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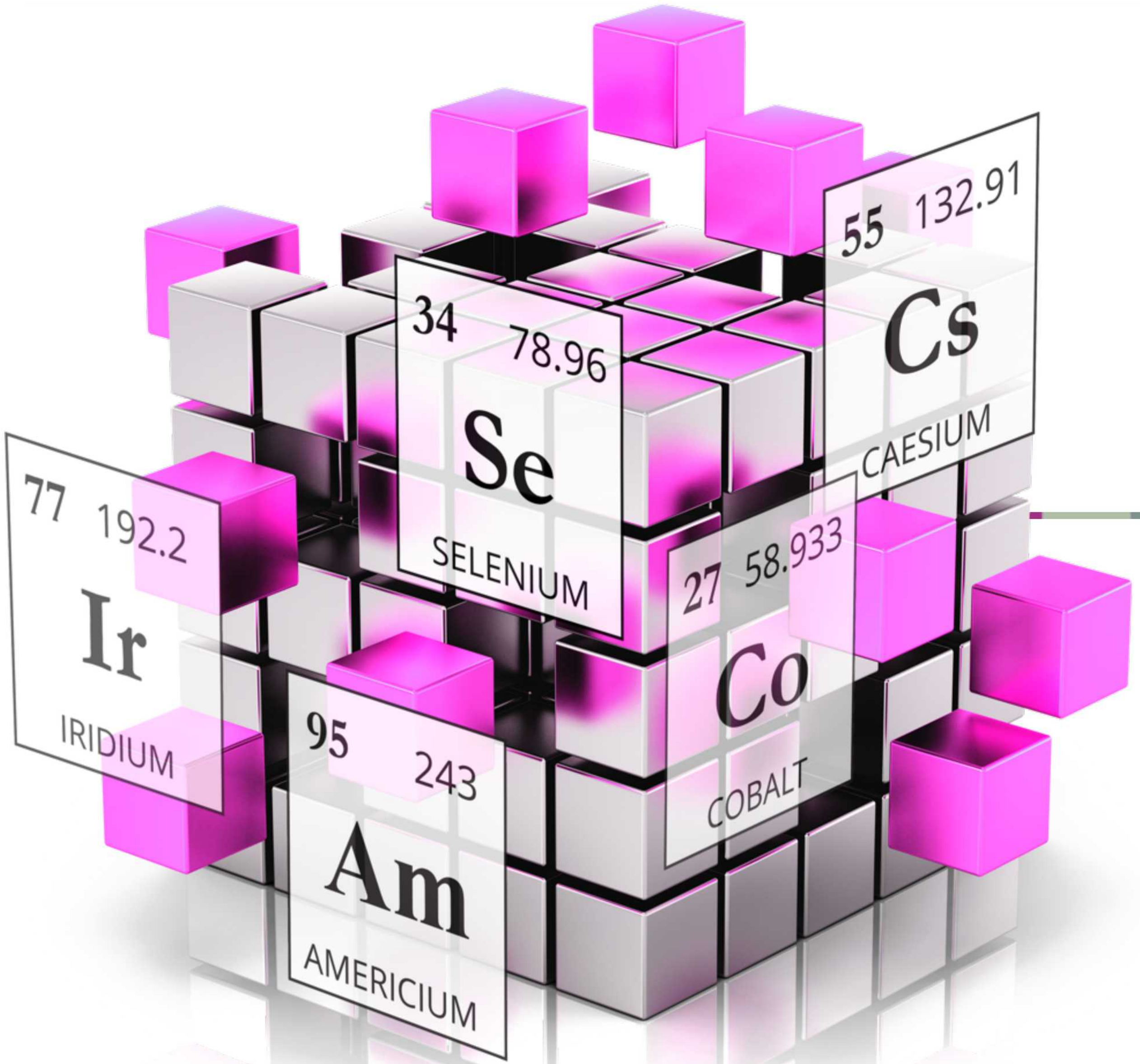

Risk-Based Radioactive Material Downselect Methodology

PRESENTED BY

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OBJECTIVES and SCOPE OF WORK

Objectives	Scope
Revise a step-by-step down-select process Set thresholds/limits for each step Provide justification for each step Generate final list of high-priority radionuclides	The scope of this study is to assess and revise a step-by-step process that identifies radionuclides viable for the development of an RDD/RED that are currently being used in sufficient quantities This process consists of well-defined steps with justifications for assumptions and considerations

RDD vs. RED
Dispersal vs. Exposure

Radiological Dispersal Device **(RDD)**	The combination of radioactive material and the means (whether active or passive) to disperse that material with malicious intent without a nuclear explosion.
Significant Radiological Dispersal Device **(RDD)**	An RDD that could (1) impact national security, national economy, national public health and safety, or any combination thereof, or (2) require a robust, coordinated Federal response to save lives, minimize damage, and/or provide the basis for long-term community and economic recovery. For the purposes of this work, this means a device with a sufficient quantity of radioactive materials to contaminate approximately 1 km^2 (~250 acres, 0.386 square miles) to the Environmental Protection Agency (EPA)/DHS Protective Action Guide relocation guideline of 2 rem in the first year.
Significant Radiological Exposure Device **(RED)**	An object used to maliciously expose people, equipment, and/or the environment to ionizing radiation, without dispersal of the radioactive material, that could cause debilitating injury to people exposed for a period of minutes to hours, or could be fatal to people exposed for a period of minutes to days.

OVERVIEW OF THE DOWNSELECT PROCESS

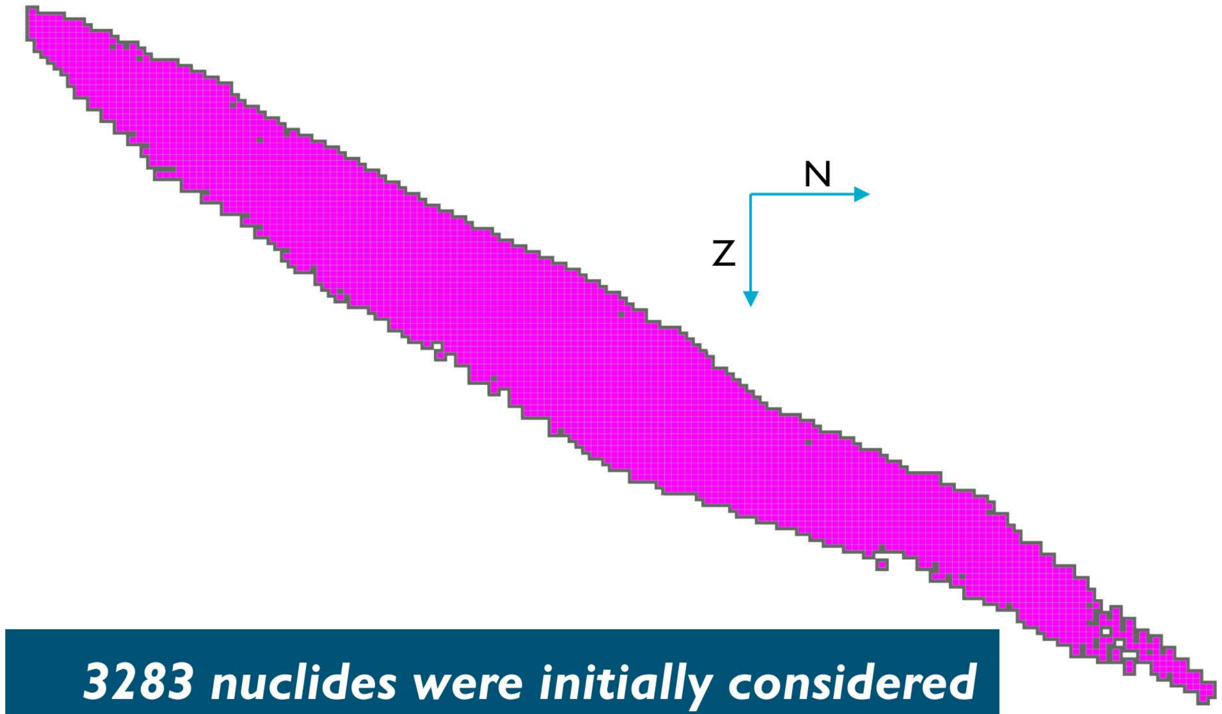
The following steps were taken to generate the final list of high-priority radionuclides:

1. List of All Possible Nuclides
2. Stable vs. Radioactive
3. Half-life Analysis (Short-Lived)
4. Specific Activity Analysis (Long-Lived)
5. Global Production
6. Applications/Use of Radionuclides
7. Categorization of Sources

Step 1:
List of All Possible Nuclides

- Used LiveChart of Nuclides by the IAEA*

- The initial list consisted of 3283 nuclides (through Z=118)



3283 nuclides were initially considered

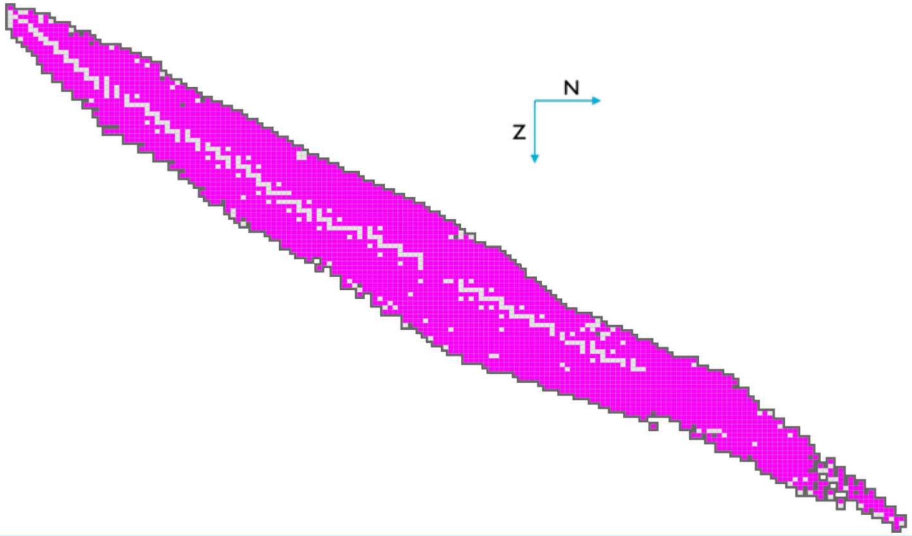
*https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

STEP 2:
Eliminate stable elements vs. radioactive

Examined **3283** nuclides from the *IAEA LiveChart** of nuclides (through Z=118)

We found **245 stable** nuclides

Removed all non-radioactive nuclides and nuclides with unknown half-lives



3038 remaining radionuclides were considered for further investigation in the following step

* https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

STEP 3:
Half-life Analysis (Short-Lived)

Approach:

Generated a histogram showing the number of radionuclides vs. half-life in single-day bins

2555 radionuclides have a half-life shorter than 1 day

Chosen Threshold/Limit:

All radionuclides with half-life shorter than 36 days were removed along with 104 nuclides with unknown half-life

- 1 year is 10 half-lives
- Unknown half-lives are typically too short to measure

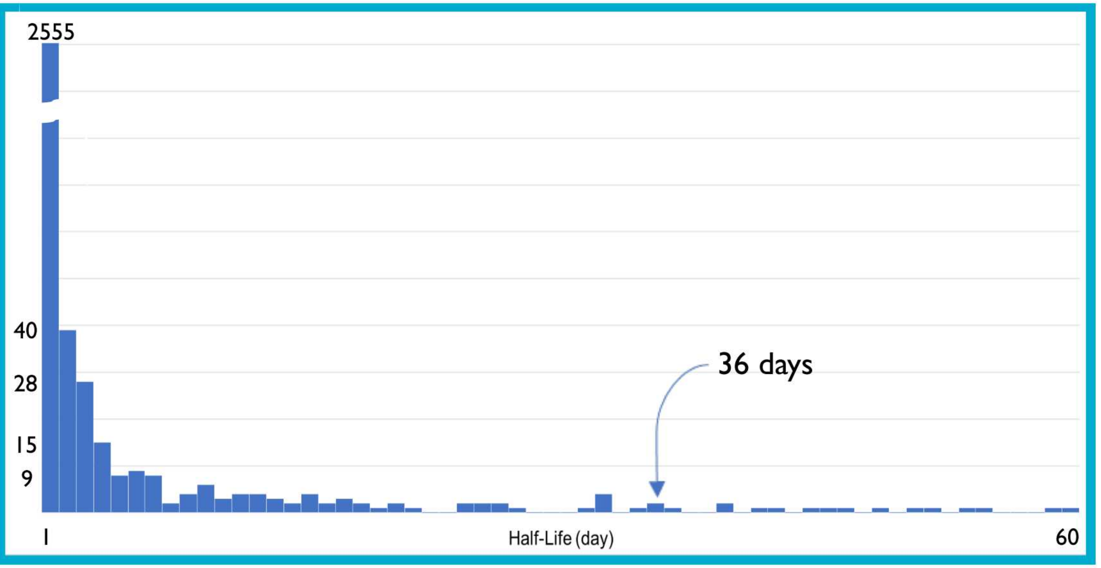
Considerations:

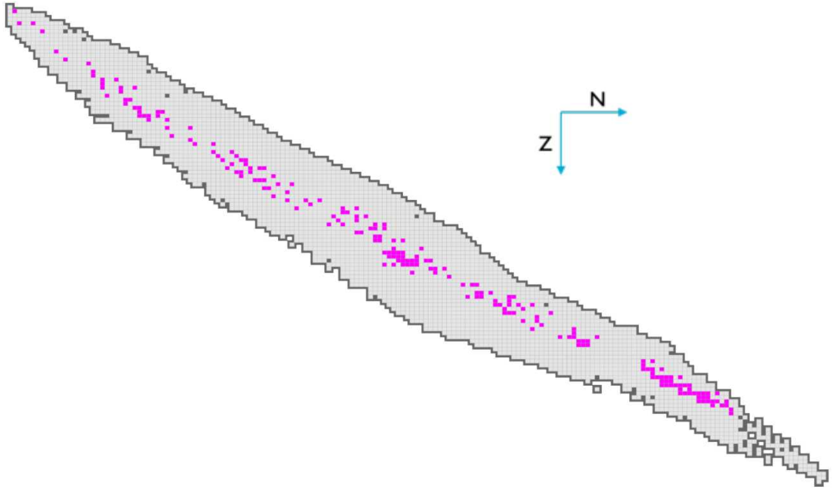
Corresponds with PAG time period (2 rem/year)

All dose will be delivered during that 1st year

More than 85% of the radionuclide will decay within 90 days

Number of Radionuclides vs. Half-Life in days





214 radionuclides remain

STEP 4:
Specific Activity Analysis (Long-Lived)

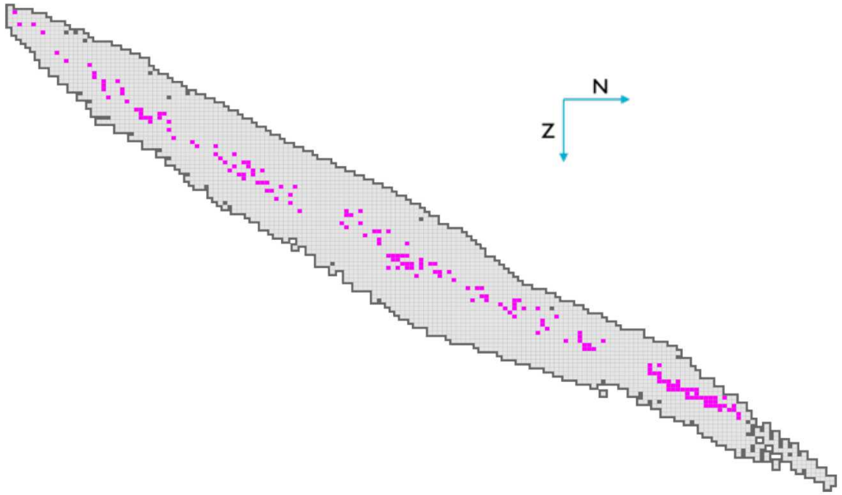
Approach:	Chosen Threshold/Limit:	Considerations:
Calculated specific activity (Ci/g) for all remaining radionuclides Used mass per curie to set limit	All radionuclides with weight per curie greater than 45kg (100 lbs) were removed Equivalent to removing all radionuclides with specific activity lower than 2.2×10^{-5} Ci/g (half-life > 6.8×10^{7} years)	Shielding and/or other materials to be stolen will increase weight to greater than 45kg (100 lbs) Difficult to produce or extract considering the required equipment and knowledge

Mass similar to the objects in images:

image: http://1.bp.blogspot.com/-sT7ZvHWBQJ8/VcJgL2eop6I/AAAAAAAABTQ/00OkYbzkyaA/s1600/download%2B%25281%2529.jpg

image: http://2.bp.blogspot.com/-HnOcLBodeaY/VcJisG20t-I/AAAAAAAABTk/xCfROi_WarY/s1600/download%2B%25283%2529.jpg

image: http://seesheilashrink.blogspot.com/2015/08/things-that-weigh-100-pounds.html



173 radionuclides remain

RECAP

Half-life (days)

3.3×10^{-27}, 4.3×10^{-27} …

1.5×10^{-37}, 1.6×10^{-37} …

Only radionuclides with a half-life longer than 36 days and a mass per curie less than 45 kg are considered for further analysis.

… 2.1×10^{25}, 2.8×10^{27}

… 2.2×10^{16}, 2.8×10^{18}

Mass per curie (kg)

36 …

173 RADIONUCLIDES

… 45

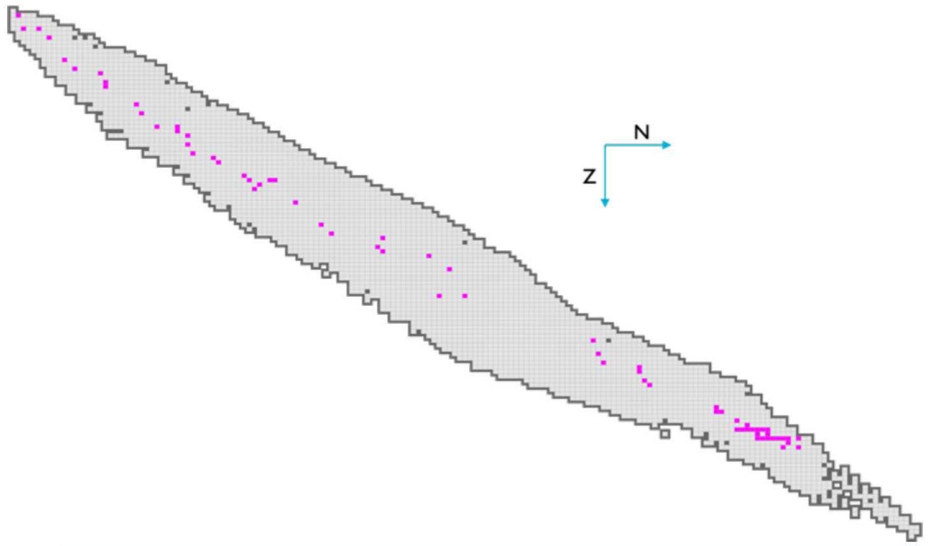
STEP 5:
Global Production

Approach:

Down-selected all radionuclides that are not being produced globally

The data on radionuclide production was collected by reviewing:

- All radionuclides produced by research reactors worldwide (IAEA registry)
- Published literature on radionuclide production via cyclotrons globally
- Published literature on medical radionuclide production in the US and other countries
- All radionuclides available for purchase in the United States



66 radionuclides remain

STEP 6:
Consider applications and uses for identified radionuclides

Approach:

Only radionuclides with known medical or industrial use were considered

- i.e., within a device, radiopharmaceutical

https://www.itnonline.com/sites/itnonline/files/styles/content_large/public/X0000_Elekta.Leksell.Gamma_.Knife_.Icon__3.jpg?itok=CEUIcpEg

http://www.theratronics.ca/images/productPics/Raycell_Mk1.jpg

http://www.meditelhealthcare.com/shimadzu-angiography-in-6-different-private-hospitals-in-antalya

39 radionuclides remain

39 Radionuclides Remain

- ^{75}Se
- ^{3}H
- ^{90}Sr
- ^{7}Be
- ^{88}Y
- ^{207}Bi
- ^{14}C
- ^{99}Tc
- ^{227}Ac
- ^{22}Na
- ^{109}Cd
- ^{234}U
- ^{26}Al
- ^{113}Sn
- ^{238}Pu
- ^{36}Cl
- ^{124}Sb
- ^{241}Am
- ^{55}Fe
- ^{125}I
- ^{244}Cm
- ^{59}Fe
- ^{127}Xe
- ^{242}Cm
- ^{60}Co
- ^{137}Cs
- ^{252}Cf
- ^{63}Ni
- ^{153}Gd
- ^{89}Sr
- ^{65}Zn
- ^{188}W
- ^{85}Sr
- ^{68}Ge
- ^{192}Ir
- ^{239}Pu
- ^{73}As
- ^{195}Au
- ^{203}Hg

STEP 7: THE FINAL CUT

Typical Quantities Used

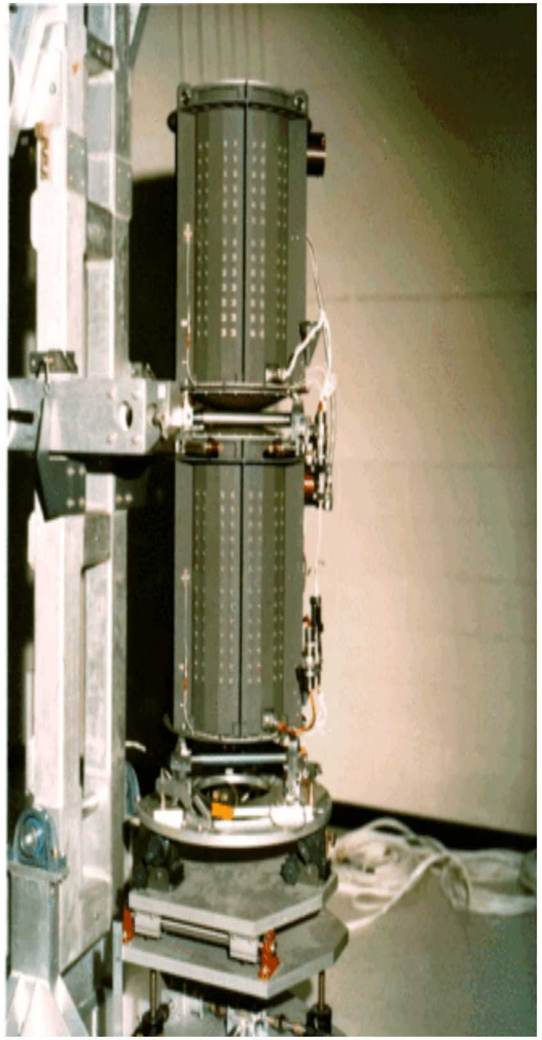
Approach:	Considerations:
Power to contaminate values based on 2 rem PAG and IAEA D-values were used to set thresholds	8 radionuclides were used in quantities that fall within Category I and 2 limits
• Comparison to the 500 mrem 2nd-year PAG was also performed.	^{90}Sr, ^{238}Pu, and ^{244}Cm were only used in RTGs and therefore removed
Radionuclides that only made the cut for their use in RTGs were not considered	Analysis of radionuclides used at high levels of Category 3 values did not add any new radionuclides to the list
Radionuclides used at high IAEA Category 3 values were also considered	

^{60}Co ^{75}Se ^{137}Cs ^{192}Ir ^{241}Am

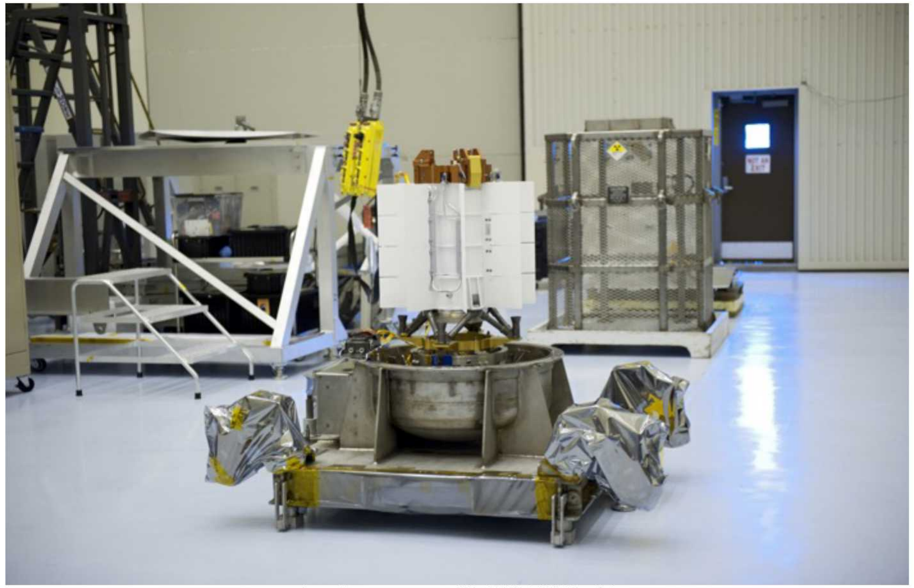
5 radionuclides remain

Radioisotope Thermoelectric Generators (RTGs)

All RTGs are either decommissioned or highly secured by the US Government



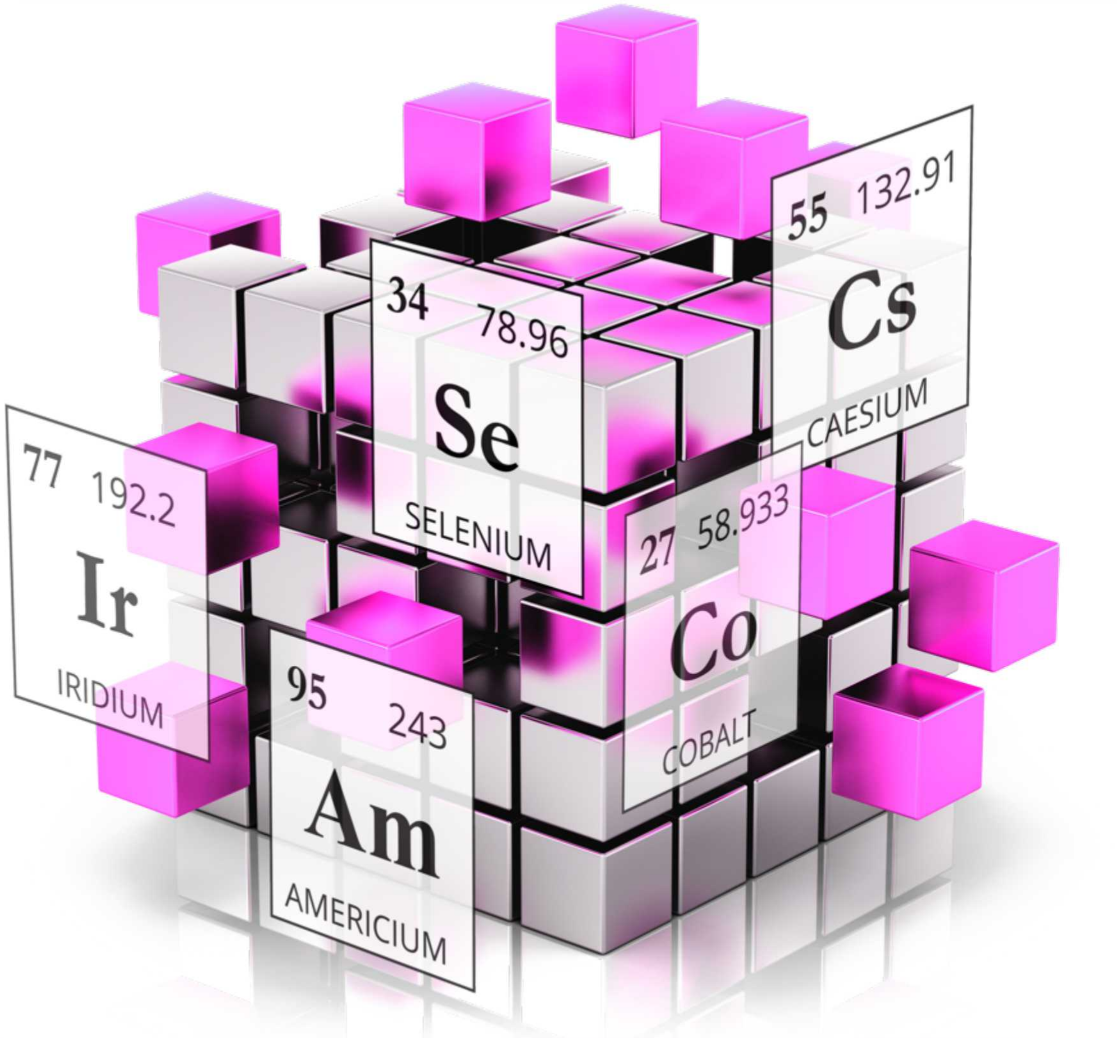
https://en.wikipedia.org/wiki/File:MHW-RTGs.gif



https://images.app.goo.gl/Mo5PNL7z4UViGaqF7

https://network.bellona.org/content/uploads/sites/3/2015/06/5003f6d66f768ba226892ed26e6da8a01-300x225.jpeg

FINAL RESULTING LIST



		Co-60	Se-75				Cs-137		Ir-192			Am-241		

SUMMARY

This study provides a reproducible method to identify which radionuclides are currently being used in quantities suitable for an RDD/RED

Five high priority radionuclides were identified

Full Recap	
Remaining Nuclides	Steps
3283	Step 1: List all possible nuclides
3038	Step 2: Remove stable nuclides
214	Step 3: Identify short-lived radionuclides for removal
173	Step 4: Identify long-lived high specific activity radionuclides for removal
66	Step 5: Determine extent of global production of remaining radionuclides
39	Step 6: Account for application or use of radionuclides
5	Step 7: Identify amount of source material used in application

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Thank You