Long-Term Nuclear Waste Storage & Reprocessing

Sharon Squassoni

Senior Fellow and Director, Proliferation Prevention Program

Towards a Nuclear Power Renaissance? Challenges for Global Energy Governance, 4-5 March 2010 in Potsdam/Berlin

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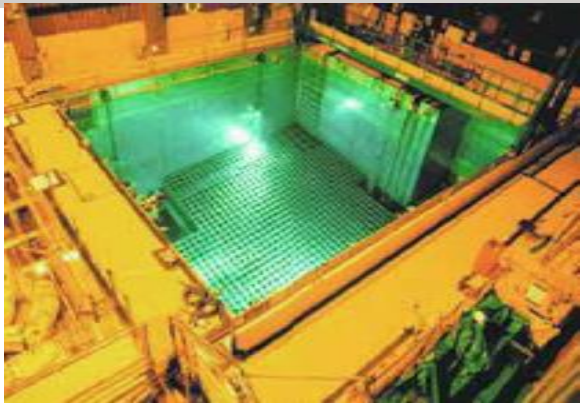


OUTLINE

- Nuclear Waste – particular challenges
- Long-term waste management options
- Current status of efforts worldwide
- Implications of expansion of nuclear energy for security, proliferation
- Key Questions

Long-term waste options

- What is “long-term?”
  - 50 years
  - 100 years
  - Thousands of years
- Beyond at-reactor storage, dry cask storage may be good for 100 years.
- International consensus that geologic repositories for waste the right approach, but no country yet has opened one
  - WIPP in US, but not for spent fuel (transuranic wastes)

What is “waste”?

- How “spent” is spent nuclear fuel (SNF)?
  - Not very – a lot of potential energy in uranium, plutonium in SNF
  - Very expensive to unleash that potential energy
  - Decisions made by governments on open or closed fuel cycles
- Closed fuel cycle approaches look forward to fast reactors and/or thorium fuel cycle.
- But commercialization still far off (if ever)
- And, still don’t avoid need for geologic repository. If storing MOX fuel, additional complications

Overview of repository efforts

- With or without reprocessing, geologic repositories considered necessary to isolate waste
- Different geologic media being explored
- Siting is biggest hurdle
- Approaches will vary
    - Volunteer/veto for siting
    - Retrievability
    - Monitoring
    - Phased management

From Andrew Orrell, "Nuclear Waste Management: The Next Half-Century," February 17, 2010 (Sandia National Laboratory)

Potential Repository Host Rocks in the USA

Property	Rock Salt	Argillaceous Rock Clay	Crystalline Rock (e.g., granite)
Thermal conductivity	High	Low	Medium
Permeability	Practically impermeable	Very low to low	Very low (unfractured) to permeable (fractured)
Strength	Medium	Low to medium	High
Deformation behavior	Visco-plastic (creep)	Plastic to brittle	Brittle
Stability of cavities	Self-supporting on decade scale	Artificial reinforcement required	High (unfractured) to low (highly fractured)
Dissolution behavior	High	Very low	Very low
Sorption behavior	Very low	Very high	Medium to high
Heat resistance	High	Low	High
Available geology	Medium	Wide	Wide
Geologic stability	High	High	High
Engineered Barriers	Minimal	Minimal	Medium

Favorable property   Average   Unfavorable property

Challenges of repositories*

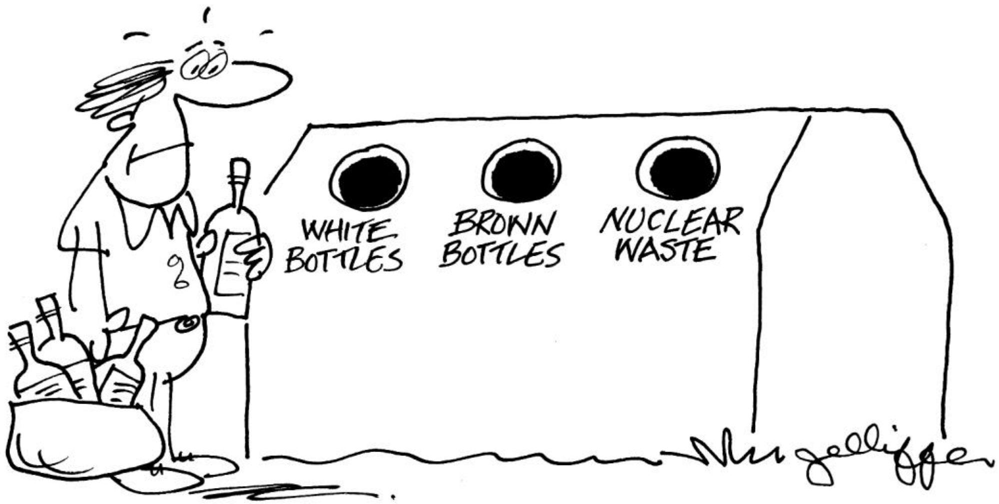
- Technical
  - Performance over geologic time
  - “Proof” not possible
  - Role of scientists
- Political/Institutional
  - Geologic time beggars the imagination
  - Siting
  - Linkage to other agendas
  - Values, ethics
  - Political implications
  - Nuclear stigma, fears

* Tom Isaacs, LLNL, February 17, 2010 briefing

Snapshot of repository efforts

- Geologic repositories
  - Sweden, Finland, France have candidate sites
  - Canada, Belgium, Japan, UK, Switzerland underway
  - Spain, ROK, China, India “thinking about it”
  - Argentina, Slovakia, Slovenia, South Africa starting out
- Obama administration has halted Yucca Mountain project
  - Zeroed out funding in FY2011
  - Will halt licensing process
  - Established Blue Ribbon Commission to evaluate potential solutions to waste problem
  - For some states, long-term waste disposal is a prerequisite for building new nuclear power plants

To recycle or not to recycle….



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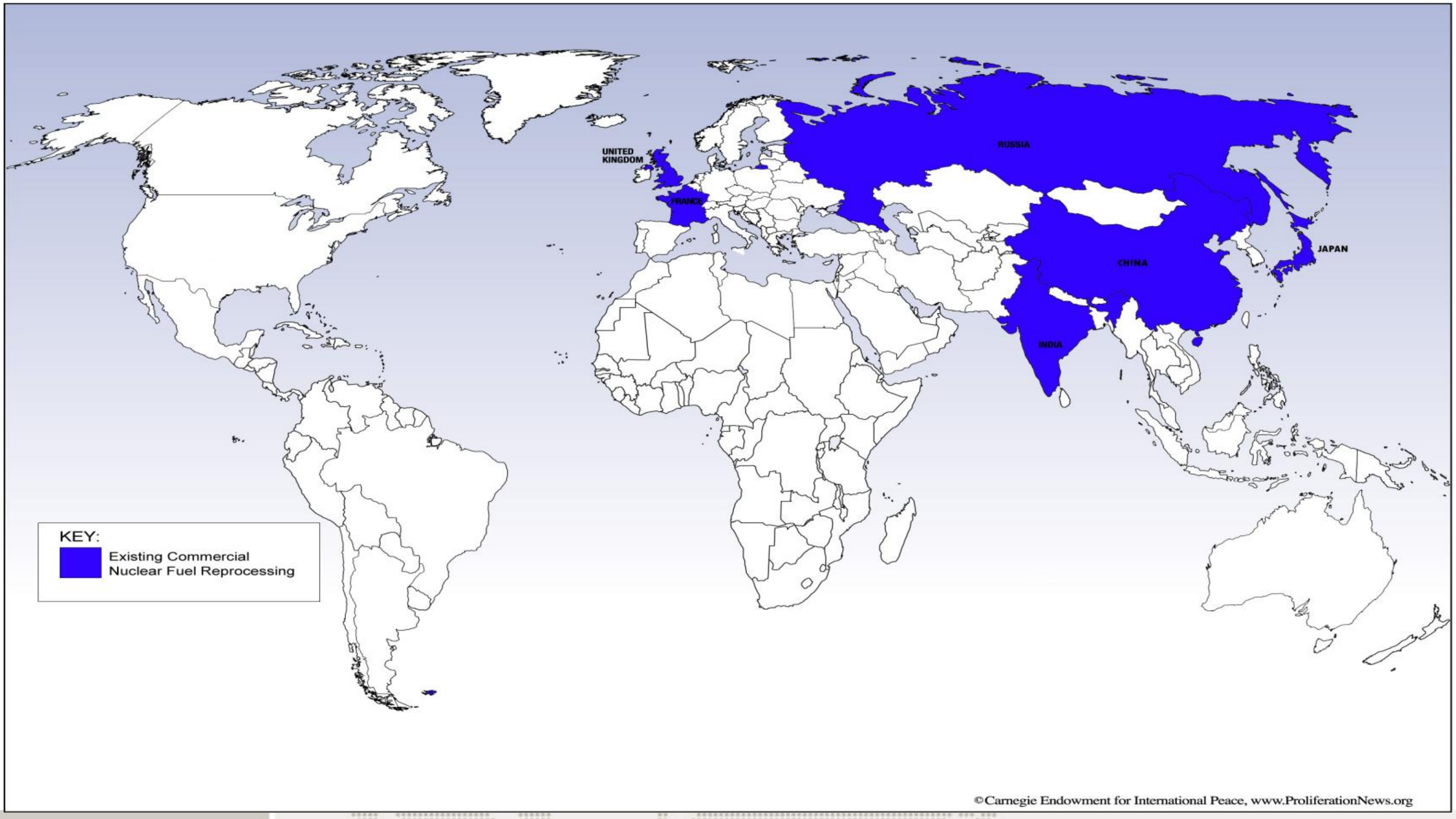
Commercial SNF reprocessing, 2009



What's going on now?

- Six countries currently reprocess SNF commercially – France, India, Japan & Russia (China is starting and UK phasing out)
- Five of six have fast reactor programs
- Only "operating" fast reactor is BN-600, which is not fueled with plutonium but HEU
- Stockpiles of civilian separated plutonium have grown to almost 250 metric tons
- Belgium, Germany, Italy, Argentina, Brazil, ROK, Taiwan abandoned interest in reprocessing
  - But ROK now wants to "pyroprocess"

Historical background on reprocessing

- PUREX developed from weapons programs; embraced in 1960s as solution to perceived uranium shortage problem, but only in context of fast breeder reactors.
- Since no breeder has been commercially viable, Pu recycled into MOX and burned once in LWRs.
- Harvard 2003 study concluded that reprocessing has to be “less than free” for fast reactor recycling to be economic, given huge capital costs of fast reactors.
- U.S. Global Nuclear Energy Partnership spurred interest in proliferation-resistant recycling technologies (UREX+, COEX, etc.) but little progress.

Japan and France

- Japan – sent SNF overseas for reprocessing (La Hague still has 21 tons) as it built capability. Tokai plant shut down since 2007 accident; Rokkosho plant $billions over budget and delayed > 10 years; MOX fuel fabrication plant under construction.
- France – has at least 72 tons of separated Pu at LaHague, half of which is foreign-owned. Recycling in LWRs (EPR reportedly can take a full core load of MOX)
  - French government 2000 study suggested recycling all LEU SNF would cost about twice as much as direct disposal.

Reprocessing as Waste Management*

- Advantages
  - Extends uranium, use plutonium resources
  - Reduces volume of long-lived actinides
  - Can tailor waste form to fit repository
- Disadvantages
  - Still need a repository
  - Not cost-effective
  - Increases overall waste volume
  - Proliferation risks

* Alison MacFarlane, February 17, 2010 briefing

Reducing Volume of Waste*

- 20 tons of SNF, if reprocessed, yields
  - 2-4 tons HLW
  - 20-30 tons ILW
  - 70-95 tons LLW
- Volume, however, is not the limiting factor in a repository
  - Instead, heat production and concentration of low-solubility species
- Effect of Spent MOX fuel on repository
  - Not recycled
  - 3 times heat output of SNF (needs more capacity)
  - 25% more I-129 in spent MOX
  - 2 times minor actinides in spent MOX

* Alison MacFarlane, February 17, 2010 briefing

Impact of Nuclear Energy Expansion

- Caveat: nuclear “renaissance” may just be nuclear “enthusiasm”
- Capacity growth in Asia is likely; uncertain how many “new” nuclear states will emerge
- Growth scenarios – modest to wildly optimistic to tripling current capacity (EIA, states’ plans, MIT’s 1500 GWe high scenario)

Nuclear Expansion Scenarios

Current Capacity: 370 GWe in 30 countries + Taiwan

- **Scenario I:** **Realistic growth to 2030 (economic model EIA) +140 GW**
- **Scenario II:** **Wildly optimistic (states' plans) to 2030) +474 GW**
- **Scenario III:** **Fourfold increase (based on climate change, MIT's "high scenario for 2050) +1300 GW**

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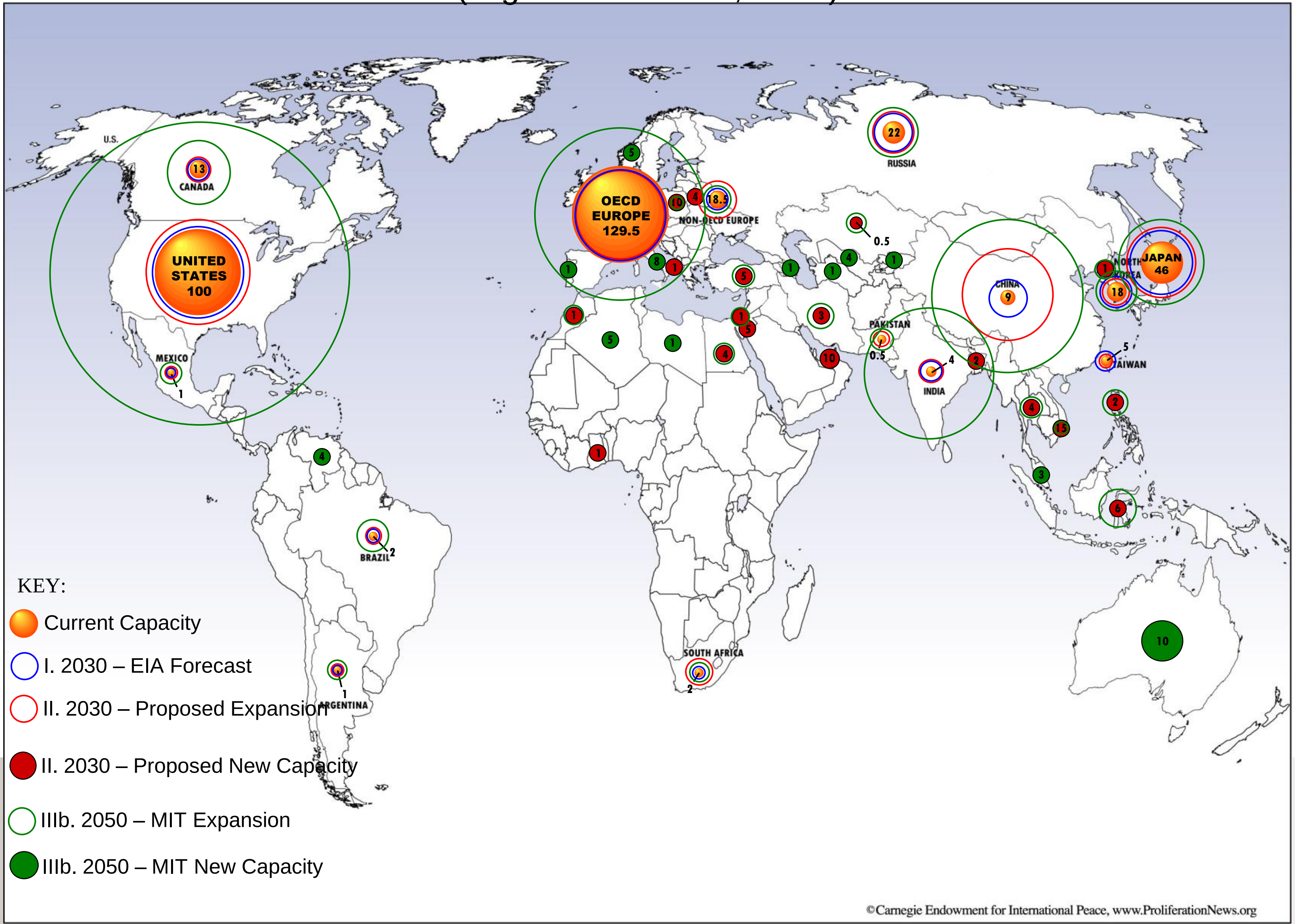
Reactor Capacities for all Scenarios*

(Gigawatts electric, GWe)



Nuclear "enthusiasm": More than just numbers…

- New kinds of reactors?
  - Different choices for advanced vs. developing states
    - **Gen IV, grid-appropriate, nuclear batteries?**
- New locations (Middle East, Southeast Asia, Africa)
- New capabilities
  - Recycling techniques + closed fuel cycles for more states?
  - More states with uranium enrichment?

Meanwhile, efforts to restrict spread of sensitive nuclear technologies are flagging; security and safety regimes not mandatory

Spent Fuel Implications of Growth

- 1 GWe = 20 tons spent fuel/year
- States just starting out with nuclear power will either store, or accept fuel leasing arrangements.
  - More storage = need for more safety, security measures
  - Fuel leasing = more transportation = more safety, security
- States are still free to choose their fuel cycle approaches; may opt for same strategy of advanced nuclear states (put off until technology changes)
- Some advanced states still pursuing fast reactors; but no need for uranium alternatives yet. Recycling will continue to produce stockpiles of Pu.

Implications for Security

Numbers

- **Terrorism threat**
  - That terrorists could sabotage npps, fuel storage
  - That terrorists could steal directly weapons-usable nuclear material from civilian facilities

Kinds

Locations

- **It matters where plants are, how SNF pools are designed, and how tight security is. Interim storage likely no riskier than at-reactor storage.**

Capabilities

- **Mitigating the risk**
  - Shape fuel cycle to limit amount of directly weapons-usable nuclear material
    - LEU, open fuel cycle
    - Limit geographic spread of sensitive fuel cycle facilities
  - Enhance focus on security
    - World Institute for Nuclear Security
    - Better adherence to international standards (CPPNM)

Implications for Proliferation

Numbers

- More reactors = more expertise, materials in flow, more enrichment. Reprocessing still likely to remain domain of NWS, but trend is toward accepting "necessity" of recycling

Kinds

Locations

- If India becomes new supplier, will it sell heavy water reactors? Proliferation risks will rise.

Capabilities

- Still no legal barrier to development of entire fuel cycle, no taboo on building fast reactors, and no progress on "Cradle-to-Grave" nuclear supply

Nuclear Security Context

- **April 2010 Nuclear Security Summit**
  - Focus is on fissile material
  - Not clear to what extent civilian stockpiles of separated Pu will be addressed
- **Enthusiasm for nuclear energy under the guise of energy security, climate change is outpacing institutional arrangements to make fuel cycle more proliferation-resistant**
- **Nuclear Supplier Group efforts to further restrict enrichment, reprocessing are flagging**

Discussion Questions

- Where to find political impetus for institutional arrangements to make fuel cycle more proliferation resistant?
- What are key obstacles to international repositories?
- What are visions for a truly proliferation-resistant fuel cycle?
- How to identify and overcome barriers to cradle-to-grave fuel supply?