Reprocessing in the U.S.: Just Say No

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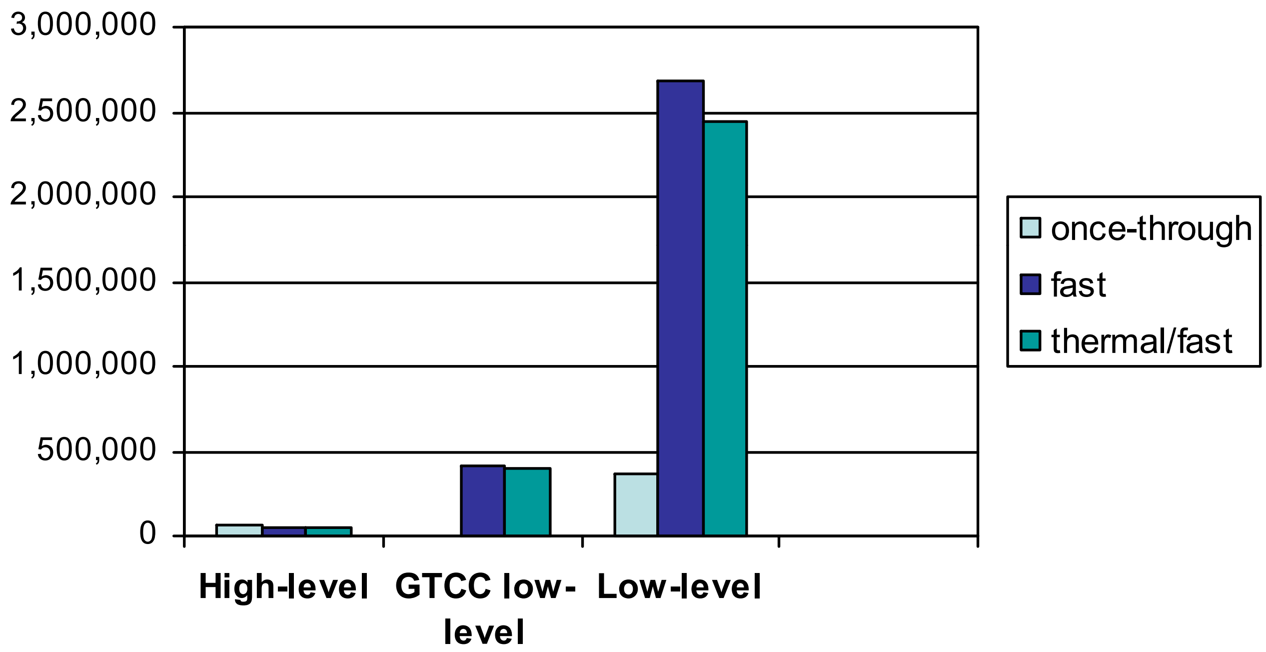
CONTEXT

- 2006: Global Nuclear Energy Partnership (GNEP)
  - Near-term, government-financed construction of commercial-scale fuel cycle facilities with reprocessing and fuel fabrication capabilities, as well as reactors to utilize reprocessed fuel
- Congress: scales back GNEP to R&D only
- April 2008: AREVA letter expressing interest in building a “used fuel recycling center” in the United States
- 2009: Redirection:
  - Obama Administration cancels GNEP program and NEPA process; refocuses on long-term, “science-based” R&D
  - But various approaches to facilitate near-term reprocessing are attempted in Congress, spurred on by lobbying by industry and national labs

REPROCESSING: DIRTY, DANGEROUS AND EXPENSIVE

- UCS opposes any approach that would move the US away from a strategy of direct disposal of spent fuel
- Reprocessing is
  - ***Dirty***: according to Argonne National Laboratory data, for the fast reactor "recycle" option with Cs/Sr removal, after 50 years
    - Cumulative volume of all waste 7 times that of direct disposal option
    - Cumulative volume of greater-than-class C low-level waste is about 160 times greater than that of direct disposal option
    - Volume of reprocessed uranium comparable to volume of spent fuel
    - High-level waste volume only 25% less than initial spent fuel volume
  - ***Dangerous***: can separate thousands of bombs' worth of strategic special nuclear material per year; so-called "proliferation-resistant" modifications of reprocessing have been shown to be essentially worthless
  - ***Expensive***: Argonne estimates reprocessing alone could cost 4-6 mils per kWh per year, or about $4 billion per year to reprocess the current U.S. spent fuel output; DOE estimated that a reprocessing and "recycle" system would cost hundreds of billions more than direct disposal

50-YR CUMULATIVE WASTE GENERATION



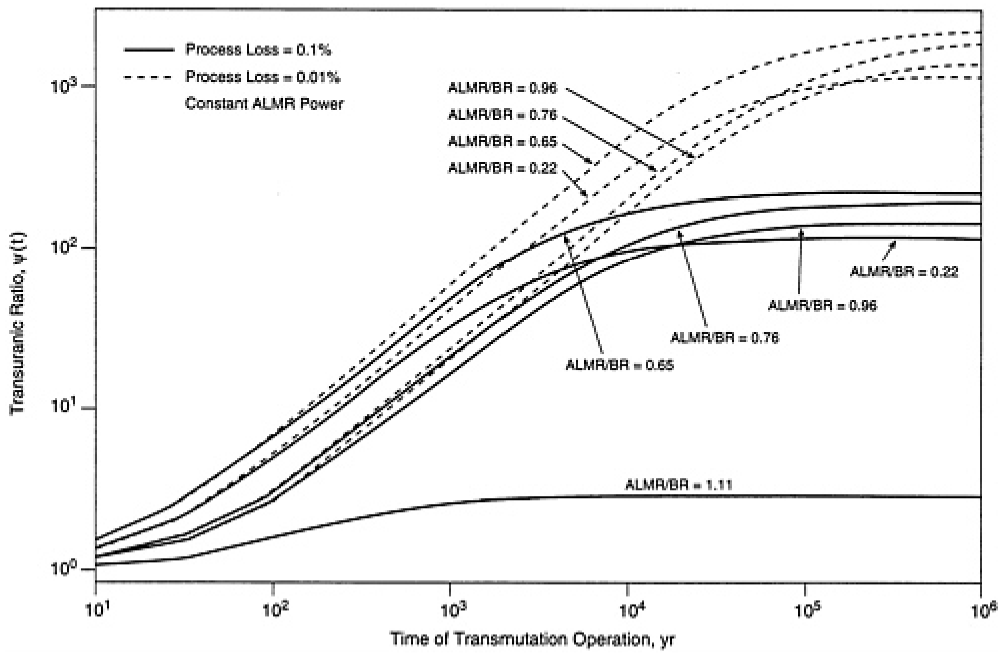
WHAT ABOUT THE TRANSURANICS (TRUs)?

- Inventories of separated plutonium and other transuranic elements (TRUs) must be also be regarded as waste if they cannot be effectively fissioned in reactors
- In 1996, the National Academy of Sciences assessed the feasibility of "separations and transmutation systems" to significantly reduce the quantity of TRUs in the nuclear fuel cycle relative to the once-through cycle
  - $\psi(t)$ = "TRU ratio"

    = ratio of once-through TRU inventory at time *t* to total TRU inventory in transmutation system (transmuter, fuel fabrication plants, spent fuel storage, process wastes)
- Report calculated $\psi(t)$ for a variety of transmutation scenarios, as a function of breeding ratio (BR) and process loss to waste

TRU INVENTORY REDUCTIONS
(from NAS STATS Report, 1996)

- Constant power scenario



"RECYCLING": TOO EXPENSIVE AND TIME-CONSUMING

- NAS conclusions:
  - A fast reactor system with 0.65 breeding ratio [0.5 TRU conversion ratio] to reprocess 62,000 t of LWR spent fuel and transmute the resulting TRUs under a declining nuclear power scenario would cost some $500 billion and require approximately 150 years to accomplish the transmutation
  - "Merely developing, building and operating the individual components of the system would give little or no benefit. To have a real effect, an entire system of many facilities would be needed in which all the components operate with high reliability in a synchronized fashion for many decades or centuries … the magnitude of the concerted effort and the institutional complexity … are comparable to large military initiatives that endure for much shorter periods than would be required …"
- UCS conclusion: reprocessing and transmutation schemes are not consistent with the intergenerational equity principle

DOE GNEP ECONOMIC ASSESSMENT

- A report by a DOE economist confirms the NAS picture (Matthew Crozat, "Evaluating the Economics of GNEP Deployment, January 8, 2007)
  - Assumptions:
    - DOE growth scenario (6-fold increase in nuclear power by 2100)
    - TRU conversion ratio of 0.5
  - Results:
    - "49% reduction in the mass of transuranics at year 100"
    - "over a third of the transuranics are tied up in the … fuel cycle"
    - Additional cost of $750 billion relative to direct disposal
- If operation of the system cannot be assured after 100 years, then the residual transuranics should be regarded as waste
  - Would require 6 Yucca Mountain-type repositories

REPROCESSING DOESN'T NEED A HELPING HAND

- New reprocessing regulations
  - should ensure that no reprocessing plant is built in the US unless there is sufficient protection against its exceptionally high safety, security and proliferation risks
  - should not facilitate licensing of inadequately safe and secure reprocessing technologies just because the industry can't do better

“GAP ANALYSIS”

- In SECY-09-0082, NRC has identified a number of high priority issues related to regulation of reprocessing, including
  - Definition of “reprocessing” and “recycling”
  - “Risk-informing” physical protection and material control and accounting (MC&A) rules for reprocessing plants

  …but NOT addressing the risks of other weapon-usable materials (Am, Np)

“RECYCLING” vs. REPROCESSING

- Reprocessing alone is NOT “recycling”
  - Generates separated plutonium and reprocessed uranium, most of which is not re-used today
- Applicants seeking a license for a “recycling” facility
  - Should be required to demonstrate that there are committed customers for all SNM that is separated
  - should have strict limits imposed on the amount of separated SNM that can be stored on site
- Will avoid large decommissioning liabilities associated with disposition of unwanted plutonium and reprocessed uranium
- Lack of “waste confidence” for all reprocessing effluents

“RISK-INFORMING” CAT I MPC&A STANDARDS?

- Gap analysis: reprocessing plants should be classified as Cat I facilities …
  - But Category I standards themselves should be weakened because they “may pose and undue regulatory burden for reprocessing facility licensees”
- There is no technical basis for a weakening of Cat I standards for any reprocessing technology presently identified

"PROLIFERATION RESISTANCE" DOESN"T EXIST

- Some argue that modified reprocessing techniques that do not separate "pure plutonium" such as COEX (50 Pu – 50 U) or pyroprocessing (Pu + U minor actinides + certain lanthanides) are "proliferation-resistant" and therefore do not need to be protected as Category I
- However, the December 2008 NNSA GNEP Nonproliferation Impact Assessment has determined that all of these alternatives "present comparable proliferation risks" and are considered to be Category I nuclear material under current DOE and NRC guidelines
- This determination should not to change even if NRC adopts an SNM categorization table and grades materials according to "attractiveness"
  - Pu will have to be diluted in U well below the 50-50 COEX mixture to reduce its attractiveness level
  - Np and Am must be considered strategic SNM

SELF-PROTECTION OF PYROPROCESSING

Electro-refining: The Best for Proliferation Resistance

	Weapon Grade Pu	Reactor Grade Pu	Electro-refining
Production	Low burnup PUREX	High burnup PUREX	✓ Fast reactor Pyroprocess
Composition	Pure Pu 94% Pu-239	Pure Pu 65% Pu-fissile	✓ Pu + MA + U 50% Pu-fissile
Thermal power (w/kg)	2 – 3	5 – 10	✓ 80 – 100
Spontaneous neutrons (n/s/g)	60	200	✓ 300,000
Gamma radiation (r/hr at ½ m)	0.2	0.2	✓ 200

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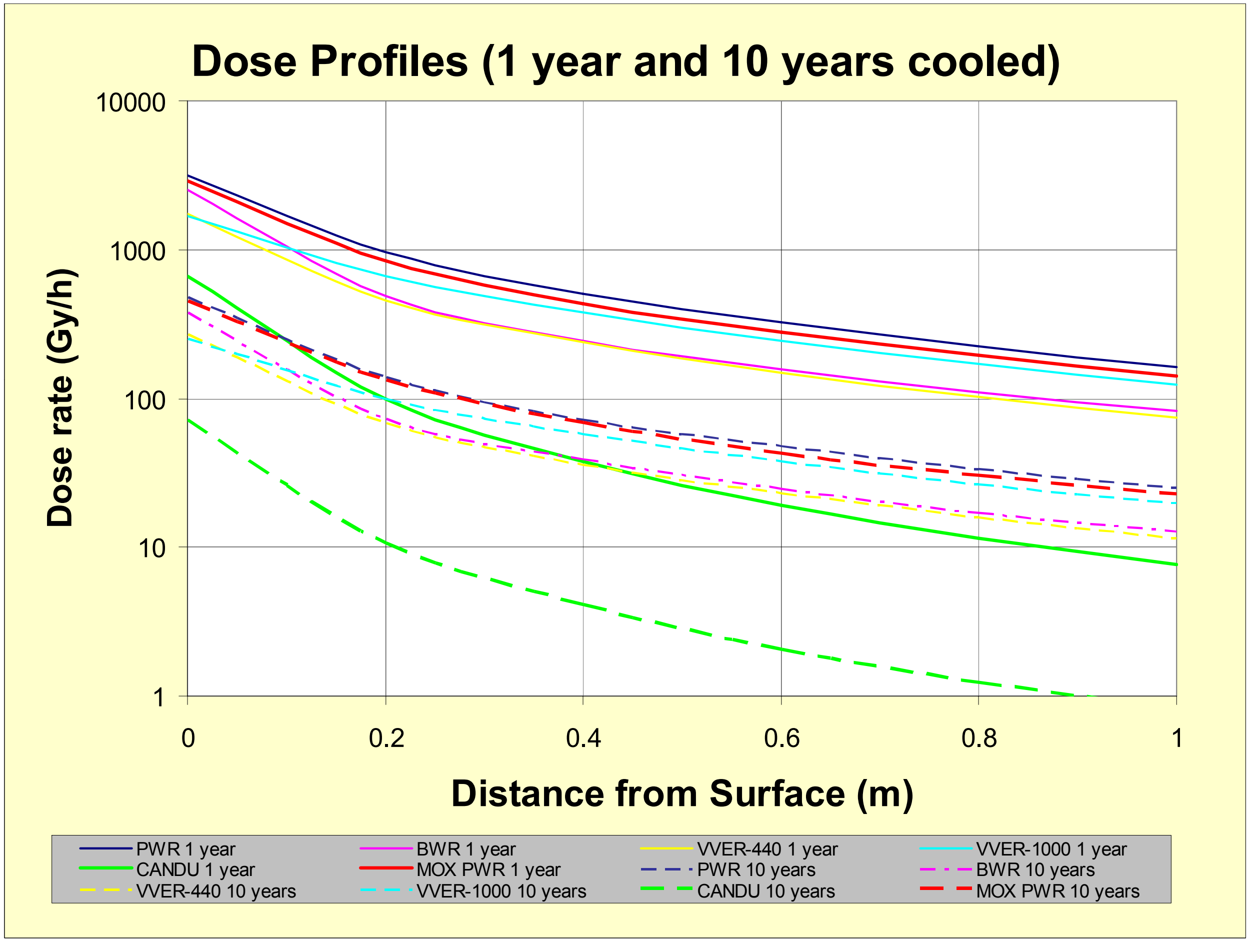
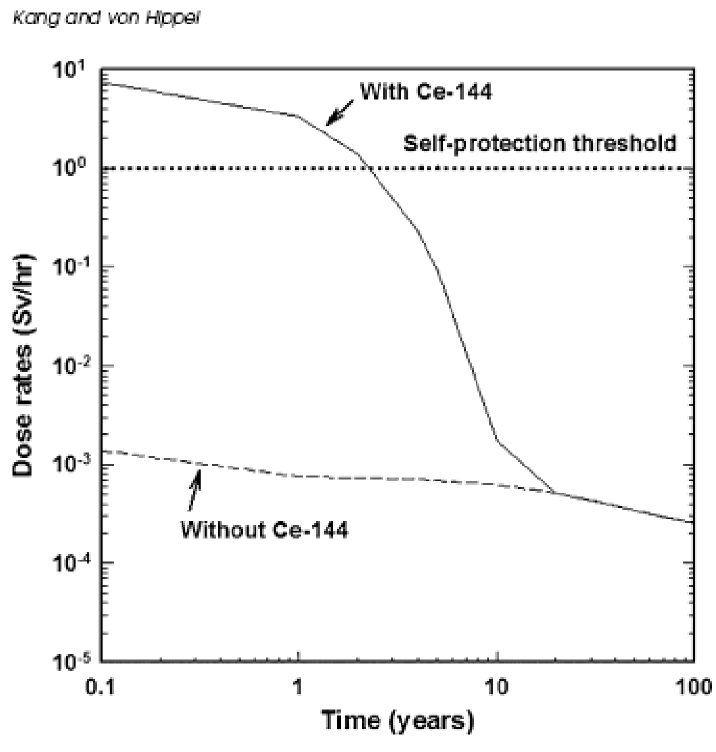
DOSE RATES AS A FUNCTION OF DISTANCE



DOSE RATES



Source: J. Kang and F. von Hippel, "Limited Proliferation-Resistance Benefits from Recycling Unseparated Transuranics and Lanthanides from Light-Water Reactor Spent Fuel," *Science and Global Security* **13** (2005)

ASSESSING SELF-PROTECTION

- Pyroprocessing would have a dose rate greater than 100 rem/hr at 1 meter only for a short period of time, after which it would disappear rapidly
- Mixing Pu with U only (COEX) has no appreciable impact on dose rate
- Conclusion: these are all minor modifications of conventional PUREX that would have no significant impact on the ability of skilled adversaries to steal weapon-usable materials and process them to produce weapons

NUCLEAR WEAPON USABILITY

- Plutonium-uranium mixtures are directly weapon-usable for a wide range of plutonium contents
  - COEX mixture is equivalent to 70 to 80%-enriched HEU oxide
- In addition, "the separation of … uranium and plutonium involves an additional chemical process that is known to most fuel chemistry experts." --- T.A. Taiwo et al., ""Co-Extraction Impacts on LWR and Fast Reactor Fuel Cycles," Argonne National Laboratory, ANL-AFCI-187, May 31, 2007.
- Unirradiated Pu-U fuel:
  - plutonium content > 12% correspond to >20% HEU in bare crit mass
  - Categorized by IAEA as direct-use material with respect to safeguards and Category I with respect to physical protection
  - NRC has downgraded of Pu-U fuel with less than 20% plutonium content, based on difficulty of stealing fuel assemblies --- but assemblies can be quickly disassembled using shaped charges
- TRU
  - DOE Manual 470.4-6 (Chg. 1): separated neptunium and separated americium must be "protected, controlled and accounted for as if they were SNM." [specifically, U-235]

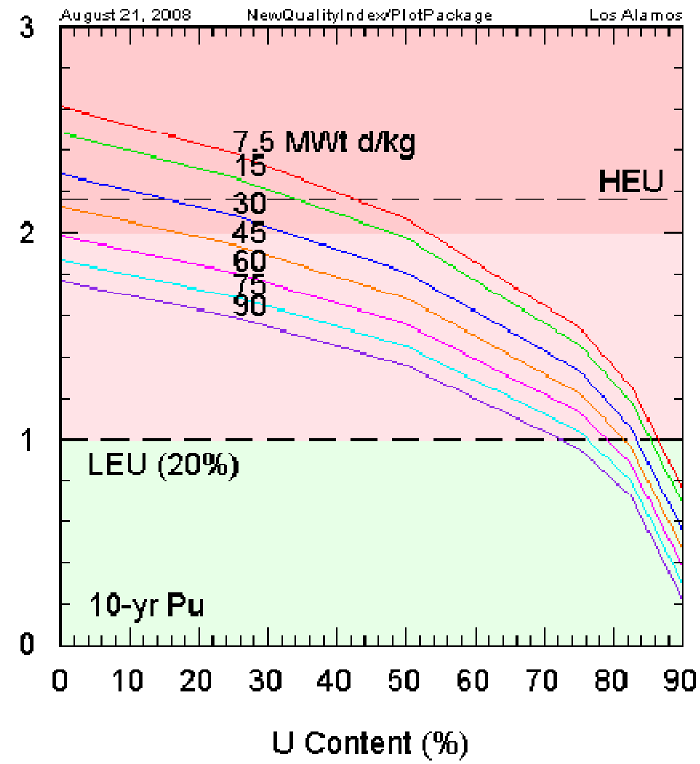
NATIONAL LAB STUDY

	Attractiveness Level	FOM[a]
WEAPONS Assembled weapons and test devices	A	
PURE PRODUCTS Pits, major components, button ingots, recastable metal, directly convertible materials	B	> 2
HIGH-GRADE MATERIALS Carbides, oxides, nitrates, solutions (≥25 g/L) etc.; fuel elements and assemblies; alloys and mixtures; UF_4 or UF_6 (≥ 50% enriched)	C	1-2
LOW-GRADE MATERIALS Solutions (1 to 25 g/L), process residues requiring extensive reprocessing; moderately irradiated material; Pu-238 (except waste); UF_4 or UF_6 (≥20%<50% enriched)	D	0-1
ALL OTHER MATERIALS Highly irradiated forms, solutions (<1 g/L), uranium containing <20% U-235 or <10% U-233 (any form, any quantity)	E	< 0[b]

NATIONAL LAB STUDY: RESULTS

- Attractiveness levels of Pu and Pu+Np mixtures (UREX+2,+3,+4) are virtually identical
- For Pu+U metal mixtures (COEX)
  - U ≤ 20%, attractiveness level B (same as plutonium metal)
  - 20% < U ≤ 82%, attractiveness level C (same as plutonium oxide)
- For Pu+TRU metal mixtures (UREX+1a, PYROX),
  - Attractiveness level C unless diluted by > 75% U
- Overall, the study confirms that there is little reduction in attractiveness associated with UREX+, COEX or PYROX compared to PUREX

EFFECT OF U DILUTION



From C. Bathke, et al., 2008

PHYSICAL PROTECTION ISSUES

- NRC Category I theft design basis threat and related security requirements become applicable for facilities possessing Category I quantities of plutonium or HEU
  - Separated Np, Am and Cm not addressed
- NRC and DOE design basis threats are different
  - Makes life difficult for NRC-licensed facilities on DOE sites (e.g. MFFF)
- NRC regulations generally do not give credit for dilution or other material properties that may reduce “attractiveness” of strategic special nuclear material
- But in 2005 NRC granted an exemption from Category I requirements to Duke Energy for possession of plutonium at a power reactor in the form of LWR mixed-oxide (Pu and U) fuel assemblies with Pu < 10 wt%
- Revision of NRC’s power reactor security regulations (§ 73.55) raised the Cat I exemption threshold to 20% wt% Pu
  - NRC’s gift to fast reactors? (driver fuel would likely be exempt)

PHYSICAL PROTECTION ISSUES (cont.)

- But no compelling technical basis exists for a relaxation of security standards for any of these materials compared to separated plutonium
- NRC should retain its attractiveness-neutral regulations
- There should be a stricter standard for exemptions from Category I security requirements than is currently on the books
  - Applicants seeks an exemption from Category I security requirements on the basis of material unattractiveness need to demonstrate that the same level of protection against the Cat I DBT would be maintained

CAT I MPC&A STANDARDS

- Gap analysis: reprocessing plants should be classified as Cat I facilities …
- … But the Cat I MC&A standards themselves are inadequate
  - Semi-annual vs. bi-monthly inventories
    - Is process monitoring technology sufficiently advanced to the point needed to detect abrupt losses?
    - Consistency with DOE standard
  - Throughput-dependent limit on the standard error of the inventory difference (SEID) (0.1% of active inventory)
    - Is this appropriate for very large reprocessing plants? (SEID could be on the order of 20-30 kg Pu, or 10-15 formula quantities, per year)
    - Can the limit be met even if it is not tightened?
  - Collusion threat restricted to two individuals
  - Impacts on MC&A of other weapon-usable special nuclear materials (Np, etc)

INRA PROPOSALS: THE WRONG DIRECTION

- The International Recycling Alliance (INRA) presented a paper in July 2008 outlining its vision for safeguards and security requirements at U.S. “recycling” plants: these proposals would weaken standards to allow licensing of inadequately secure facilities
  - INRA proposes *decreasing* the frequency of physical inventories for reprocessing plants from every 9 months to every year, instead of increasing it for consistency with other NRC Category I facilities
  - Because the NRC SEID limit of 0.1% of active inventory is “not attainable in a typical reprocessing plant,” INRA proposes raising the bar by replacing regulatory caps with license conditions based on actual plant measurement errors (which are at least ten times higher)

CONCLUSIONS

- NRC needs to revise its regulations for facilities handling weapon-usable materials to ensure that all SNM will be appropriately protected against the threats that our country faces
- The burden should be on applicants to demonstrate that they can account for and protect these materials to the highest standard before construction begins