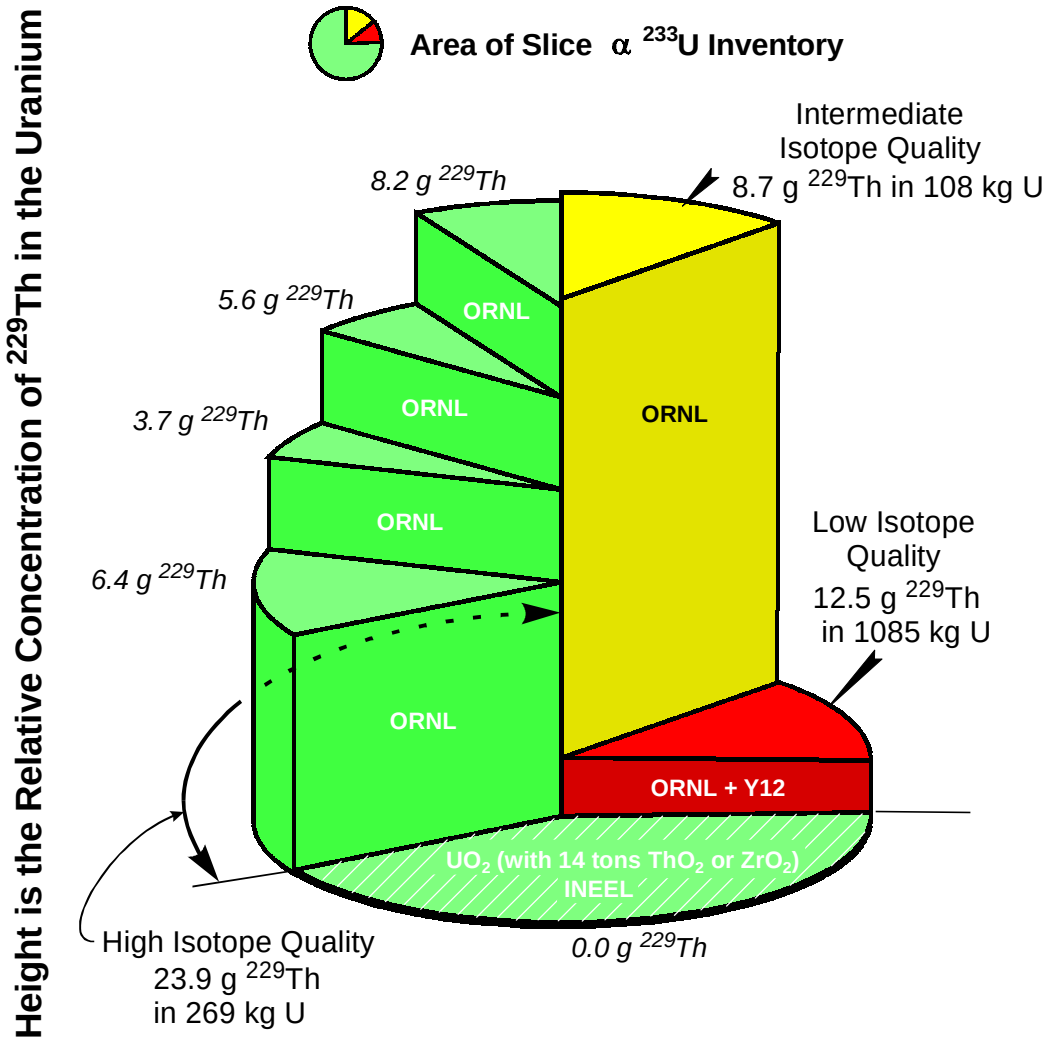
Today = Clinical Trial (Only Existing Production Route)



Future (If Successful Clinical Trials, Demand May Exceed Supply from ^{233}U)



Relative Concentrations of ^{229}Th Recoverable From Separated ^{233}U Inventory



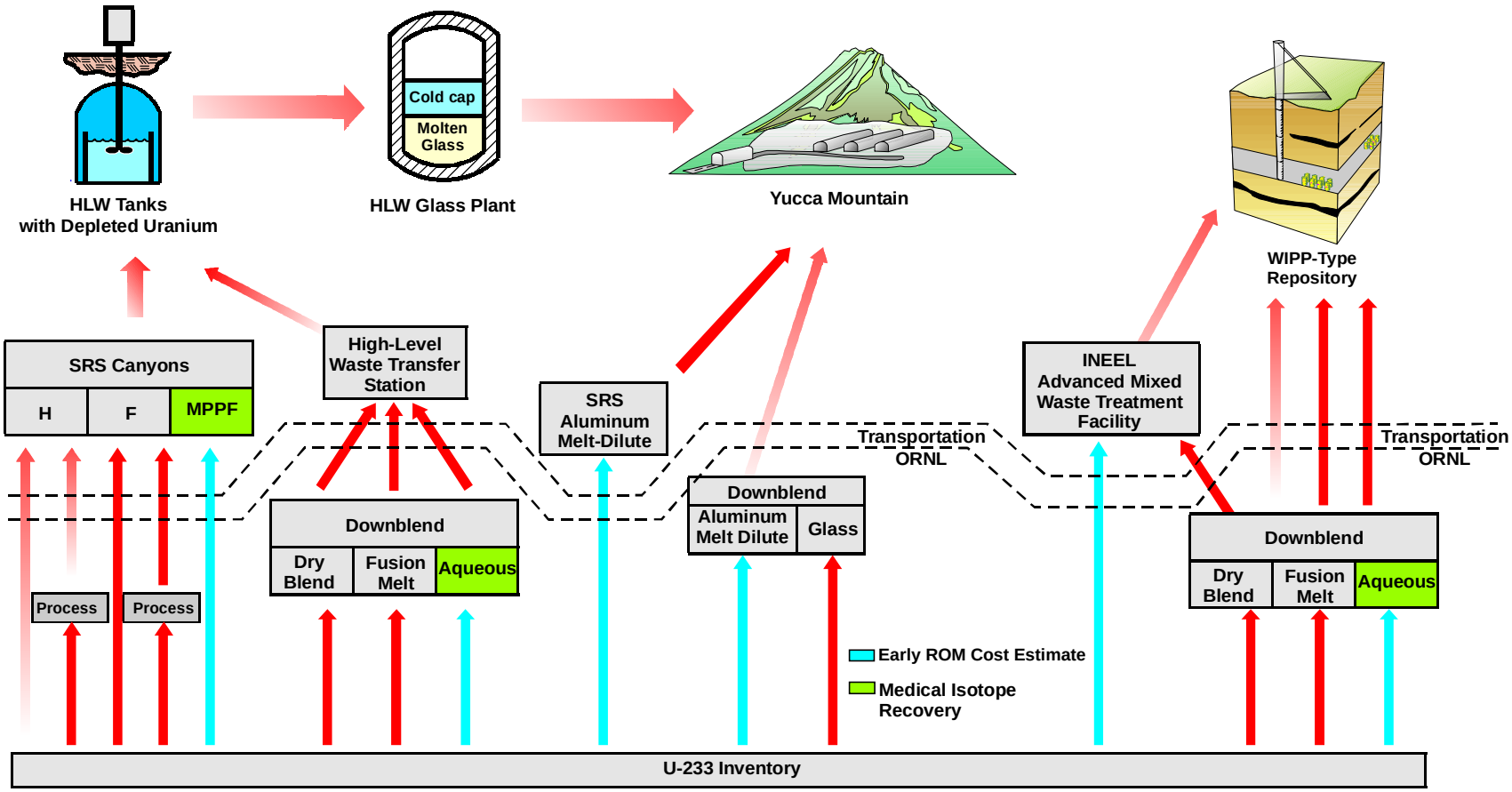
ORNL DWG 2001-196

Disposition Program

DOE Examined ^{233}U Disposition Options: Program Ended In FY-2000

- **Goal: arms control**
- **Key requirement: convert to non-weapons useable ^{233}U: Two strategies**
  - **Isotopic dilution with DU (<12% ^{233}U in ^{238}U)**
  - **Chemical dilution**
- **Two disposal sites identified**
  - **WIPP**
  - **Yucca Mountain**
- **Program cancelled (lower priority)**

Pathways Examined For ^{233}U Disposal



Options For Disposition of ^{233}U (all cases downblended to non-weapons-^{233}U)

- **WIPP disposal**
  - **Full downblend**
  - **12 %^{233}U in DU-lined drum (contact-handled)**
  - **Blend with TRUW (INEEL)**
- **Yucca Mountain disposal**
  - **Process and feed to HLW tanks (containing DU), convert to HLW glass**
  - **Aluminum melt-dilute (SRS process for SNF)**
  - **Fusion melt (vitrification)**
  - **Aqueous processing**

Disposal Is Complicated

- **WIPP is the logical disposal site based on ^{233}U properties (alpha emitter); but**
  - **Uncertain if ^{233}U meets legal requirements (defense transuranic waste)**
  - **Radiation complicates disposal**
- **Uranium-233 could be sent to Yucca Mountain but difficult acceptance criteria**
  - **YM designed for high-heat wastes**
  - **Added waste form requirements for higher temperature environment**

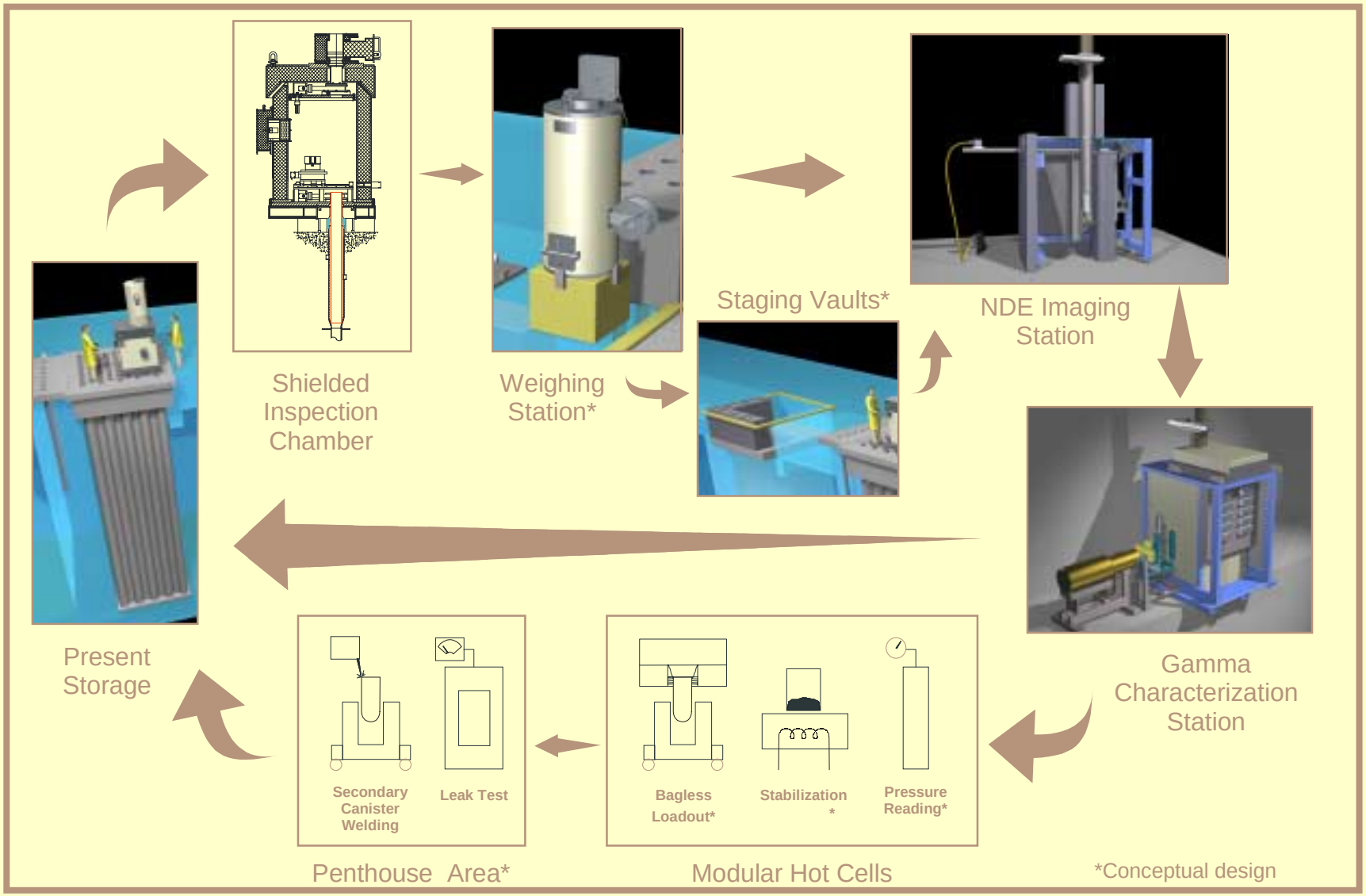
DNFSB 97-1 Recommendation

- **Safe Storage of ^{233}U by DOE**
  - **All Sites (ORNL, INEEL, LANL, LLNL, others)**
  - **Primarily aimed at separated ^{233}U, not spent nuclear fuel**
- **Technical Issues**
  - **No DOE approved storage standard**
  - **Infrequency of inspections**
  - **Aging storage systems**

DOE Response to DNFSB 97-1

- **DOE issued Implementation Plan in 1997**
- **^{233}U Technical Team established**
- **Storage Standard issued July 2000**
  - **DOE-STD- 3028-2000 - *Criteria for Packaging and Storing Uranium-233-Bearing-Materials***
  - **Basis for Inspection and Repackaging of Inventories**
- **ORNL Inspection and Repackaging Project defined**

^{233}U Package Inspection Paths



Request for Proposals

Proposal for ORNL ^{233}U Disposition

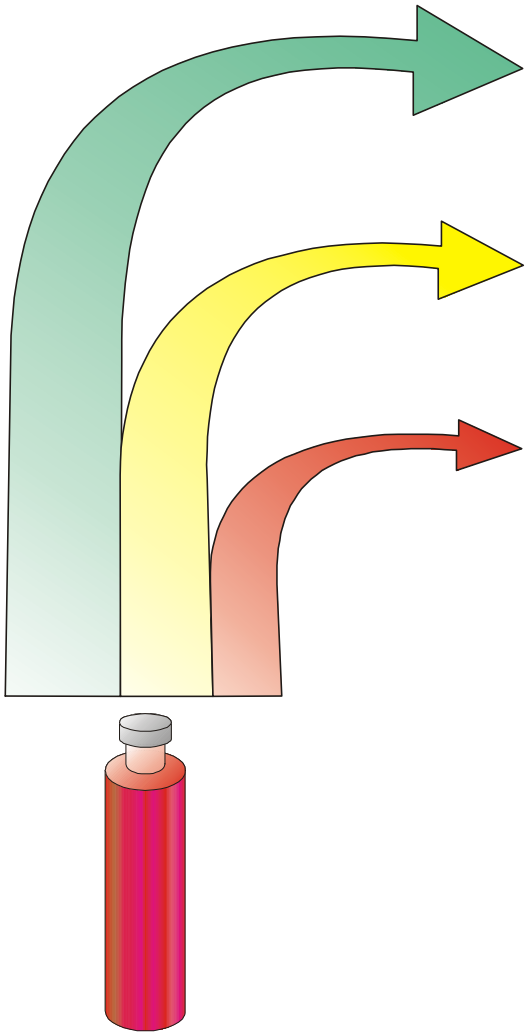
- **Draft Request For Proposals Issued January 31**
  - **Down-blend and repackage ^{233}U inventory**
  - **Extract ^{229}Th for medical research and use**
  - **Lease ^{229}Th for extraction of ^{225}Ac and ^{213}Bi**
  - **Remove down-blended uranium from Building 3019**
  - **Prepare Building 3019 for decommissioning**
- **Site Tours By Prospective Bidders In May**
- **DOE has revised scope in response to bidder comments and funding**
- **Final Request for Proposals Imminent?**

Conclusions

- **High-quality ^{233}U handling properties**
  - **Clean ^{233}U similar to plutonium**
  - **Low-quality ^{233}U has a significant gamma dose**
- **Near-term clinical demand for limited quantities of ^{233}U decay products**
- **Safety issues (DNFSB) are being resolved**
- **RFP underway**
- **Ultimate disposal options are limited to WIPP and Yucca Mountain**

Backup Information

The ^{233}U Inventory Was Divided into Three Categories Based on Those Characteristics That Control its Potential Future Usage



High Quality
- Low radiation levels
- <15 ppm ^{232}U
- Isotopically pure

Intermediate Quality
- High radiation level
- >15 ppm ^{232}U
- Isotopically pure

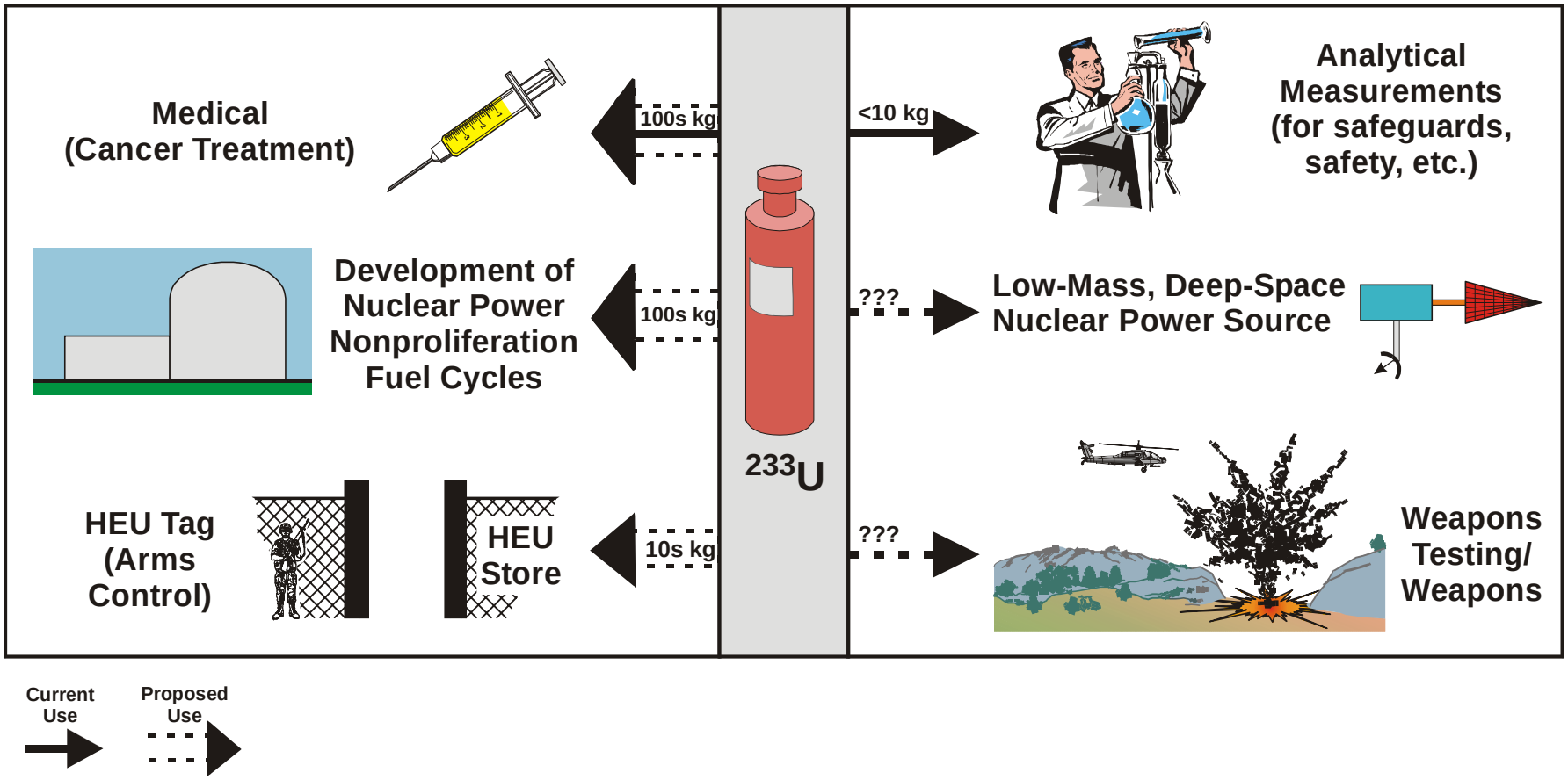
Low Quality
- High concentrations other uranium isotopes
- ^{235}U, ^{238}U, etc.

Characteristics of Major Batches of Separated ^{233}U in Inventory in Oak Ridge

Batch no.	Location/designation	Material[a] and packaging	Total U (kg)	Uranium isotopics: ^{233}U (kg)	Uranium isotopics: ^{235}U (kg)	Uranium isotopics: ^{232}U (ppm)	Number of packages: Current	Number of packages: After repackaging
High Isotopic Quality								
1	Oak Ridge National Laboratory (ORNL)	U_3O_8 monolith in 27 welded stainless steel cans with tin-plated cover (same as CEUSP)	65.2	60.3	0.0	15	27	27
2	ORNL (2 similar batches)	UO_x powder in 247 stainless steel screw-top cans	108.8	103.1	0.0	4–9	247	73
3	ORNL	U_3O_8 powder in 1,645 welded stainless steel plates in 130 packages	46.0	45.0	0.0	6	130	62
4	Multiple/remaining small lots	Multiple forms-60 packages	49.0	47.9	0.0	b	60	33
Subtotal			***269.0***	***256.3***	***~0.0***		***464***	***195***
Intermediate Isotopic Quality								
5	ORNL/Savannah River Site (SRS)	UO_3 powder in 140 welded inner aluminum-in-aluminum cans	67.4	61.6	0.0	156	140	140
6	ORNL/Molten Salt Reactor Experiment (MSRE)	49 NaF traps to be converted to UO_X monolith-powder in 49 welded Haynes alloy 230 cans	40.6	33.9	~1.0	160–200	49	49
Subtotal			***108.0***	***95.5***	***~1.0***		***189***	***189***
Low Isotopic Quality								
7	ORNL/Consolidated Edison Uranium Solidification Program (CEUSP)	U_3O_8 monolith in 403 welded stainless steel CEUSP cans; Monoliths also contain CdO and Gd_2O_3	1,042.6	101.1	796.3	120	403	403
8	Y-12	5 cans	42.6	0.9	38.7	0.15	5	5
Subtotal			***1,085.2***	***102***	***835***		***408***	***408***
Total			***1,462.2***	***453.8***	***836***		***1,061***	***792***

[a]With minor exceptions, most of the material is in oxide form. Current programs will convert most non-oxide ^{233}U into an oxide form for long-term storage.
[b]Includes small lots to be shipped to Oak Ridge. Most small lots have <15 ppm ^{232}U, some lots have a higher ^{232}U content.

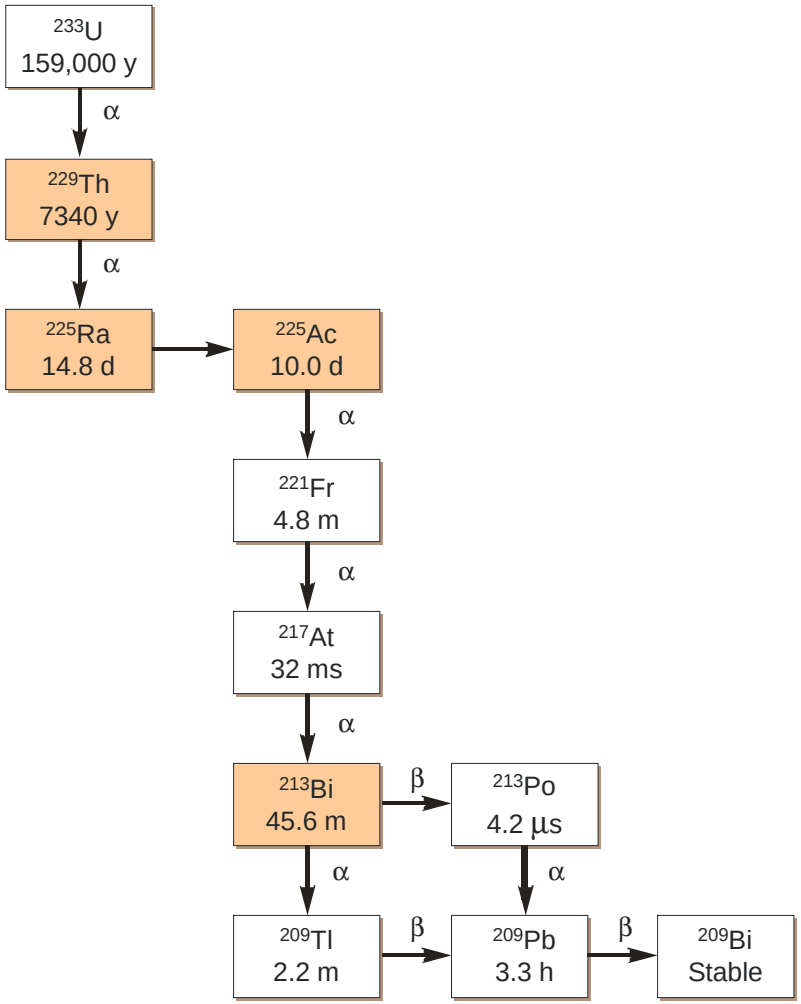
Potential Uses for ^{233}U



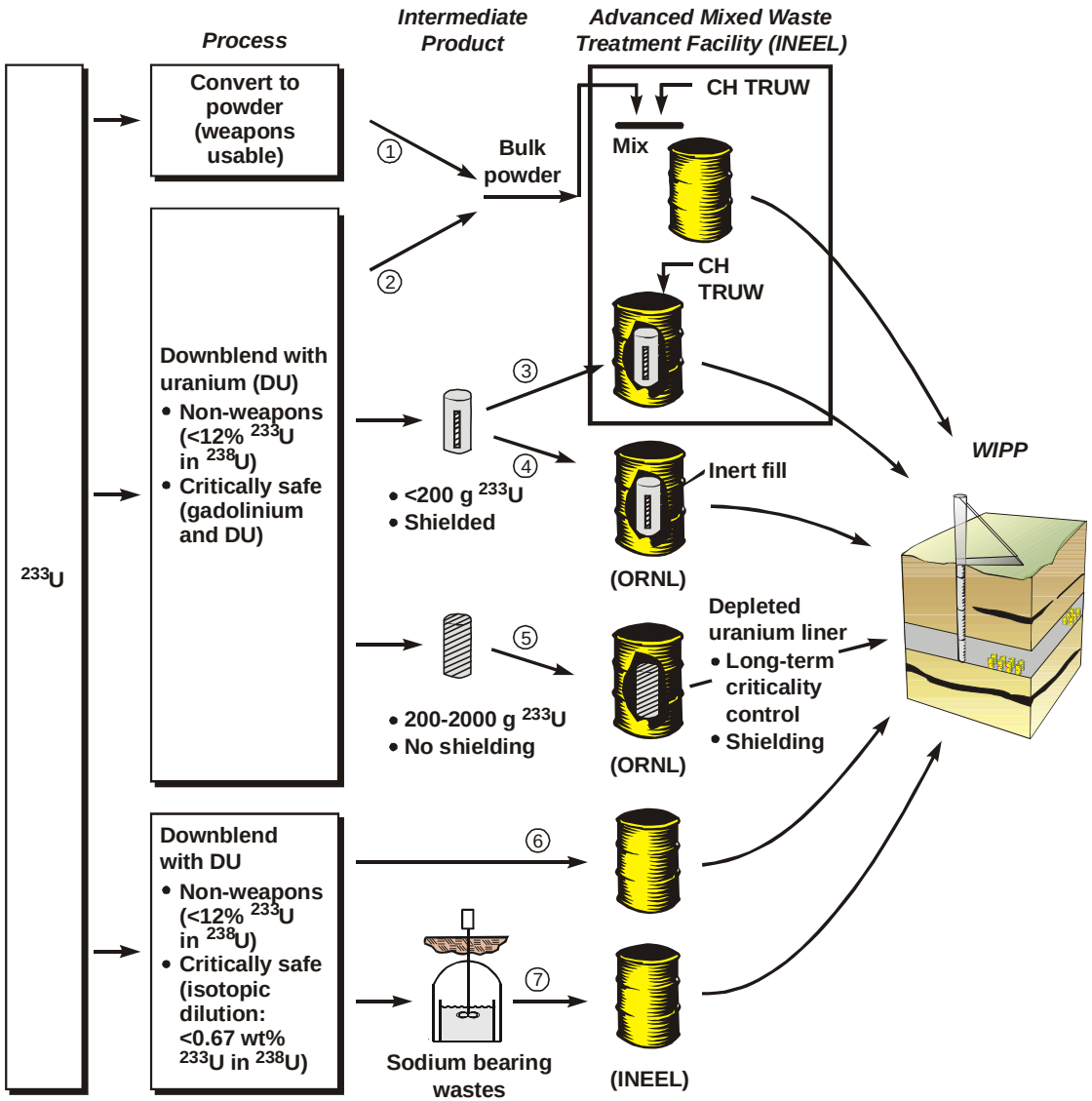
Uranium-233 Uses, Categories, and Potential Inventory Requirements

Use	Acceptable ^{233}U isotopic quality for different applications			^{233}U quantity to be kept
	High	Intermediate	Low	(constraints)
Medical (cancer treatment)	Yes	Yes	Yes	(High cost for 1Th from low-quality ^{233}U)
Proliferation resistant fuel	Yes	Yes	No	(All high-quality ^{233}U is kept, intermediate quality ^{233}U is desirable)
HEU isotopic tag	Yes	Yes	No	~100 kg of high or intermediate quality
Analytical (safeguards, etc.)	Yes	No	No	Small
All others	Yes	No	No	Small

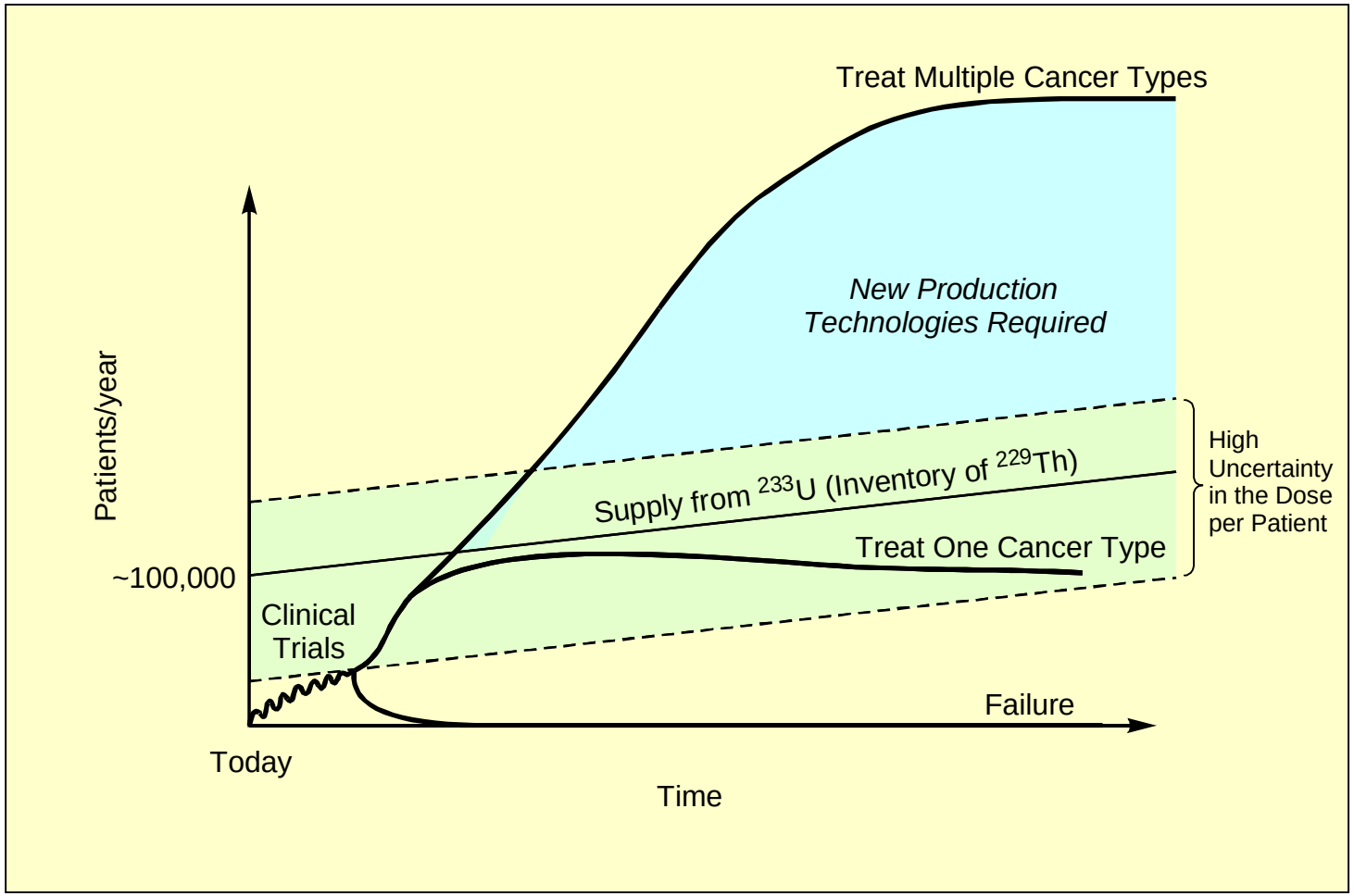
^{233}U Decay Chain



WIPP ^{233}U Processing and Disposition Options

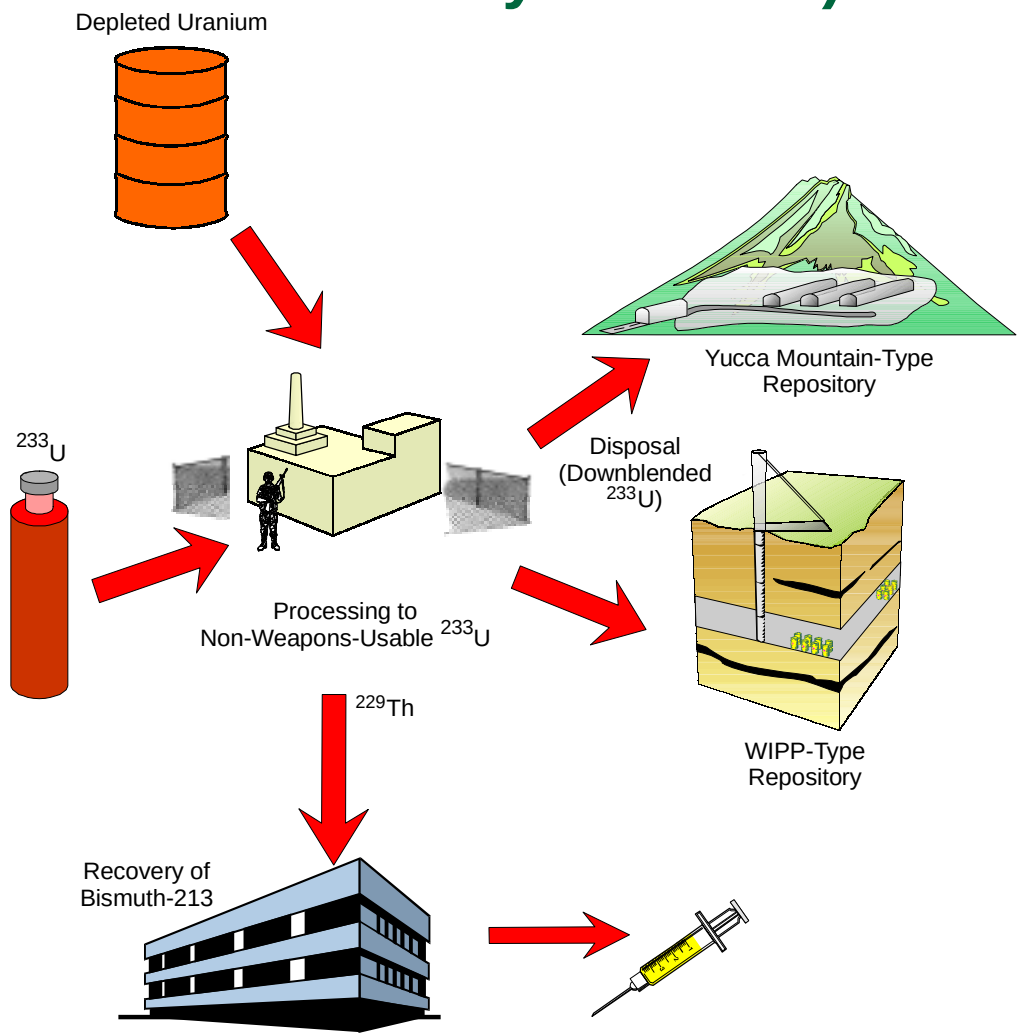


The Demand for ^{213}Bi from ^{233}U for Medical Purposes Depends Upon the Success of Clinical Trials

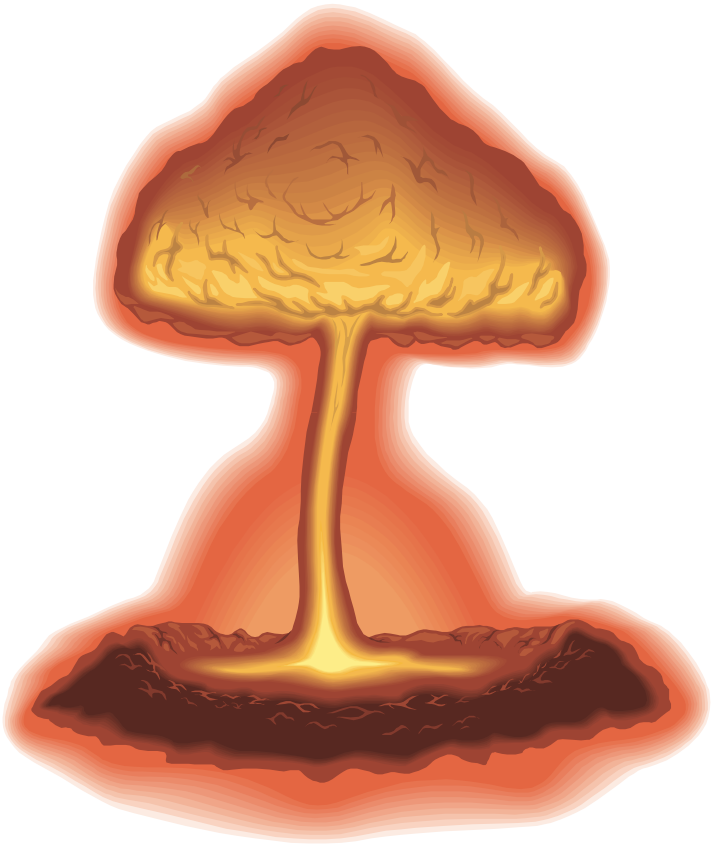


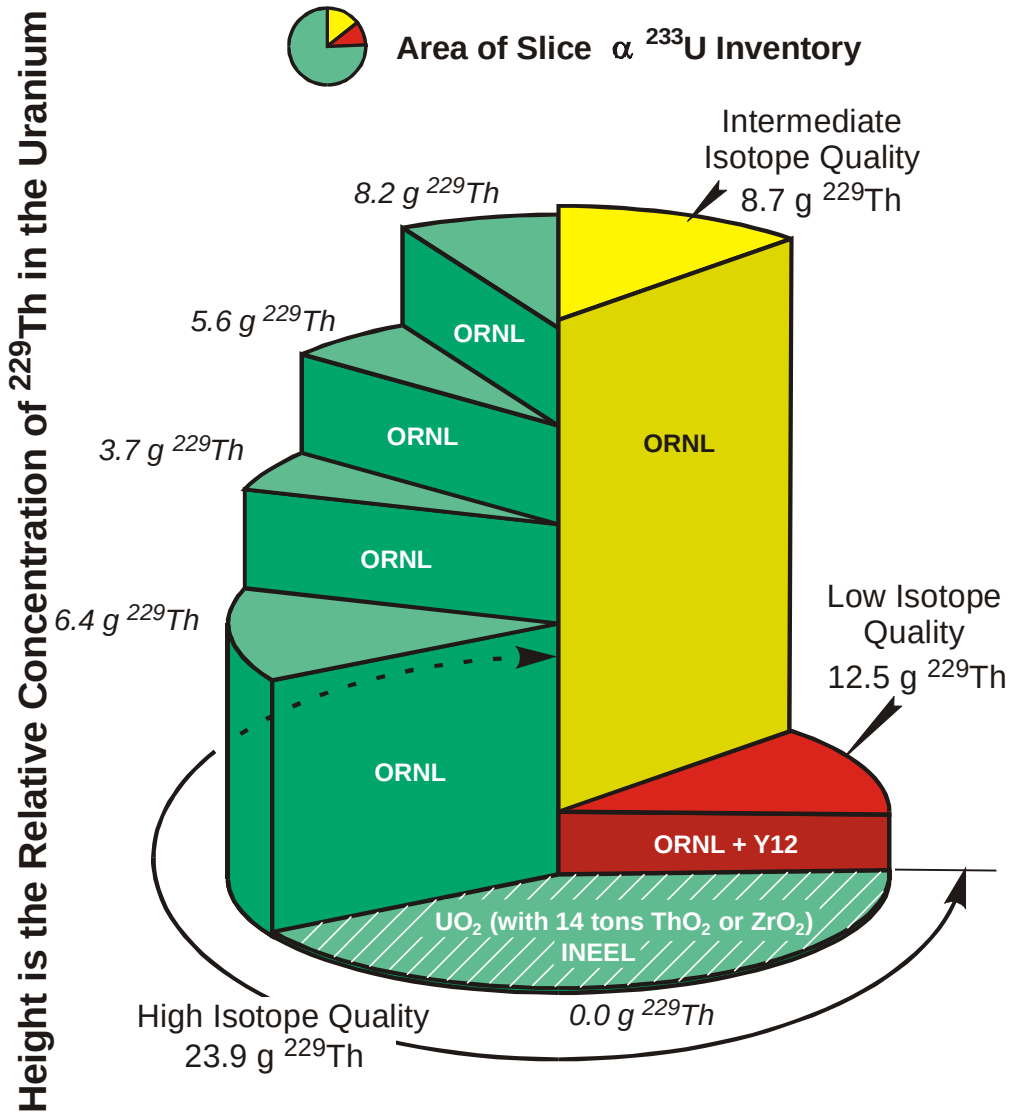
ORNL DWG 2000-92

Some Disposition Options Allow Incremental Low-Cost Recovery of ^{229}Th (Intermediate Product That Decays to ^{213} Bi)



Uranium-233, Like Plutonium and HEU, is a Weapons-Usable Material





Relative Concentrations of ^{229}Th Recoverable From the Separated ^{233}U Inventory