USES FOR ^{233}U

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Outline

- Uranium-233 characteristics and categories
- Replacement cost
- Uses
- Conclusions

Uranium-233 Characteristics And Categories

Key Characteristics Of ^{233}U

- Weapons-usable fissile material (one of three: ^{233}U, ^{235}U, and ^{239}Pu)
- Alpha activity is somewhat less than that of plutonium
- Contains varying levels of ^{232}U impurities from the production process
  - Uranium-232 ($t_{1/2}$ = 72 years) decays to ^{208}Tl
  - Thallium-208 decays, emitting high-energy (2.6 Mev) gamma rays
  - Uranium-232 content determines ^{233}U radiation levels

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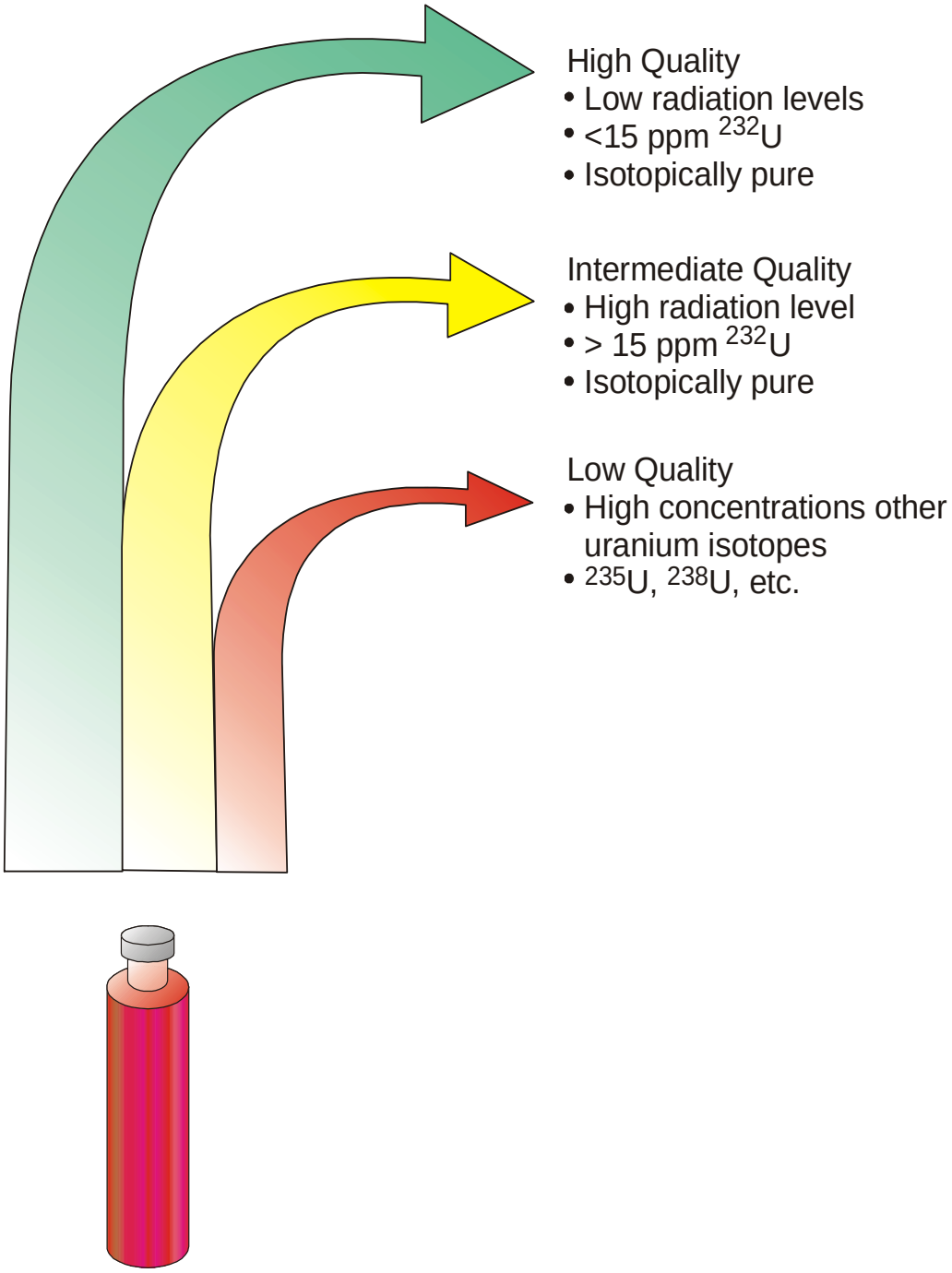

The Uranium-233 Inventory Was Divided Into Three Categories Based on Those Characteristics that Control its Potential Future Usage

When Considering Retain Or Disposition Decisions, The Existing ^{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

Quality Of Major Batches Of Separated ^{233}U In Inventory At Oak Ridge[a,b]

Isotopic quality	Total U (kg)	Isotopics		Uses[c]	
		^{233}U (kg)	^{232}U (ppm)[c]	Medical ^{229}Th (g)	Other
High[a]	269.0	256.3	<15	23.9[c]	Yes
Intermediate	108.0	95.5	>100	8.7	Yes
Low	1,085.2	102.0		12.5	No
Total	1,462.2	453.8		45.1	

[a]For comparison with other weapons-usable materials, the plutonium inventory is ~100 metric tons. The high-enriched uranium (HEU) inventory is several hundred metric tons.

[b]Only the Oak Ridge inventory of ^{233}U is shown. In addition, there is a second high-isotopic-quality ^{233}U inventory at the Idaho National Engineering and Environmental Laboratory (INEEL). The INEEL high-isotopic-quality ^{233}U is from the Light-Water Breeder Reactor Program and contains 351.4 ^{233}U—most of which is in the form of UO_2 mixed with 14 tons of ThO_2. There would be a significant cost to separate the ^{233}U from the thorium to use this material.

[c]As discussed in the following presentation, there are multiple uses for ^{233}U. The medical application is for the use of a decay product of ^{233}U. The quantity of the decay product depends upon how long the ^{233}U has been in storage since it was last purified.

Replacement Costs

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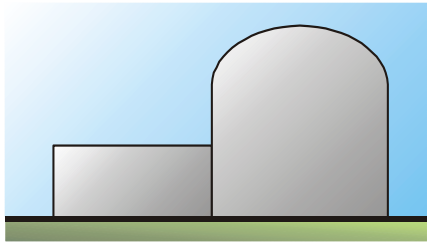
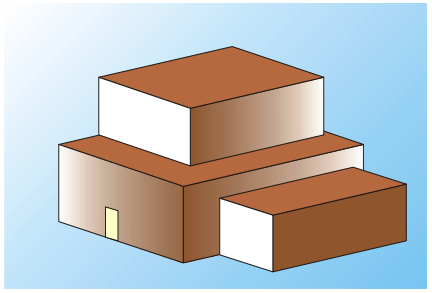
Cold War Capabilities



- Production Capacity: Tons
- Cost: $2–4 million/kg

Today



- Production Capacity: ~0.3 kg/year (Advanced Test Reactor)
- Cost: $30 million/kg

Production Costs for High-Quality ^{233}U are High and Production Capacity is Limited

Costs Of Production

- Historical production costs are estimated at ~$2 to 4 million/kg
- Current production capability is limited and expensive
  - Production capability (Advanced Test Reactor) ~0.3 kg/year
  - Production costs[a] ~$30 million/kg
- Production costs are strongly dependent upon the desired ^{233}U isotopic purity
  - Categorization of inventory is by isotopic-purity levels
  - Chemical purification costs are small compared to differences in production costs for different ^{233}U isotopic-purity levels

[a]Does not include target fabrication, target processing, or waste management.

Uses

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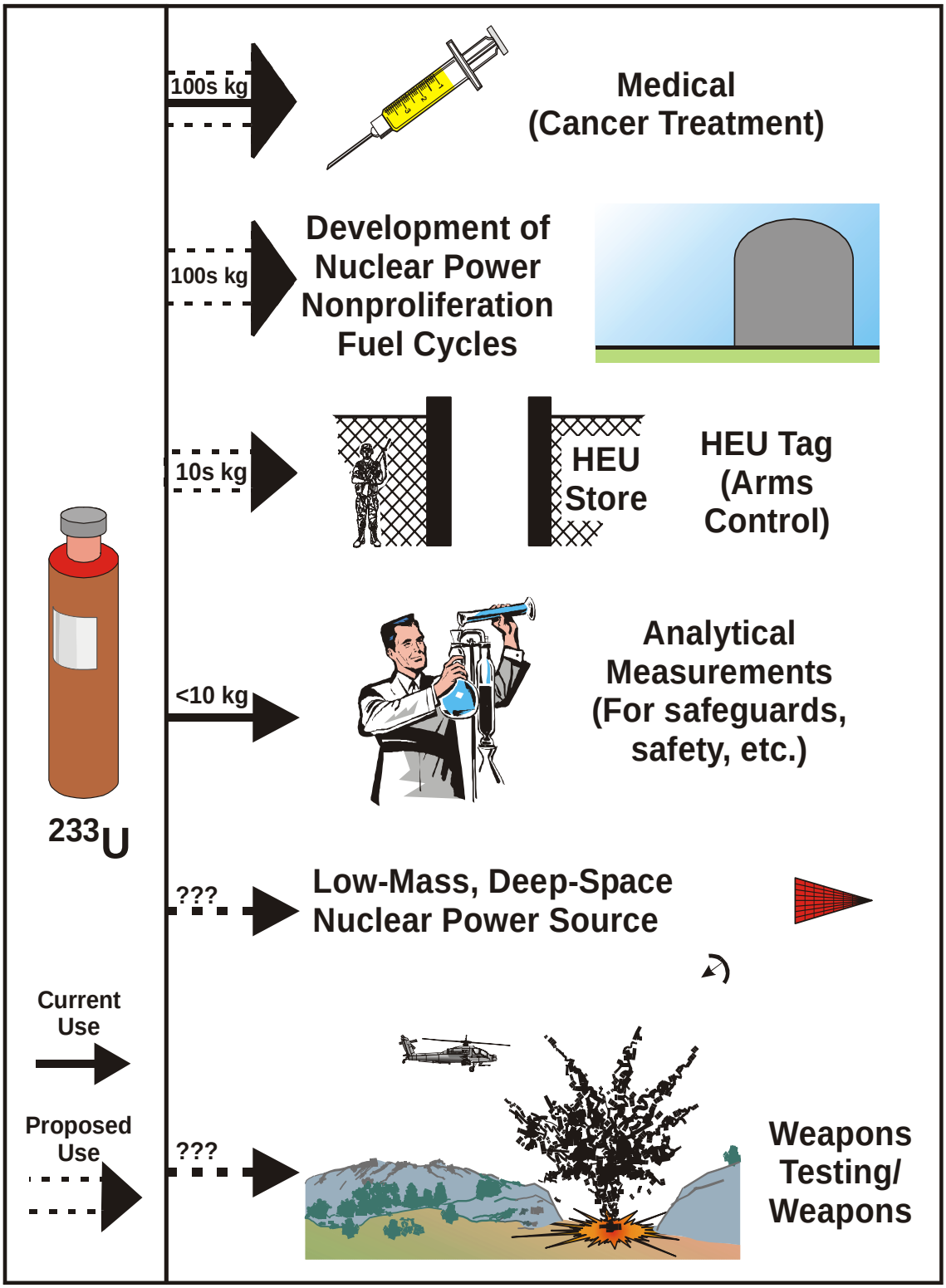

Potential Uses For ^{233}U

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

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

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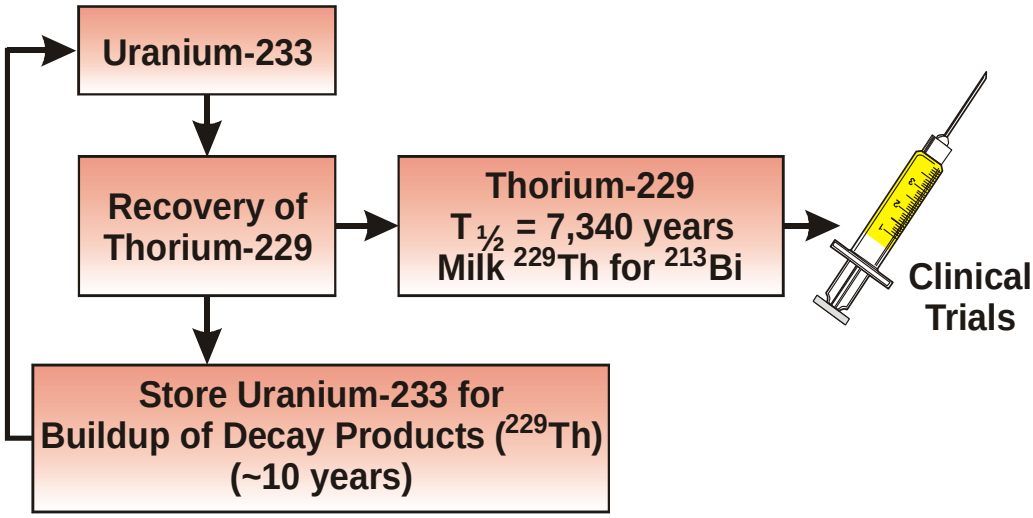
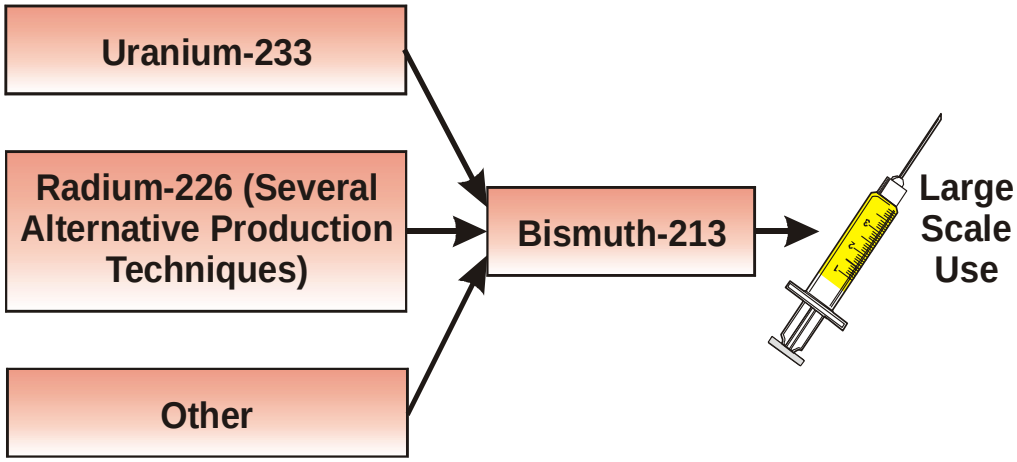
Today = Clinical Trial (Only Existing Production Route)



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



Clinical Trials are Underway Using Bismuth-213 for Treatment of Cancer. Bismuth-213 is a Decay Product of Uranium-233

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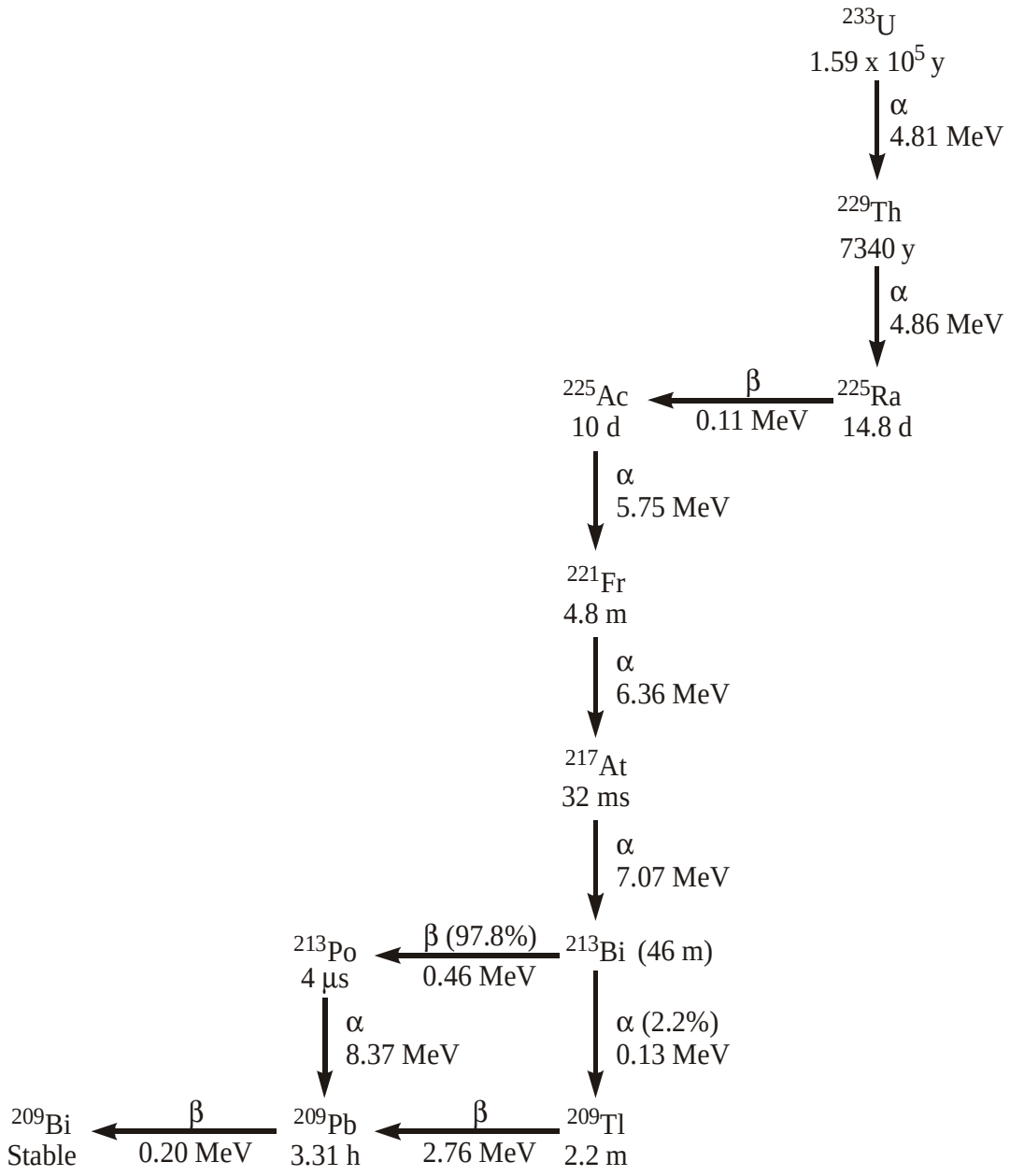

(Average radiation energies are listed for principal modes of decay.)

^{233}U Decay Chain

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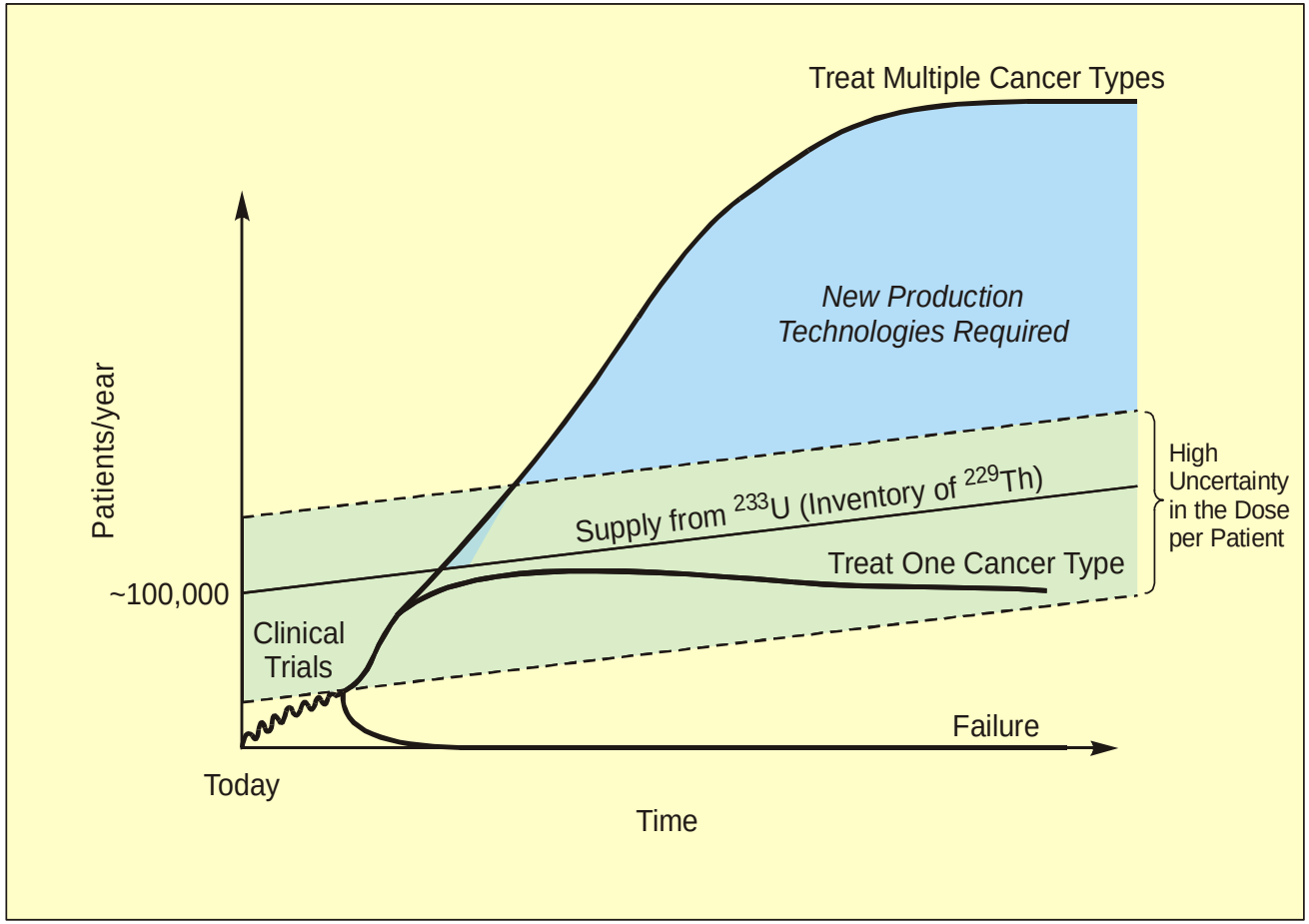

The Demand for ^{213}Bi from ^{233}U for Medical Purposes Depends Upon the Success of Clinical Trials

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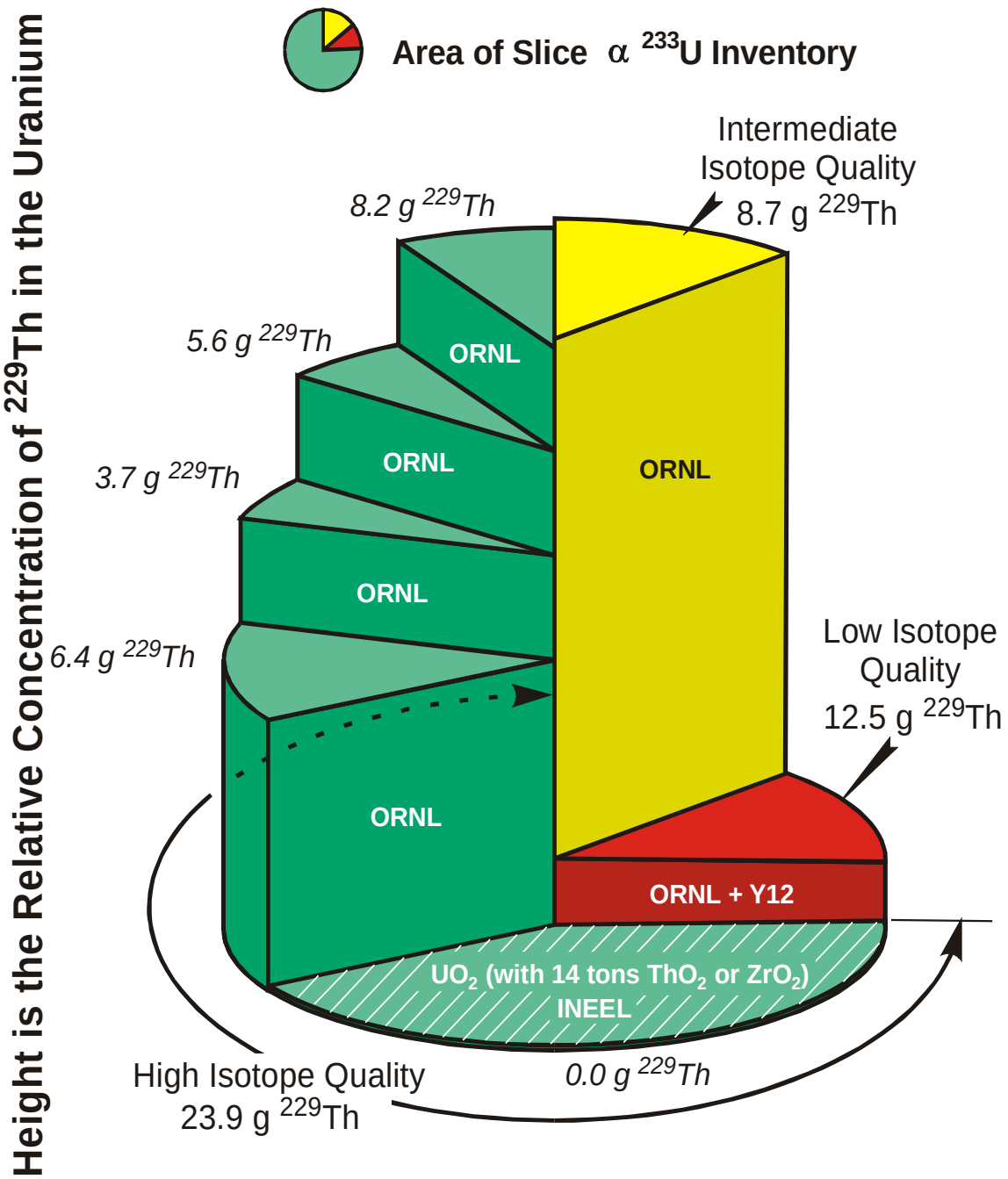

Relative Concentrations of ^{229}Th Recoverable From the Separated ^{233}U Inventory

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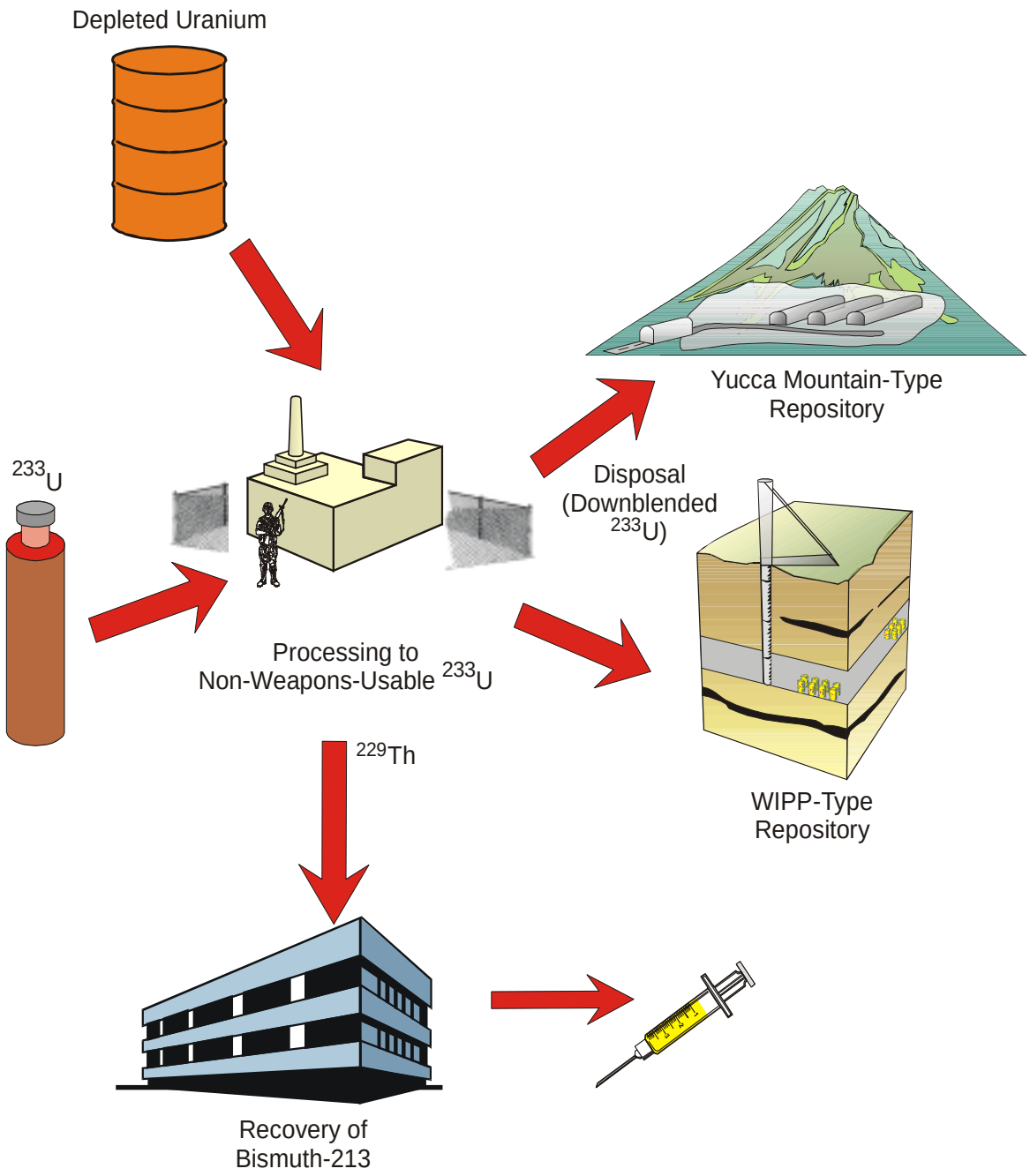

Some Disposition Options Allow Incremental Low-Cost Recovery of ^{229}Th (Intermediate Product That Decays to ^{213}Bi)

Medical Uses Could Use Most Of The ^{233}U Inventory, But There Are Many Medical And Technical Uncertainties

- Bismuth-213 (decay product of ^{233}U) is being used for treatment of cancer in clinical trials (Sloan Kettering Memorial, etc.)
  - Initial results are favorable, but it will be several years before it is known if the ^{213}Bi will become a major medical isotope
  - If successful, the demand for ^{213}Bi would exceed that available in the ^{233}U inventory (significant uncertainty in the dose/patient)
- Uranium-233 is the only existing source of ^{213}Bi
  - Alternative production sources for ^{213}Bi are being developed [if it becomes a successful medical isotope, the demand will exceed the ^{229}Th (^{213}Bi) inventory in the ^{233}U]
  - Relative economics of different production techniques will likely be understood in the next several years
  - Bismuth-213 production costs from ^{233}U are strongly dependent upon the ^{229}Th concentration in the ^{233}U—which is variable[a]

[a]Thorium-229 is recovered from ^{233}U. The ^{213}Bi is then recovered from the 229^{Th}.

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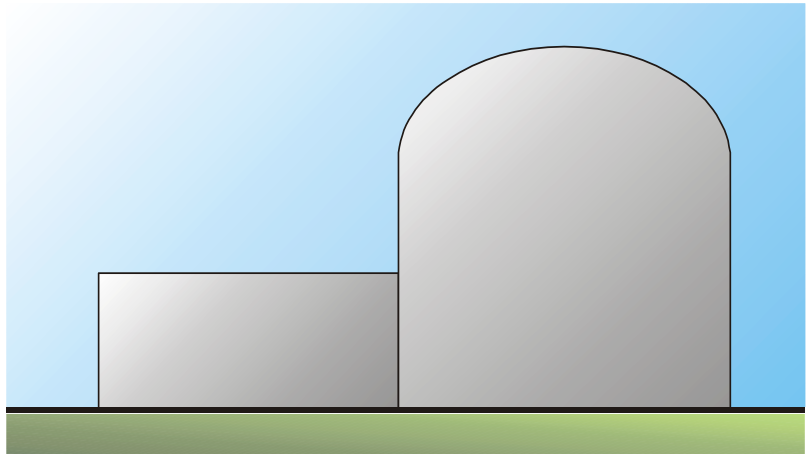
Proliferation-Resistance Mechanisms

Radiation Barrier

- $^{233}U/^{232}Th$ Cycle
- High Radiation Levels (^{232}U)
- No ^{239}Pu

Isotopic Dilution Barrier

- $^{233}U/^{239}Pu/^{238}U/^{232}Th$ Cycle
- Nonweapons = 12 wt % ^{233}U in ^{238}U
- Fuel Cycles Create Some ^{239}Pu



Most Proposed Proliferation-Resistant Nuclear Fuel Cycles Use ^{233}U. If the United State Wants to Maintain the Option to Develop Such Fuel Cycles, High and Intermediate Isotopic Quality ^{233}U Should Be Retained

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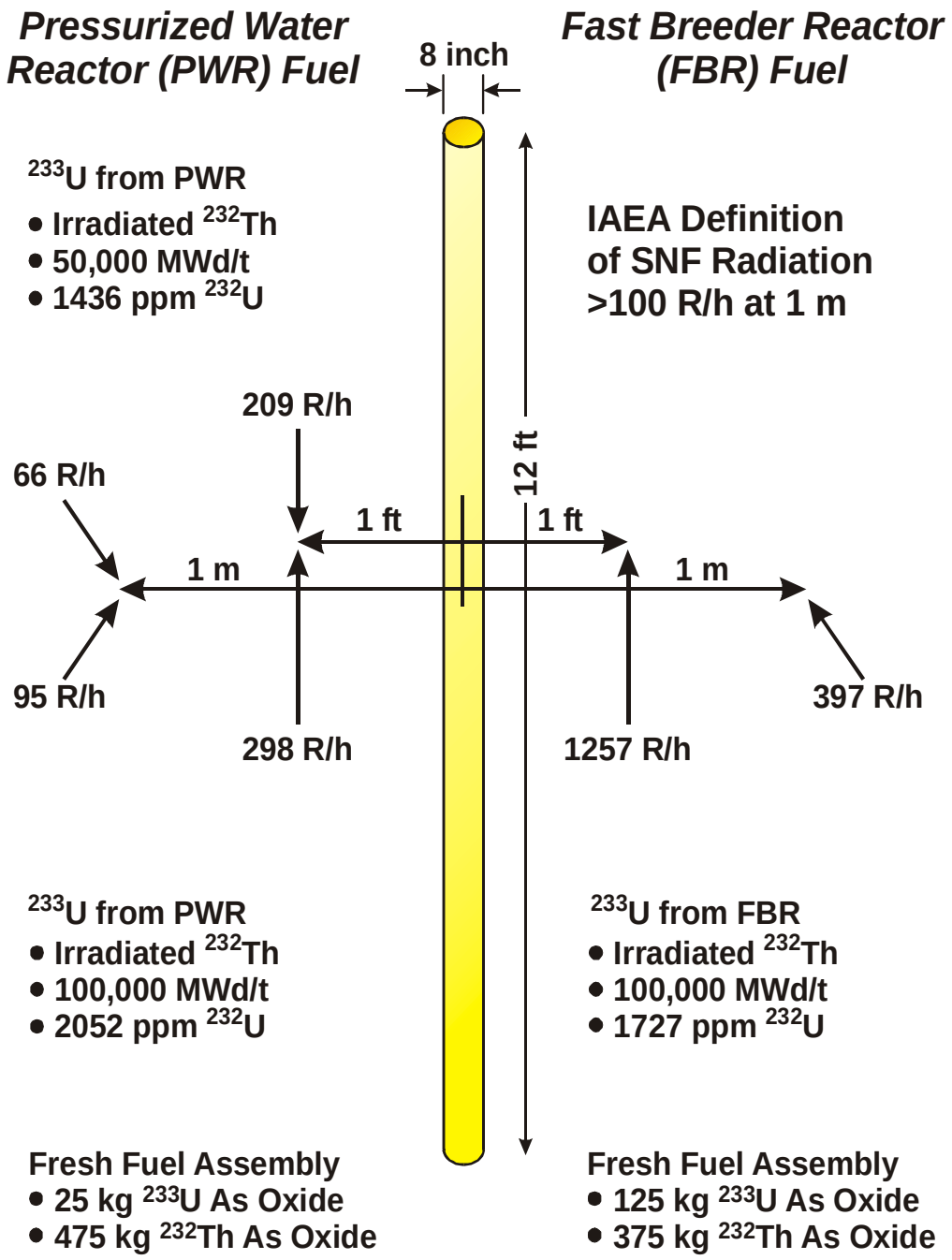

The Maximum Radiation Levels of Fresh Fuel With High-Burnup ^{233}U can be Very High

If The United States Wants To Maintain The Option For Timely Development Of Proliferation-Resistant Fuel Cycles, The Entire Inventory Of High-Isotopic-Quality And Probably All The Intermediate-Isotopic-Quality ^{233}U Should Be Kept

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- Proliferation-resistant fuel cycles (once-through and recycle) are designed to prevent access to weapons-usable materials

- Most proliferation-resistant fuel cycles use a ^{233}U–^{232}Th fuel cycle and one of two methods to prevent fissile material diversion for use in nuclear weapons

  - Radiation barrier: the fuel cycles are designed to build up the ^{232}U impurity during ^{233}U production with resultant very high gamma radiation levels in fresh fuel

  - Isotopic dilution: the ^{233}U can be isotopically diluted with ^{238}U to be non-weapons-usable material (<12 wt % ^{233}U in ^{238}U)

- For this application, the ^{233}U is needed for critical mass experiments and prototype fuel assemblies. Low-isotopic-quality ^{233}U is of little value

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Very-High Burnup, Low-Enriched Uranium—Thorium (^{233}U) Once-Through Fuel Cycles Are Being Investigated For Light-Water Reactors (LWRs). Their Development May Require The Use Of ^{233}U

- There are strong incentives for higher-burnup LWR fuels (economics and less spent nuclear fuel)
- The U.S. Department of Energy/Nuclear Energy, national laboratories, and nuclear fuel fabricators are examining LWR fuels with thorium to address current fuel limitations and nonproliferation concerns
  - The addition of some thorium may reduce uranium consumption in high-burnup fuels
  - Thorium oxides improve fuel physical properties and may address issues such as the rim effect that limits burnup
- The FY 2002 budget includes joint U.S.–Russian programs to examine more proliferation resistant fuel cycles
- For these applications, the ^{233}U would be needed for critical mass and burnup experiments. Low-isotopic-quality ^{233}U is of little value

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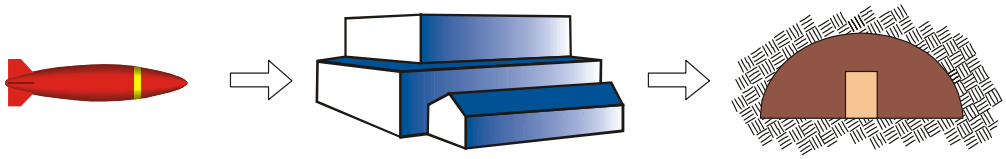
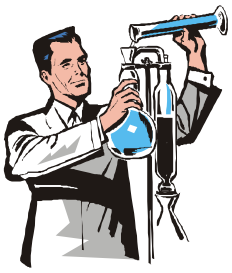
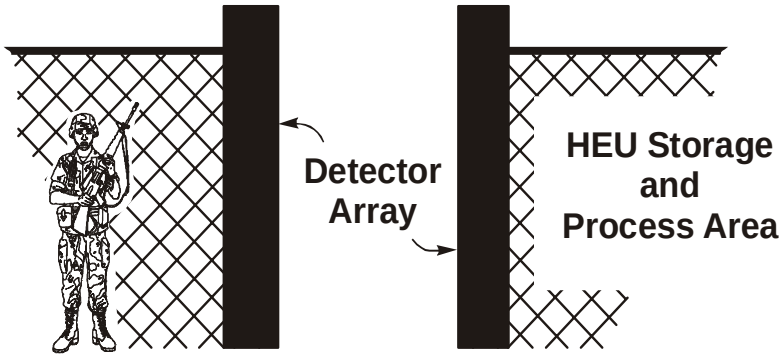
Confirm HEU from the Nuclear Weapon Being Deweaponized is not the Same HEU from Earlier Deweaponization Program (^{233}U Fingerprint)



Identify Source of any Stolen HEU That is Recovered (^{233}U Fingerprint)



Detect Diversion(^{232}U Gamma Signal)



Uranium-233 may be Added in Small Quantities to Highly-Enriched Uranium to Uniquely Tag Individual Lots (Defense Threat Reduction Agency)

Uranium-233 Is Being Evaluated By The Defense Threat Reduction Agency And Others As A Tag For Russian HEU In Storage

- High ^{232}U content (high radiation level) ^{233}U can be added to HEU in very small quantities to increase the gamma signal to be equivalent to that of plutonium. This allows easier detection of diverted HEU passing by portal monitors

- Low ^{232}U content ^{233}U can be used to uniquely identify lots of HEU. Modern analytical techniques can measure 1 part ^{233}U in 10^8–10^9 parts HEU

  - Identify source of any stolen HEU that is recovered

  - Confirm, as part of an arms control agreement, that HEU from a nuclear weapon that is being disassembled is not the same HEU from a nuclear weapon that was disassembled earlier

- Less than 100 kg of high or intermediate ^{233}U would be required

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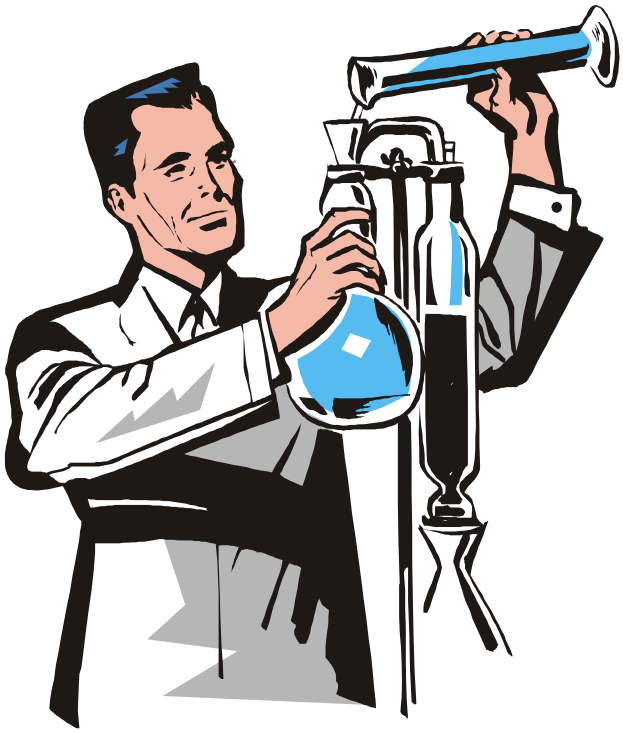

Uranium-233 Is Used In Multiple Analytical Procedures For Safeguards Measurements And Other Purposes. Only Small Quantities Are Used (<<1kg/y)

Uranium-233 Is Used In Certain Analytical Tests To Determine The Quantities Of Uranium In A Sample—A Critical Application

- **Uranium-233 is required for certain safeguards tests used by the International Atomic Energy Agency and other government groups**
- **The quantities required are very small—grams per year**

There Are Several Other Uses But These Do Not Currently Appear To Be Realistic Uses

- For certain space missions, ^{233}U reactors have somewhat lower masses than HEU reactors; but, alpha characteristics of ^{233}U imply greater safety concerns

- Uranium-233 can be used to construct nuclear weapons but the United States is currently committed to plutonium weapons

- Wild cards: Are there unidentified uses?

  — India is producing ^{233}U

  — Other countries have ^{233}U inventories

Conclusions

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)[a]	Yes	Yes	Yes	(high cost for ^{229}Th 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 taggent	Yes	Yes	No	~100 kg of high or intermediate quality
Analytical (safeguards, etc.)	Yes	No	No	Small (<100 kg[b])
All others	Yes	No	No	Small (<100 kg[b])

[a]Half the high-isotopic-quality ^{233}U is at INEEL as unirradiated LWR fuel assemblies and fuel pellets. This ^{233}U is mixed with ThO_2. This is not useful for medical isotope production until the thorium is removed and decay products built up in the ^{233}U.

[b]These three uses together would require maintaining <100 kg if high-isotopic-quality ^{233}U.

The Potential Need For ^{233}U Is Controlled By Three Possible Uses: Medical, Proliferation-Resistant Fuel Cycles, And HEU Taggants.

- **Medical uses of ^{213}Bi (^{233}U decay product) will be known within a few years if sufficient supplies are available for animal and clinical trials**

- **Use of proliferation resistant fuel cycles depend upon policy and economic considerations**

- **Use of HEU tags depends upon arms control policy and actions**

Low-Isotopic-Quality ^{233}U (Half The Total Uranium In Inventory) Is Potentially Useful Only For Medical Applications

- Other applications require relatively pure ^{233}U
- The low-isotopic-quality ^{233}U material has a potentially significant short-term value, but a small long-term value
  - A large quantity of medically useful isotopes are in this material because this ^{233}U has been in storage for many decades
  - The costs of recovery of medically useful isotopes from this material will be higher than from other ^{233}U sources because of the low concentrations of desired isotopes (unless component of disposition processing options)
  - If medical isotopes are recovered, the small quantity of ^{233}U in the low-isotopic-quality material implies slow generation of added medical isotopes