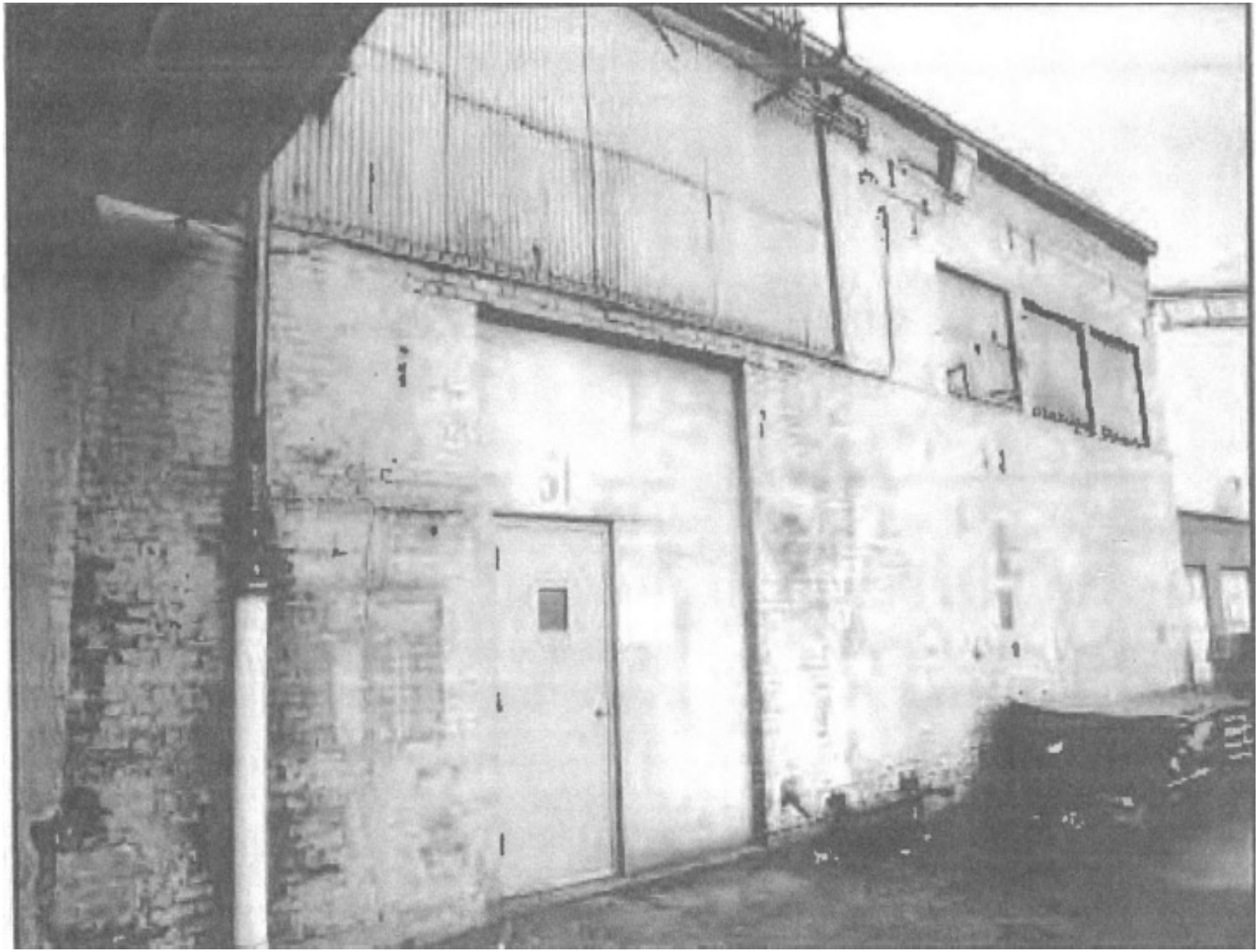
Chicago Pile - 1

December 2nd, 1942

(*Smithsonian*, 2015)

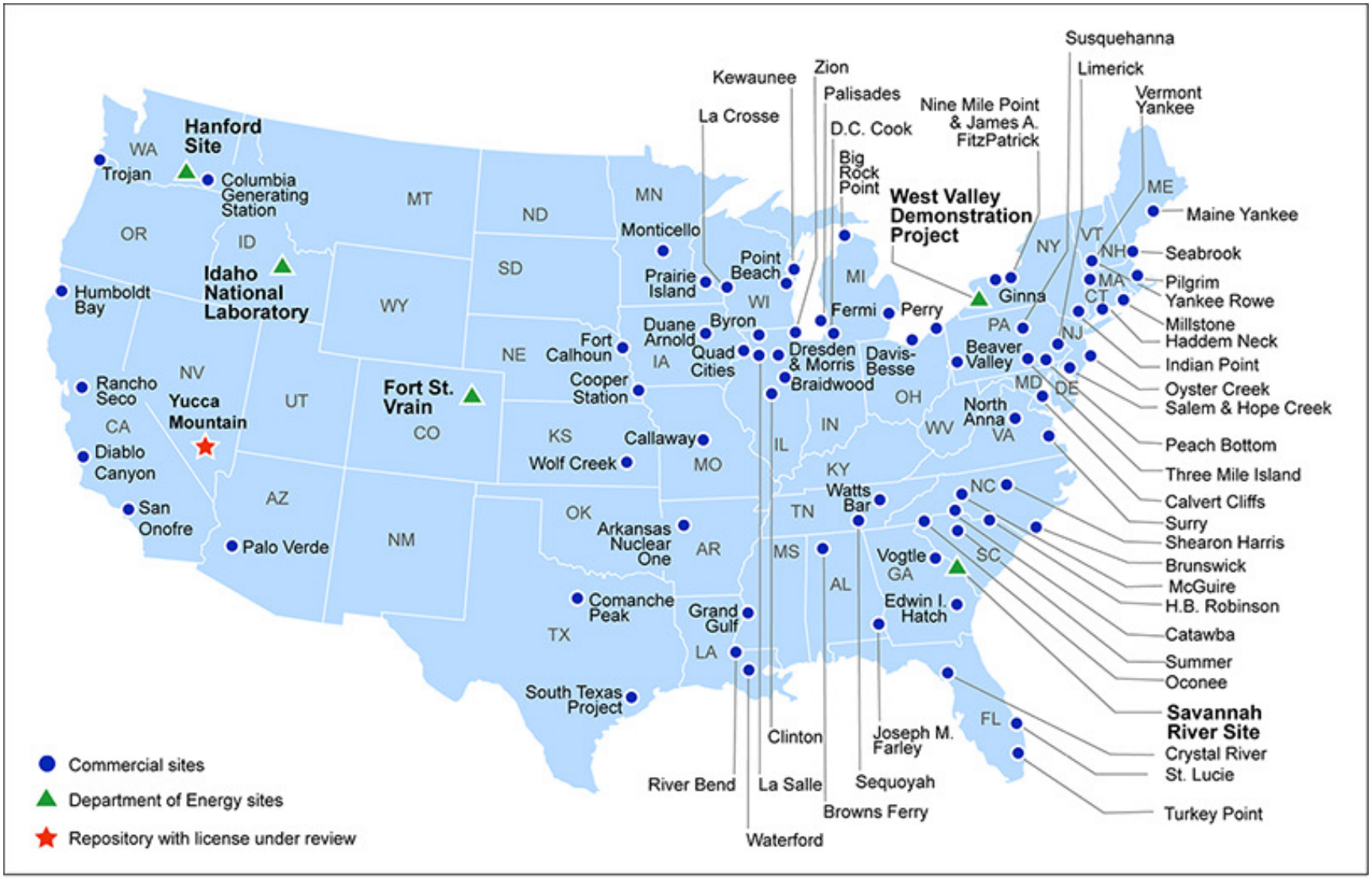
J. Jones (2016) *Military History of the Upper Great Lakes*



Building 51 of Mallinckrodt Chemical Works
Downtown St. Louis in January 1994

Linking Legacies (1997)

Nuclear Waste Locations in the United States



Source: Department of Energy. | GAO-17-174

Nuclear Waste in the U.S.: 2020

uranium mine & mill tailings	438 million m^3 3,000 MCi
depleted uranium (UF_6)	500,000 metric tonnes
high-level waste (defense reprocessing)	380,000m^3 2,400 MCi
buried waste (TRU, LLW, hazardous)	6.2 million m^3
spent nuclear fuel (commercial)	~ 88,000 mTHM ~ 60,000 MCi
contaminated soil	79 million m^3
contaminated water	1,800 to 4,700 million m^3

Estimated clean-up and disposal cost = 300 billion US dollars

Stanford | FSI Freeman Spogli Institute for International Studies

Stanford | Precourt Institute for Energy

The U.S. Nuclear Waste Management & Disposal Strategy: Status and Possible Futures

Rod Ewing

Stanford | CISAC Center for International Security and Cooperation

"Lunch & Learn" Seminar

European Joint Programme on Radioactive Waste Management

October 6, 2021

U.S. Nuclear Waste Management Program

Gordian Knot

Why does the United States find itself in this current situation?

- Managing spent fuel and high-level waste has been a low priority.
- A Technical – if temporary – "Fix" was available to manage spent nuclear fuel and high-level waste.
- Implementing a technical "Fix" was not as easy as expected.
- Key bargains in the Nuclear Waste Policy Act (1982) have fallen apart.
- "Yesterday's solutions have become today's problems"
- No geologic repository.

Reset of America's Nuclear Waste Management *Strategy and Policy*

Reset Steering Committee

- **Sally Benson** – Precourt Energy Institute, Stanford
- **Peter Davies** – Sandia National Laboratories
- **Rod Ewing** – School of Earth Sciences & CISAC, Stanford
- **Saida L. Engström** – SKB (Sweden) – vice-president
- **Bernd Grambow** – Subatech - director
- **John Kessler** – EPRI (retired)
- **Allison Macfarlane** – GWU and NRC Chairman (retired)
- **Daniel Metlay** – Nuclear Waste Technical Review Board
- **Mark Peters** – Idaho National Laboratory (Director)
- **Christophe Poinssot** – CEA (France)
- **Kathryn Shaver** –Nuclear Waste Management Org. (Canada) vice-president
- **Chris Whipple** – ENVIRON (retired)

https://cisac.fsi.stanford.edu/sites/default/files/reset_steeringcommitteebios_2018.pdf

Steering Committee

First Meeting
Presentations and Discussion

February, 2014

Critical Issues

- ✓ Structure, properties, characteristics and behavior of a new nuclear waste management organization
- ✓ Integration of the entire nuclear waste system – from cradle-to-grave
- ✓ Definition of a consent-based process
- ✓ Review of regulations, risk methodology and concept of safety
- ○ Risk assessment of the *status quo* of the U.S. system over the next several hundred years

#1 Critical Issues: New Organization

- What are the structure, properties, and characteristics of a new nuclear waste management organization?
  - *What are the values of the organization?*
  - *How does the organization interact and communicate within it political and technical sphere while maintaining credible, constructive interactions with the affected public and state governments?*
  - *How does the organization set priorities?*
  - *How does the organization learn and change, particularly as it moves from the research stage to implementation and construction of the repository?*
  - *How does one design an organization that will function for a very long time, perhaps more than one hundred years, through a constantly changing political environment?*
  - *How should such an organization be funded?*

#2 Critical Issues: Integration of the Nuclear Fuel Cycle

- Integration of the entire nuclear waste system - from production of spent fuel to its final disposal.
  - *Can incentives for all parties be aligned such that they drive the back-end of the nuclear fuel cycle to a final solution - permanent geologic disposal?*
  - *Does the Standard Contract between the utilities and the federal government require modification?*
  - *Are regulations consistently applied across all activities at the back-end of the fuel cycle, such as for storage, transportation and geologic disposal?*

#3 Critical Issues: Public Engagement

- What is a consent-based process?
  - *What constitutes consent?*
  - *How does a community or state give informed consent?*
  - *To what extent can a local community, tribe or state affect the repository design and strategy?*
  - *When and how can a local community, tribe or state withdraw consent?*
  - *Once consent is achieved, how can important aspects, such as the type of waste to be disposed, be modified? Who has the power to modify the agreement?*
  - *Can a consent-based siting process succeed in the federal system of the United States?*

#4 Critical Issues: Risk, Regulations and Safety

- Do we need to revise our regulatory framework?
  - *Is a quantitative, probabilistic approach necessary or realistic?*
  - *What is the relation between calculated risk and safety?*
  - *Does such an approach instill pubic confidence or skepticism?*
  - *Are there alternative approaches?*
  - *How are these issues addressed in other countries?*
  - *Although the ultimate goal of the back-end of the nuclear fuel cycle is geologic disposal, this results in an emphasis on long-term impacts, but what about risk and safety during the early period of construction and emplacement of the waste into a repository?*

#5 Critical Issues: *status quo*

- Risk assessment of the *status quo* of the U.S. system over the next several hundred years.
  - *What are the risks of continued storage of spent nuclear fuel at reactor sites?*
  - *What are the risks associated with the transportation of spent nuclear fuel, first to an interim storage site and then to a geologic repository?*
  - *Does consolidated storage prior to geologic disposal reduce the overall risk?*

Recommendations

- Create a new nuclear waste management organization and a new ***funding scheme.*** The new organization would be a not-for-profit, utility-owned corporation – "polluter pays".

- Develop a new *process* of public engagement in which a consent-based process is *based on a redistribution of power among affected parties.*

- Integrate all activities at the back-end of the nuclear fuel cycle *by aligning incentives to the final goal of geologic disposal.*

- Revise the regulatory approach *such that quantitative probabilistic analysis is only one element of a safety case approach to the safety assessment.*

- *Realize that by its very nature a nuclear waste management strategy must be an effort that addresses technical and societal issues.*

New Waste Management Organization

A New Waste Management Organization: Brief History

" . . the existing organization for radioactive waste management is likely to be unworkable if left unchanged."

They recommended:

". . . a national Radioactive Waste Authority be established as a federally chartered public corporation."

Willrich and Lester (1977) *Radioactive Waste*

#1 New Waste Management Organization & Funding Scheme (1)

- The lynchpin to all of the recommendations is a new, independent, single-purpose, national organization responsible for nuclear waste management.

- Although the BRC recommended a FEDCORP approach, we find advantages to careful consideration of a **utility-owned nuclear waste management organization**.

- Regardless of the type of organization, it must be designed to operate:
  - *In a manner that creates trust.*
  - *Over a long period of time, at least one hundred years.*
  - *With considerable public engagement and scrutiny.*
  - *With regular national and international reviews.*

- The scope of its charge in terms of nuclear waste type must be defined.
  - *All nuclear wastes?*
  - *There is value to having parallel efforts for defense waste and commercially generated waste.*

#1 New Waste Management Organization & Funding Scheme (2)

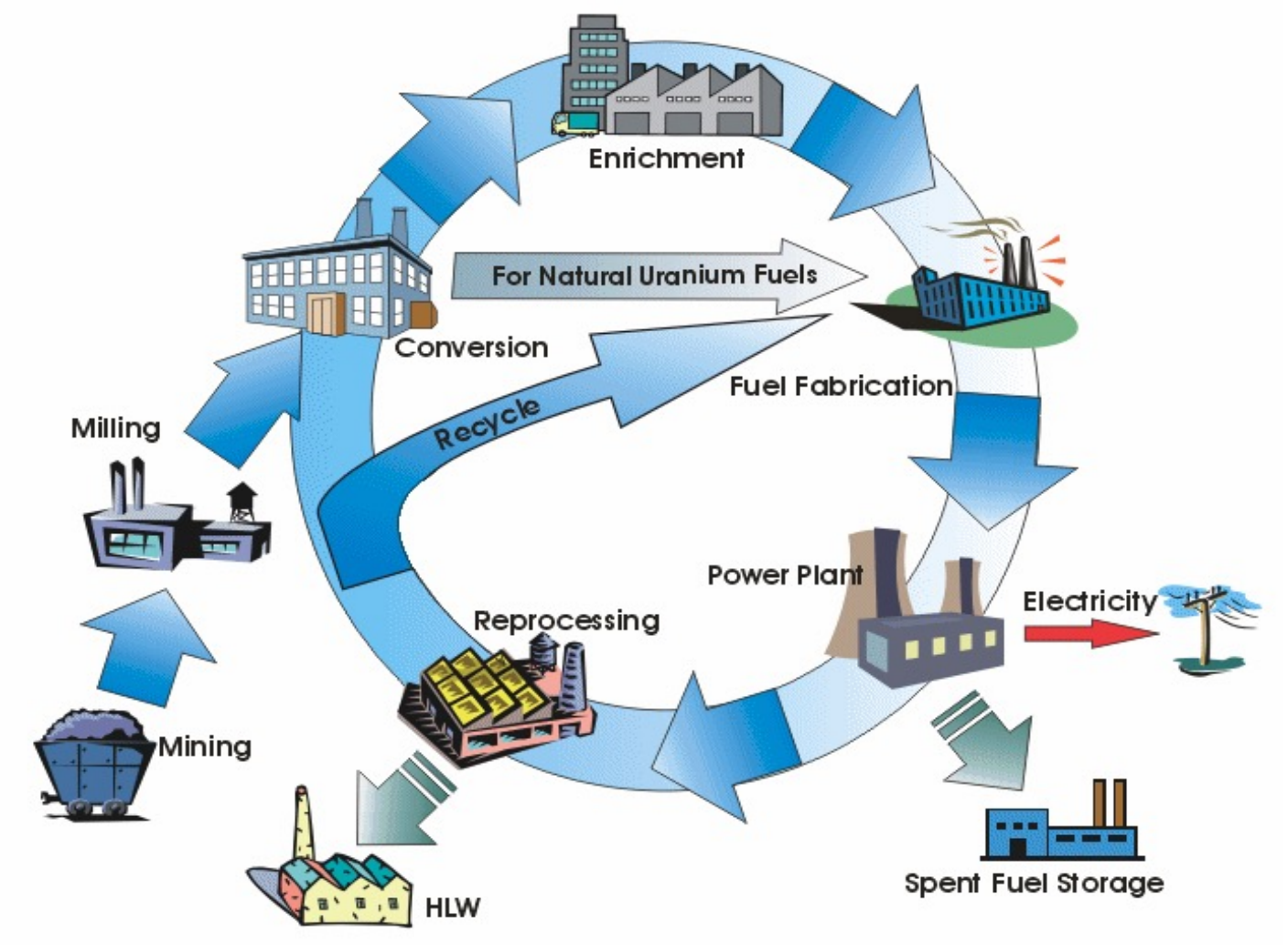
- Considering the challenge of geologic disposal over unprecedented time frames, the new organization must be able to direct a robust science program, manage a major engineering and construction project, handle large quantities of highly radioactive material – and do this under intense public scrutiny and engagement.

- Maintaining public trust and scientific integrity have to be part of the DNA of the new organization – valued throughout all parts of the organization and through all stages of repository development. Public trust must involve early and continuing engagement with the public and state authorities. Scientific integrity requires transparency in data collection and interpretation, publication in peer-reviewed journals and tolerance for the tough questions that go with any rigorous scientific process.

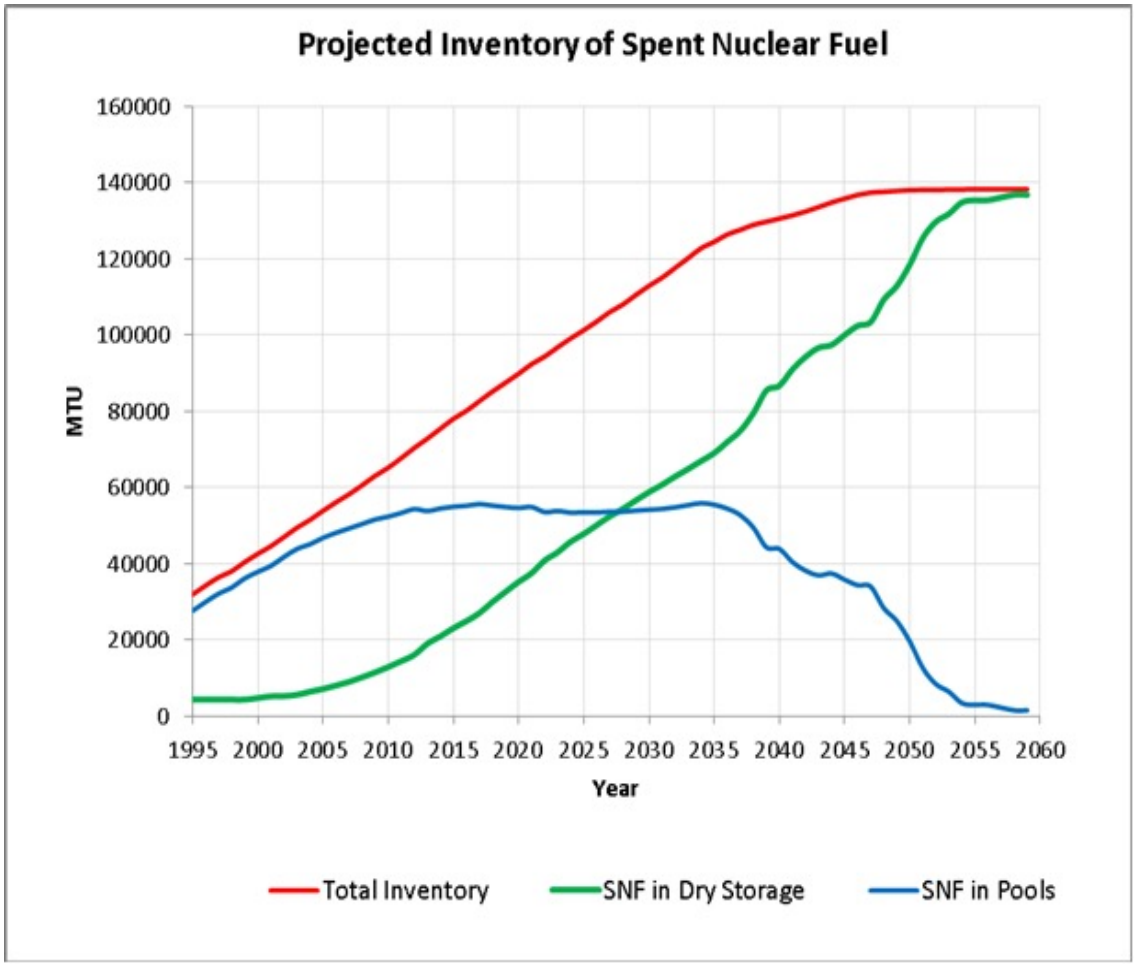
- A new funding scheme.
  - *Funding must be moved from annual Congressional allocations to full, timely access by the new waste management organization.*
  - *Nuclear Waste Fund should be transferred to the new organization over a period of 25 years.*

Integration of the Back-end of the Nuclear Fuel Cycle

Nuclear Fuel Cycle



U.S. Spent Fuel Inventory



Richard *et al.* (2015) *SAND2015-5503*

Integration

- ***Integration*** *of the back-end of the fuel cycle should include clear plans for storage (on-site and centralized), transportation, and the final disposal of spent fuel and high-level waste.* ***The incentives at every stage should be aligned to the final goal – geologic disposal.***

- *This requires many decisions, such as the selection of waste containers, a determination of transportation methods and routes, and the design and development of a geologic repository. Each of these activities is tightly interdependent. Their proper function requires thoughtful, but challenging, decisions to ensure that they remain integrated. For the U.S. program,* ***disconnects among these activities have become increasingly evident because of the continuing delay in the development of a deep-mined geologic repository for spent nuclear fuel and high-level radioactive waste.***

- *Integration is greatly facilitated when one party or institution is responsible for the spent fuel from the point of generation until final disposal.*

Indefinite surface storage is not a solution,
but rather a symptom of the failure of the integration
of the back-end of the nuclear fuel cycle.

#2 Integration of the Back-End of the Nuclear Fuel Cycle (1)

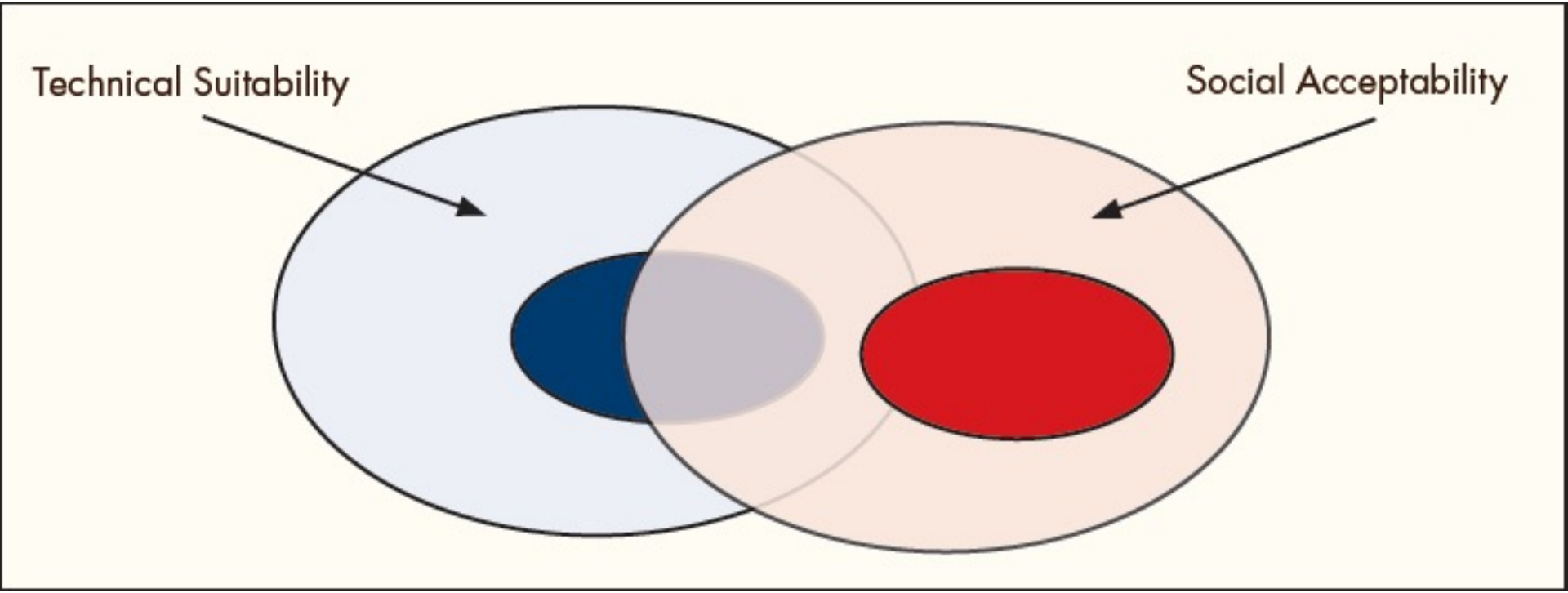
- Congress revise existing laws so that:
  - Responsibility for storage, transportation, and disposal of commercially generated spent fuel, and perhaps high-level radioactive waste, be given to a new independent waste management organization.
  - The *corpus* of the Nuclear Waste Fund is transferred to the new organization.
  - The Department of Justice should consider the impact of their payments on the integration of the back-end of the fuel cycle, *e.g.,* enable the packaging of smaller, potentially repository-appropriate canisters for earlier transport.
  - The nuclear utilities and the new organization must work together to establish an integrated system for spent fuel and high-level waste management that has the capability to repackage spent nuclear fuel from the current, relatively large casks and canisters into canisters that are designed for geologic disposal.

#2 Integration of the Back-End of the Nuclear Fuel Cycle (2)

- The Standard Contract must be revised to support geologic disposal rather than continued storage on site.
- The spent fuel at presently shut down sites should be the highest priority for consolidation and disposal. This requires a revision of the Standard Contract.
- Finally, Congress must reaffirm that a geologic repository (or repositories) is the final goal for the fate of highly radioactive waste, such as spent nuclear fuel and the high-level waste from reprocessing.

Public Engagement
Consent-Based Sitting

Public Engagement



Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository . . .
(2015) Nuclear Waste Technical Review Board

Public Engagement

- The implementer and the regulator have to establish strong bonds of ***trust*** with the local, tribal, and state governments involved and have to sustain that trust for many decades.

- An effective mechanism has to be put in place that allows local, tribal and state governments to exercise decisive decision-making ***power*** throughout the repository-development program.

Consent-Based Sitting is a Process of Trust-Building

- Collaborate in the design of the siting process.
- Entrust the siting process to a strong and trustworthy organization.
- Articulate a clear decision-making path.
- Assemble information required to support participation.
- Sustain the process by behaving in a manner that fosters public trust and confidence.

Allocating Power Among the Parties

- The process for approval of a repository site should be one that gives substantial authority to the local municipality, tribe or state to stop the process of site selection and repository construction.

- The decision by local, tribal and state governments to object should come after an appropriate period of engagement and the completion of important scientific and engineering studies, but not at the end of the process.

- A possible point of decision could be anytime before the formal submission of the license application.

- The reversal of local, tribal or a state's objection could only be overturned by a supermajority of both houses of Congress.

#3 Public Engagement: Consent-Based Process

- A consent-based process is a continuous process – not a single binding, legal agreement.
- The process should be designed by the parties.
- The process must provide an opportunity for a community or state to withdraw.
- Communities, tribes and states must be have the means of making their own evaluation and expert judgments.
- The consent-based process will work best if multiple sites are being investigated and characterized.

Standard and Regulations
Risk and Safety

History of Standard and Regulations

NRC established	1974
Nuclear Waste Policy Act	1982
NRC high-level waste regulations 10 CFR 60	1983
DOE site selection guidelines, 10 CFR 960	1984
EPA standard, 40 CFR 191	1985
Nuclear Waste Policy Act Amendment	1987
EPA standard remanded by federal court	1987
Energy Policy Act of 1992	1992
NAS *Technical Bases for Yucca Mt. Standard*	1995
EPA standard for Yucca Mountain, 40 CFR 197	2001
NRC regulation for Yucca Mountain, 10 CFR 63	2001
DOE Yucca Mountain suitability criteria 10 CFR 963	2001
Presidential recommendation for Yucca Mountain site	2002
EPA Yucca Mountain Standard – remanded	2004
EPA Yucca Mountain Standard (revised compliance period)	2008
DOE submits the license application	2008
DOE withdraws the license application – “with prejudice”	2010
Federal court instructs the NRC to continue the license review	2013

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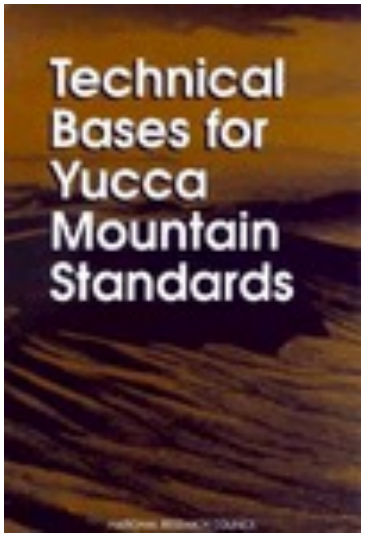


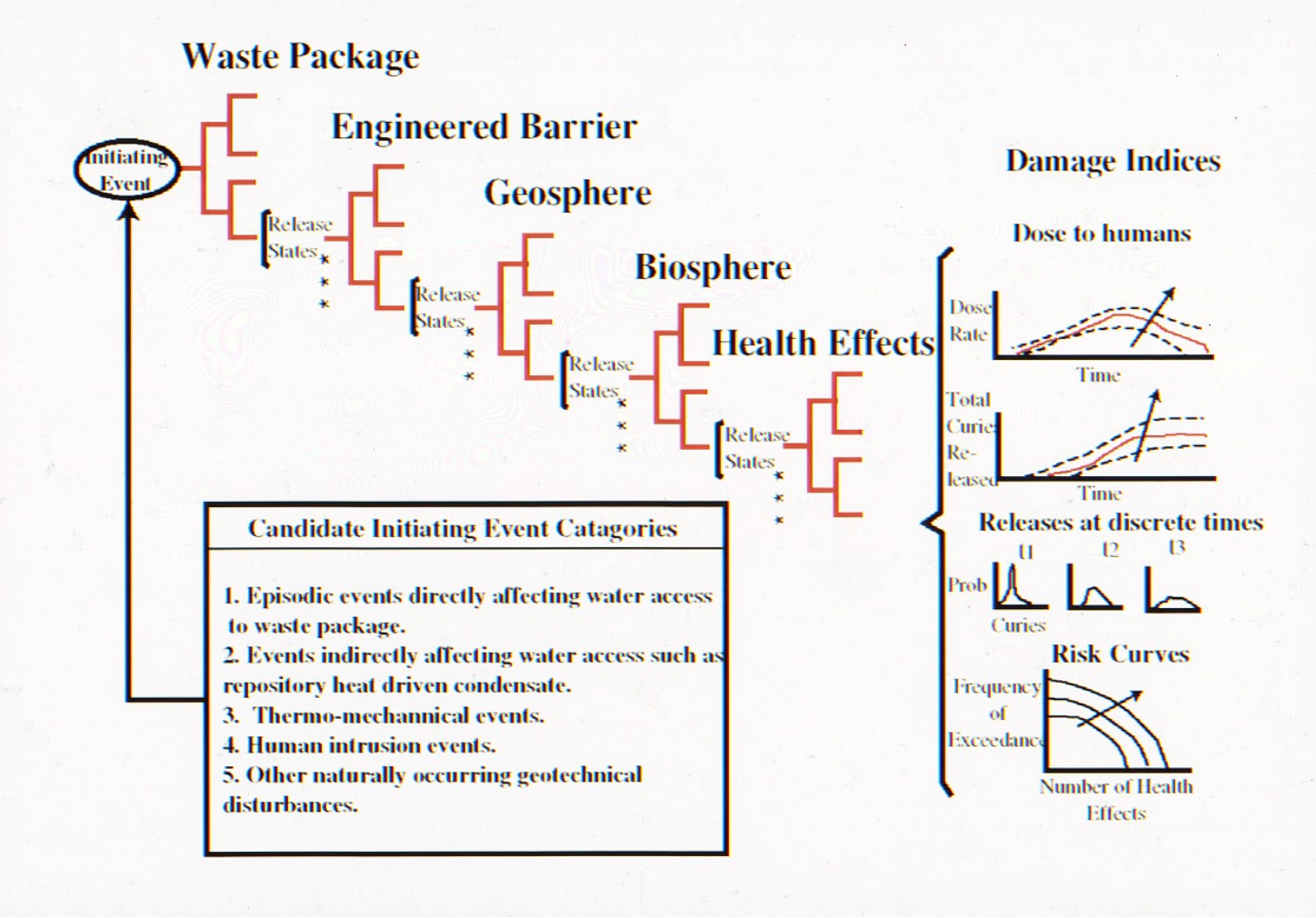
Critical Aspects of the "Evolved" Standard

- Site-specific standard
- Risk-based => Dose-based
- Period of compliance = 1,000,000 years
- Total system performance evaluated without sub-system requirements for individual barriers.
- Compliance determined mainly on the basis of "quantitative," probabilistic performance assessment of the whole system.
- For Yucca Mountain the standard:
  - 15 mrem (= 0.15 mSv)/year for first 10,000 years
  - 100 mrem (= 1 mSv)/year from 10,000 to 1,000,000 years

Quantitative Performance Assessment

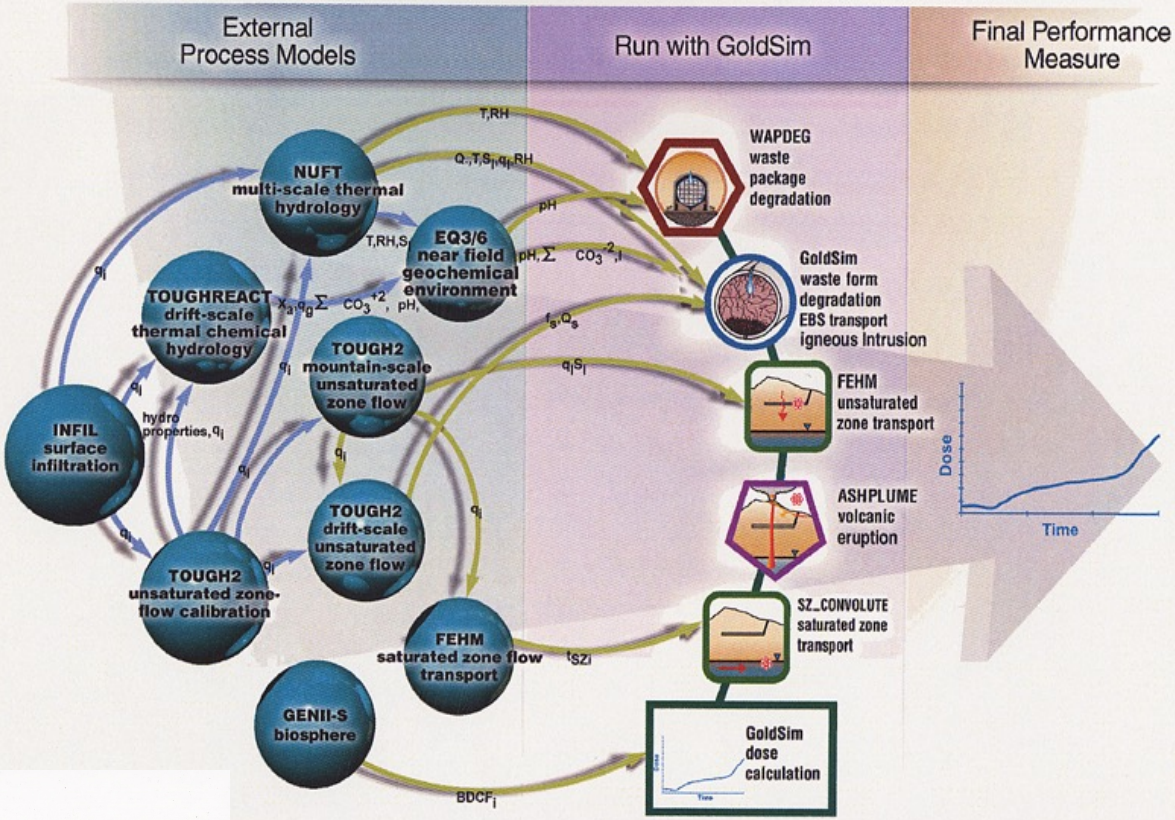
- Identifies the processes and events that might affect the disposal system.
- Examines the effects of these processes and events on the performance of the disposal system.
- Estimates the cumulative releases of radionuclides, considering the associated uncertainties.
- Estimates are incorporated into an overall probability distribution of cumulative release.

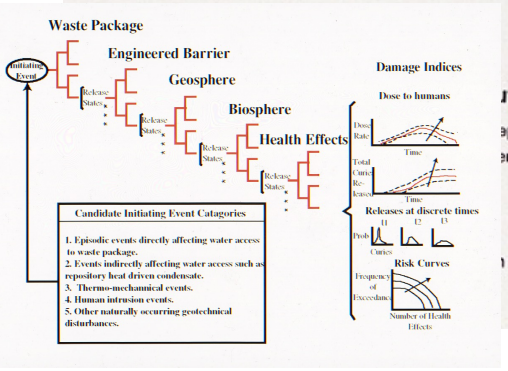
"Quantitative" Total System Performance Assessment



Garrick & Kaplan (1995)

Overview of Model Linkage
(Total System Performance Assessment - Site Recommendation)





Parameters

T	Temperature	I	Ionic Strength
RH	Relative Humidity	t_{SZi}	Saturated Zone Transport Time
S_l	Liquid Saturation	$BDCF_i$	Biosphere Dose Conversion Factor
X_a	Air Mass Fraction	q_g	Gas Flux
q_l	Liquid Flux		
q_i	Infiltration Flux		

Legend

Response Surface Between Process Models

Response Surface from Process Model to GoldSim

00185DR_Figure 2.ai

Safety Case

"The synthesis of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe after closure and beyond the time when active control of the facility can be relied on."

Nuclear Energy Agency (2004) *Post-Closure Safety Case for Geologic Repositories*

#4 New Regulatory Approach

- Generic standard.
- Safety Case approach.
- This is an iterative process.
- Facilitates regular, independent, review.

  - *U.S. Waste Classification*

Recommendations

- Create a new nuclear waste management organization and a new ***funding scheme.*** The new organization would be utility-owned – “polluter pays”.
- Develop a new *process* of public engagement in which a consent-based process is *based on a redistribution of power among affected parties.*
- Integrate all activities at the back-end of the nuclear fuel cycle *by aligning incentives to the final goal of geologic disposal.*
- Revise the regulatory approach *such that quantitative probabilistic analysis is only one element of a safety case approach to the safety assessment.*
- *Realize that by its very nature a nuclear waste management strategy must be an effort that addresses technical and societal issues.*

*Way Forward?**

- Do the heavy lift –change now and start over.

- Proceed with the license application to construct Yucca Mountain as a geologic repository, but this may well be "unworkable".

**These are my thoughts, not of the steering committee.*

A Third Way Forward

Analyze the *status quo* effects for the US program over the next 200 years.

Thank you

https://cisac.fsi.stanford.edu/research/projects/reset-nuclear-waste-policy