Introduction to Nuclear Chemistry and Fuel Cycle Separations

Nuclear Fuel Cycle Fundamentals

Frank L. Parker
Department of Civil and Environmental Engineering
Vanderbilt University School of Engineering

Nashville, Tennessee

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Nuclear Fuel Cycle Fundamentals

a. The Nuclear Fuel Cycle (milling, additional refinement including conversion, enrichment, reprocessing, waste management, and waste disposal),

b. Fission yields,

c. Actinide elements,

d. Important fission products,

e. Problems created during Cold War

   i. Waste tanks,

   ii. Site Contamination-radioactive and non-radioactive,

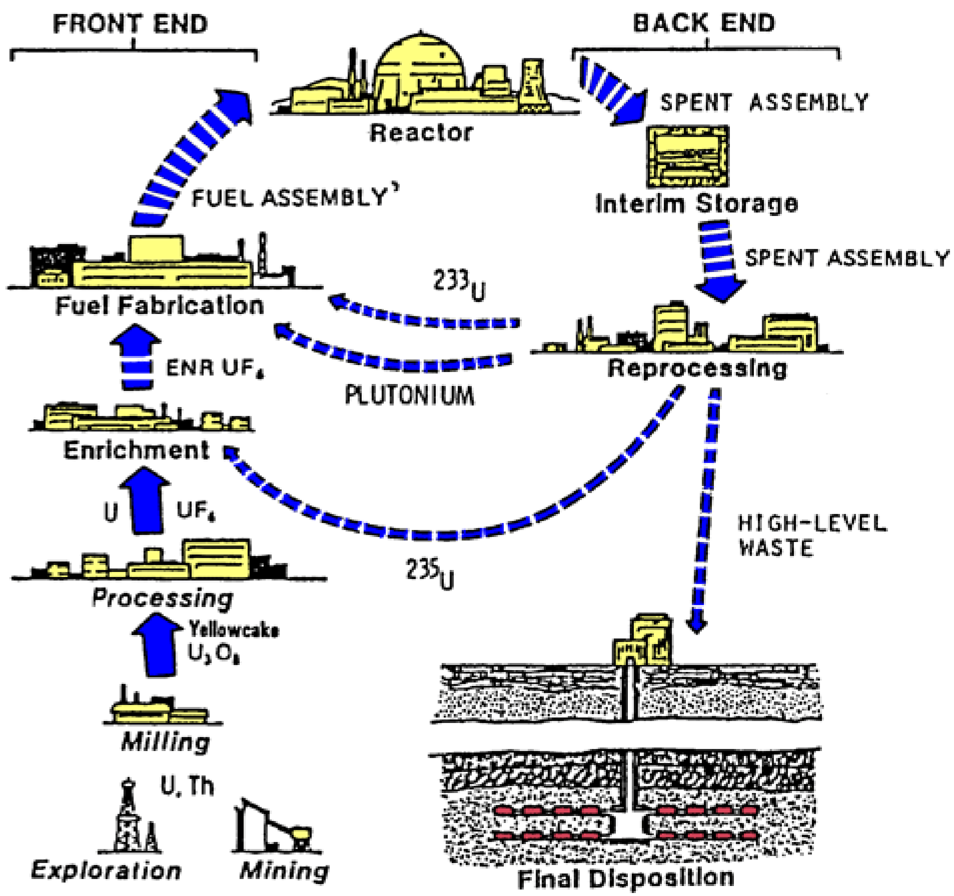
   iii. Stewardship of abandoned sites.

ALL SITES AND OPERATION ARE DIFFERENT. THEREFORE, NUMBERS GIVEN ARE ONLY REPRESENTATIVE

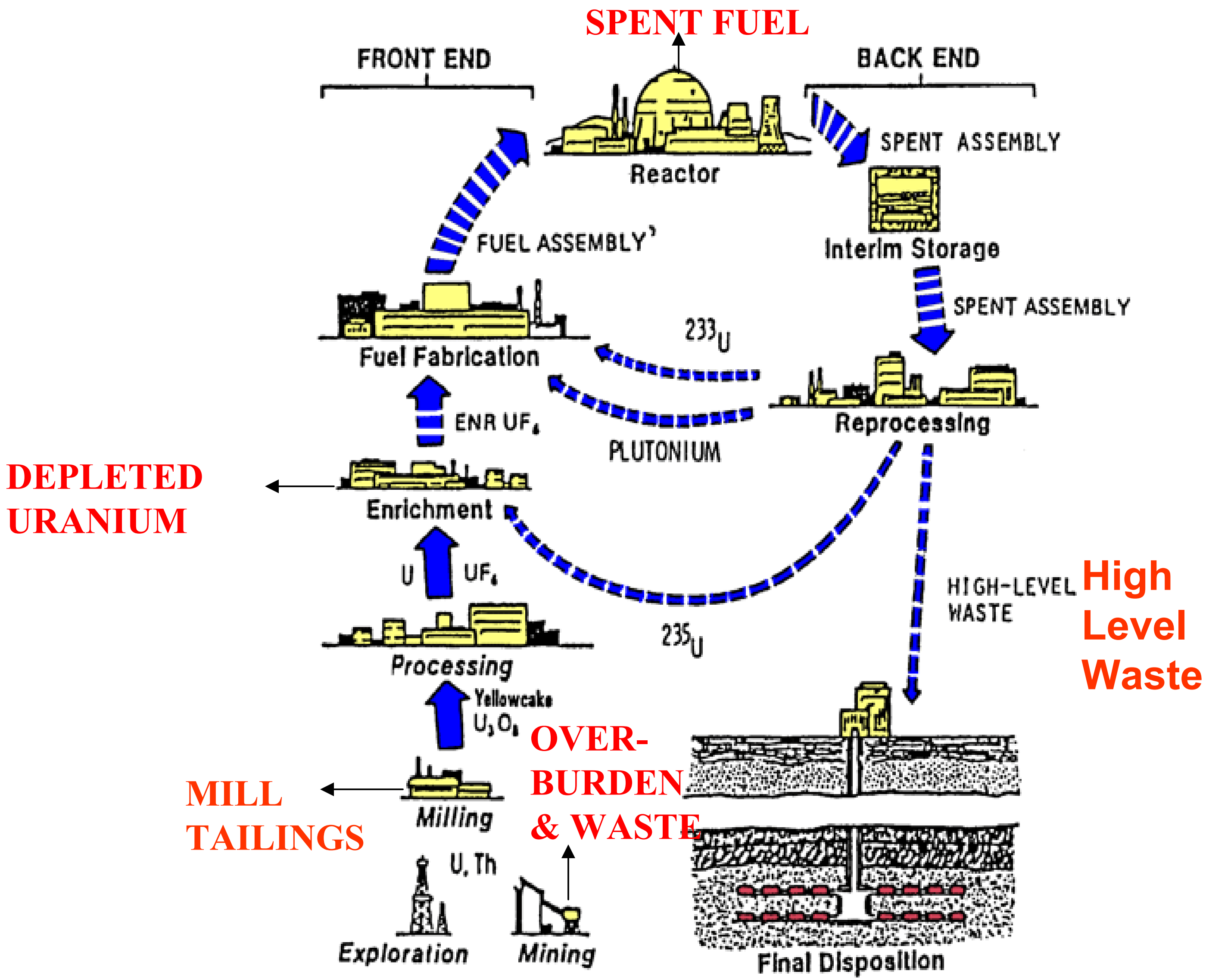
Utilize Lessons Learned from the Past as You Move Forward

Nuclear Fuel Cycle Fundamentals

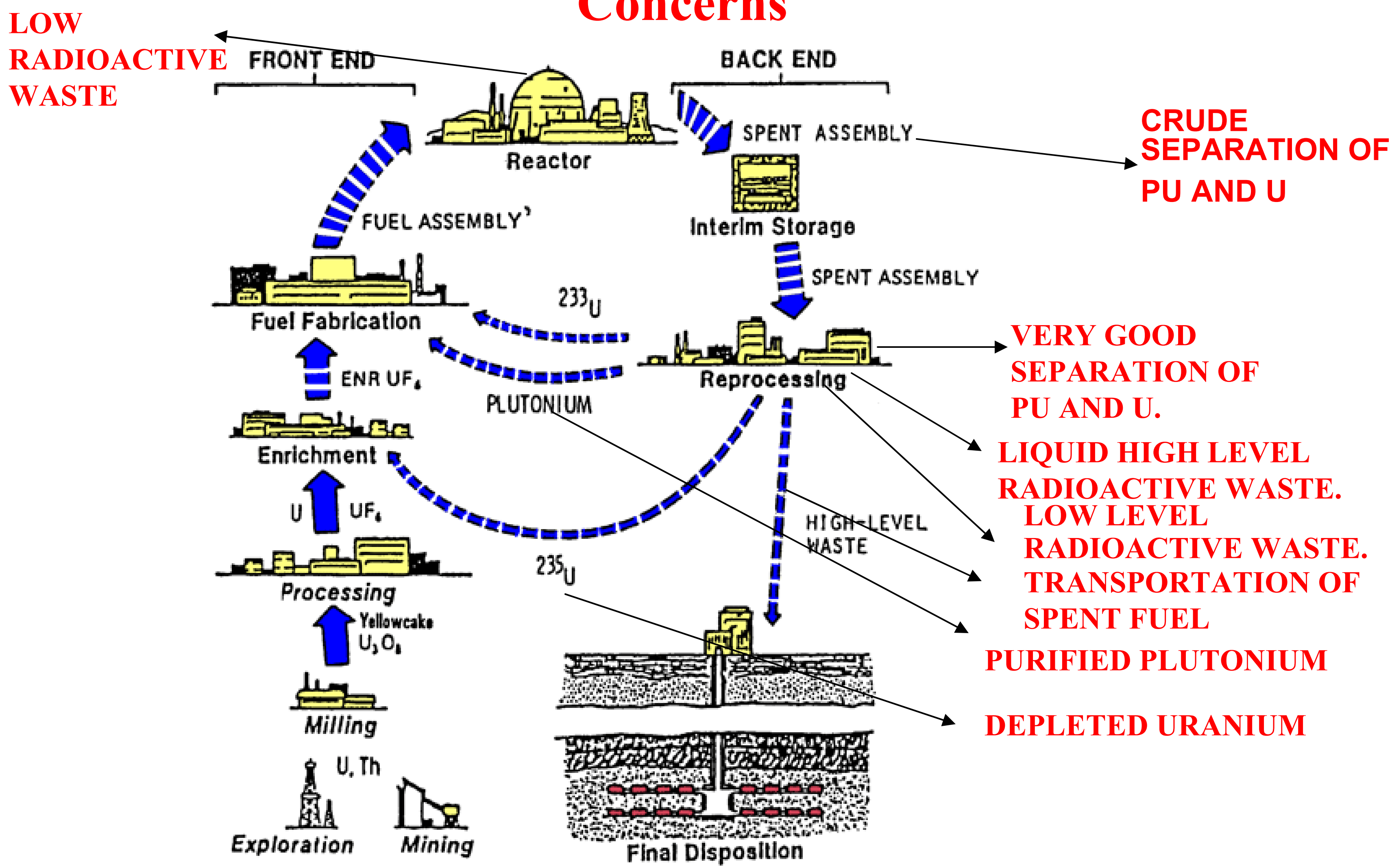
http://www.nrc.gov/materials/fuel-cycle-fac/stages-fuel-cycle.html



Major Waste Producers in the Fuel Cycle



Nuclear Fuel Cycle Proliferation and Radiological Security Concerns



Worldwide Nuclear Fuel Cycle Occupational Exposures, 1990-1994, UNSCEAR 2000

http://www.unscear.org/unscear/en/publications/2000_1.html

Practice	Monitored Workers, Thousands	Average Annual Dose, mSv	
		Monitored Workers	Measurably Exposed Workers
Mining	69	4.5	5.0
Milling	6	3.3	
Enrichment	13	0.12	
Fuel Fabrication	21	1.03	2.0
Reactor Operation	530	1.4	2.7
Reprocessing	45	1.5	2.8
Research	130	0.78	2.5
Total	800	1.75	3.1

Overview of Representative Ecological Risk Assessments Conducted for Sites with Enhanced Radioactivity, November 2007-Conclusions

- For the **aquatic environment**, the non-human biota that are most likely to receive the **highest doses** appear to be **crustaceans, mollusks** and wildlife (**birds and mammals**) relying on the aquatic environment.
- For the **terrestrial environment**, the species that are expected to receive the **highest doses** generally appear to be **vegetation, invertebrates and small mammals.**
- For **normal operations at nuclear fuel cycle sites**, the **potential for effects** in nonhuman biota is **low** and well below reference dose rates at which adverse health effects to populations of nonhuman biota might be anticipated. This holds **true for normal operation and accidents at sites of the early development of weapons and civilian nuclear fuel cycles**.

- Populations of **biota** exposed to **very high levels of radiation**, arising from major accidents, such as **Chernobyl**, seem likely to **recover within a short period** once the **source of exposure is significantly reduced or removed**.

http://www.world-nuclear.org/uploadedFiles/org/reference/position_statements/pdf/wna-senes.pdf

Not Just a Technical Problem

America's Energy Future: Technology Opportunities, Risks, and Tradeoffs NAS 2007-

- This study will critically evaluate the current and projected state of development of energy supply, storage, and end use technologies. The study will not make policy recommendations, but it will analyze where appropriate the role of public policy in determining the demand and cost for energy and the configuration of the nation's energy systems
- Estimated times to readiness for deployment
- Current and projected costs (e.g., per unit of energy production or savings)
- Current and projected performance (e.g., efficiency, emissions per unit of output)
- Key technical, environmental, economic, policy, and social factors that would enhance or impede development and deployment
- Key environmental (including CO2 mitigation), economic, energy security, social, and other life-cycle impacts arising from deployment
- Key research and development (R&D) challenges

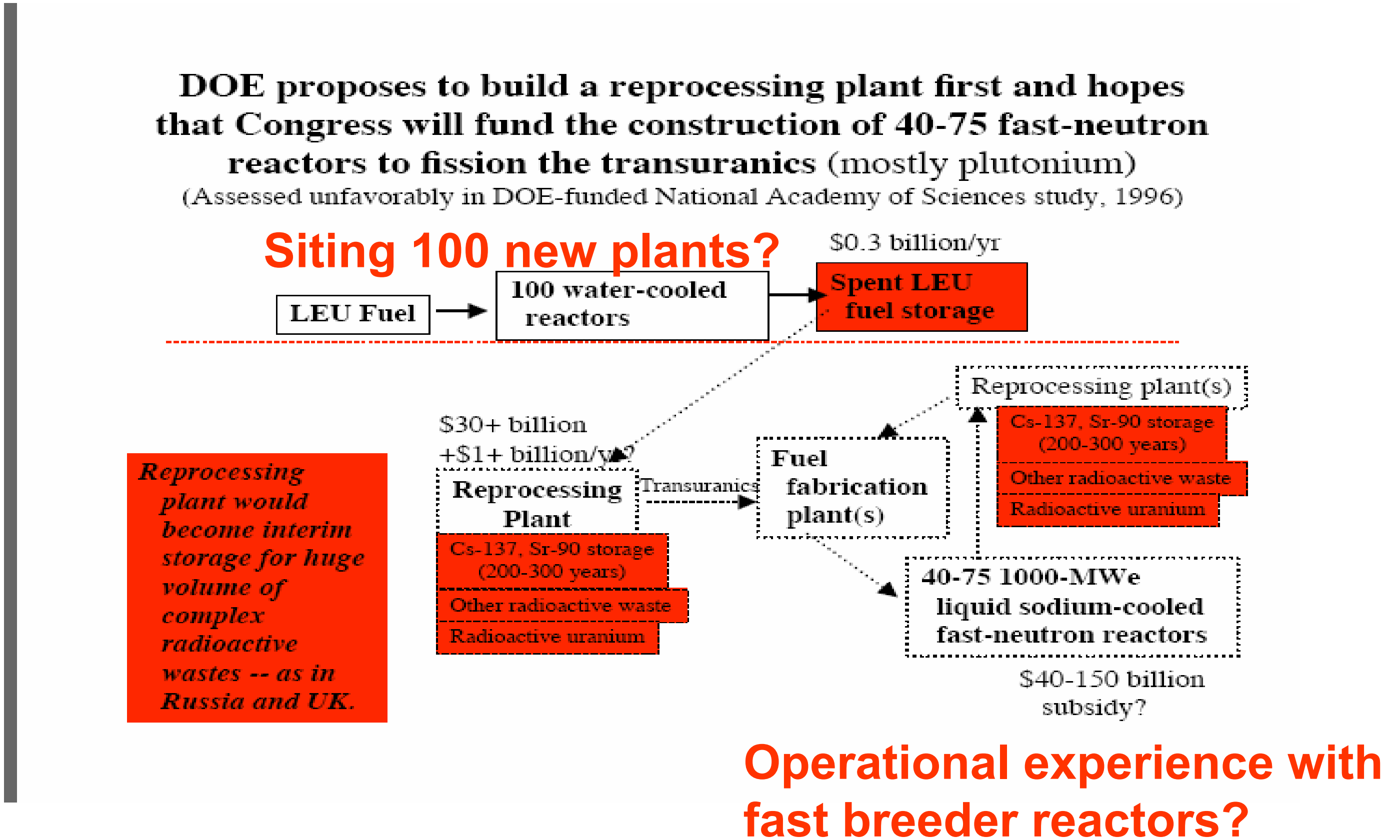
Global Economic Conditions and Demand for Energy- Non-Proliferation and Terrorist Concerns-Geopolitical Concerns, Etc. Will Not Discuss Those Topics But They Will Influence The Technology Decisions More Than What We Shall Discuss.

Managing spent fuel in the United States: The illogic of reprocessing

[report on www.fissilematerials.org)]

Frank von Hippel, Princeton University

http://www.carnegieendowment.org/files/FvHReprocPanelCarnegie**26June07**Rev.pdf



La Hague reprocessing plant cost $20 Billion to build, $1Billion/yr to operate vs.$0.4 Billion/yr total cost for spent fuel storage

Risks of GNEP's Focus on Near-Term Reprocessing

MATTHEW BUNN, NOVEMBER 14, 2007, UNITED STATES SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

"Some elements of GNEP could make important contributions to reducing proliferation risks. Unfortunately, **GNEP's heavy focus on building a commercial-scale reprocessing plant** in the near term would, if accepted, **increase proliferation risks** rather than decreasing them."

Gregory Jaczko, NRC Commissioner, March 10, 2008, **$500 Billion federal loan guarantee needed for a nuclear renaissance.**

WORLD AT RISK:

The Report of the Commission on the Prevention of WMD Proliferation and Terrorism, December 2, 2008

http://www.preventwmd.gov/report

- **Our margin of safety is shrinking, not growing.**
- **The Commission believes that unless the world community acts decisively and with great urgency, it is more likely than not that a weapon of mass destruction will be used in a terrorist attack somewhere in the world by the end of 2013.**
- **the nuclear aspirations of Iran and North Korea pose immediate and urgent threats to the Nuclear Nonproliferation Treaty.**
- **ADDED**
- **France has offered reactors to Georgia, Libya, the UAE, Saudi Arabia, Egypt, Morocco and Algeria.**
- **Pakistan has sold nuclear weapons technology to other countries and has a nuclear arsenal.**

Security Must be Sustainable

Gamimi Seneviratne, Nuclear News, December 2008

Anita Nilsson, Director IAEA’s Nuclear Security Program

“I believe that a new nuclear energy program will have difficulty getting started if it is not perceived by the public to be both safe and secure. I will be very surprised if a new reactor will be built anywhere without the public getting good answersabout its protection against terrorists or criminals or both.”

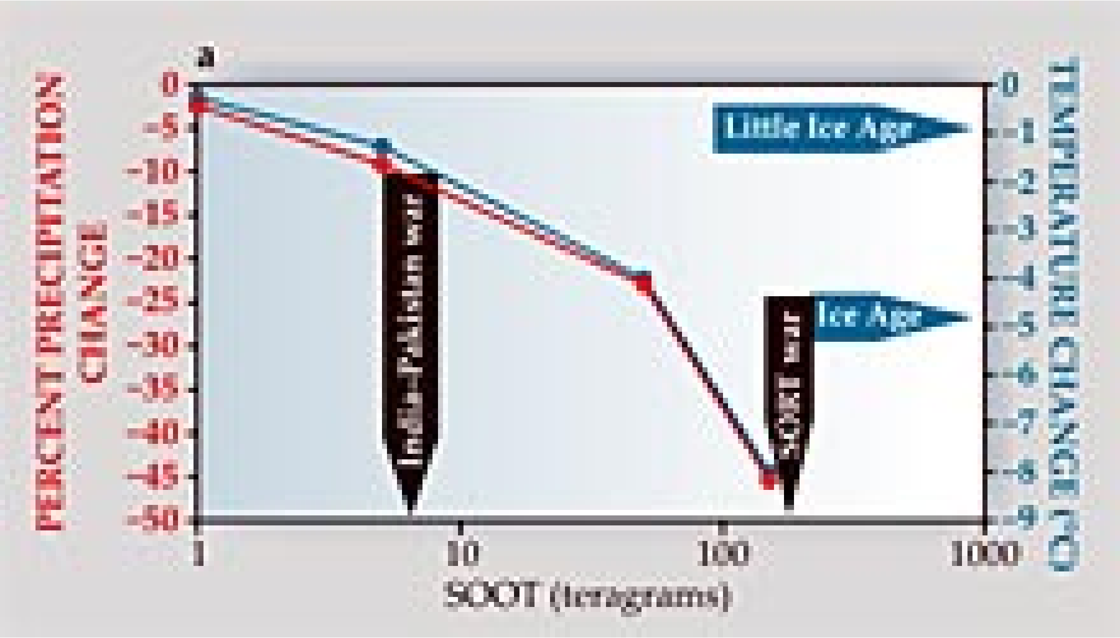
Environmental Consequences of Nuclear War

Toon, Owen B., Alan Robock and Richard P. Turco, Physics Today, December 2008

"A regional war involving 100 Hiroshima-sized weapons would pose a worldwide threat due to ozone destruction and climate change. A superpower confrontation with a few thousand weapons would be catastrophic."

Environmental Consequences of Nuclear War

Toon, Owen B., Alan Robock and Richard P. Turco, Physics Today, December 2008



Change in global average temperature (blue) and precipitation (red)
Indo-Pakistan war and Strategic Offensive Reduction Treaty (SORT) war
(US and Russia 1700-2200 deployed warheads)

Stove Piped-Each With Their Own Agenda
No Global Solution Possible

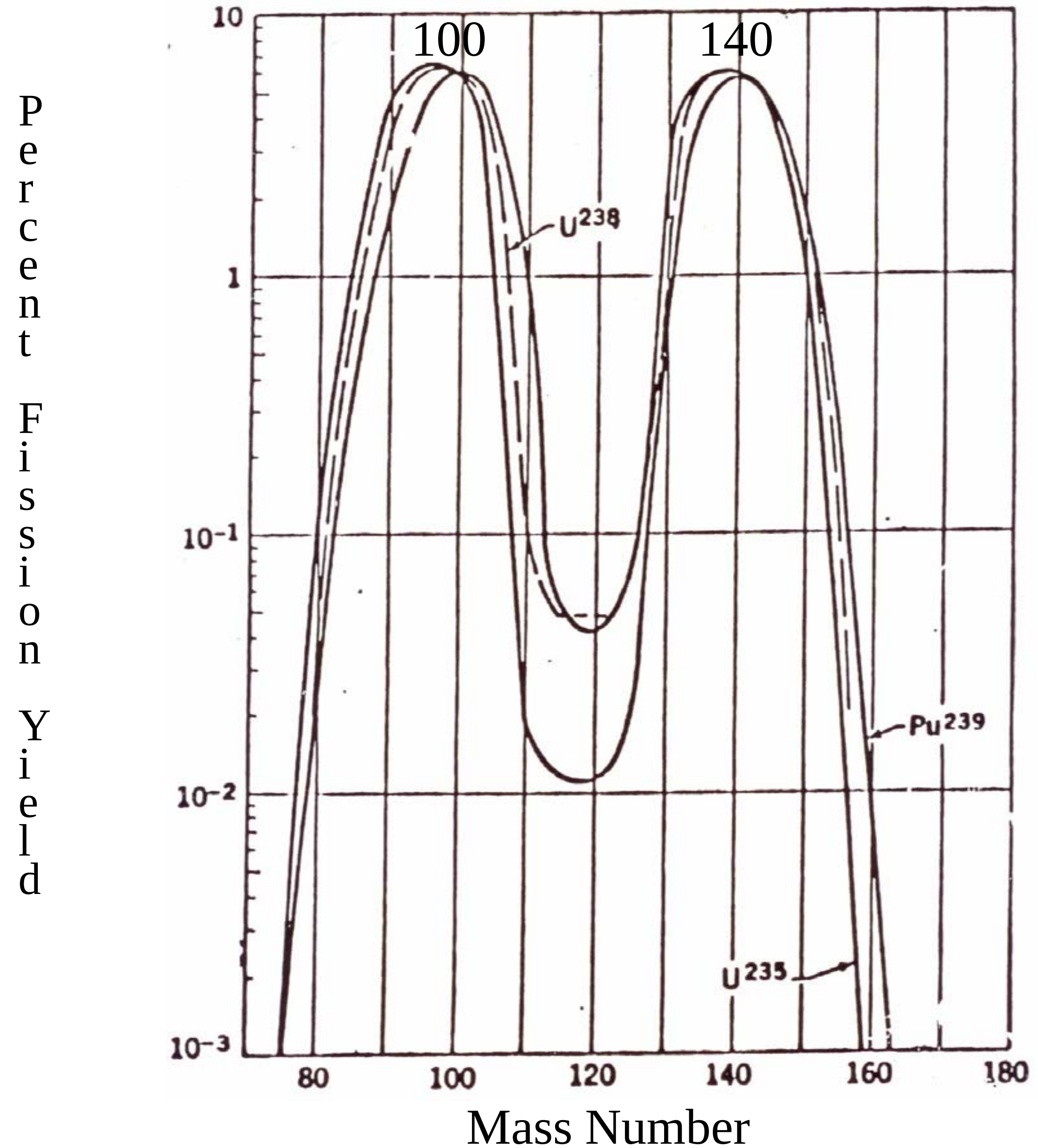
Typical Requirements for the Operation of a 1000 MWe Nuclear Power Reactor

(http://www.world-nuclear.org/info/inf03.html)

Mining	20 000 tonnes of 1% uranium ore
Milling	230 tonnes of uranium oxide concentrate (with 195 t U)
Conversion	288 tonnes UF_6 (with 195 t U)
Enrichment	35 tonnes UF_6 (with 24 t enriched U) - balance is 'tails'
Fuel fabrication	27 tonnes UO_2 (with 24 t enriched U)
Reactor operation	8640 million kWh (8.64 TWh) of electricity at full output
Used fuel	27 tonnes containing 240kg plutonium, 23 t uranium (0.8% U-235), 720kg fission products, also transuranics.

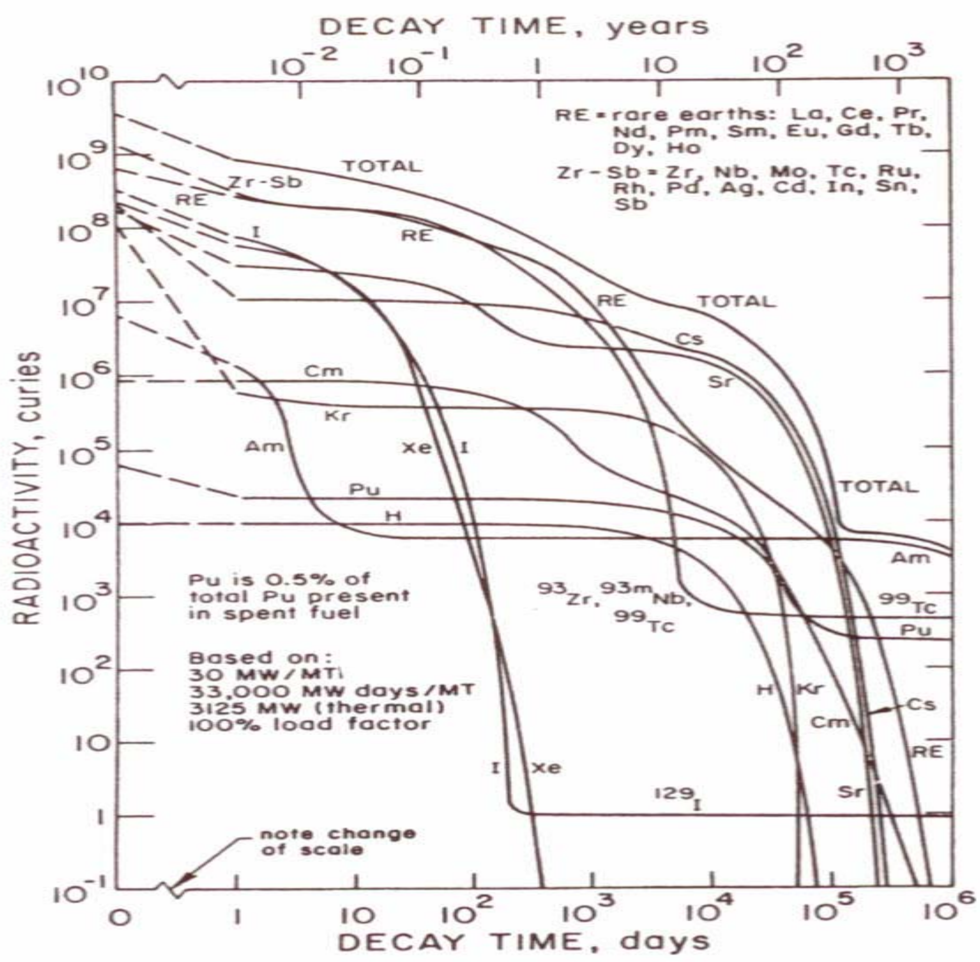
Concentrate is 85% U, enrichment to 4% U-235 with 0.25% tails assay - hence 140,000 SWU required, core load 72 tU, refuelling so that 24 tU/yr is replaced. Operation: 45,000 MWday/t (45 GWd/t) burn-up, 33% thermal efficiency. (In fact a 1000 MWe reactor cannot be expected to run at 100% load factor - 90% is more typical best, so say 7.75 TWh/yr, but this simply means scaling back the inputs accordingly.)

Fission Yields for Slow-Neutron Fission of U-235 and Pu-239 and Fast-Neutron Fission of U-238



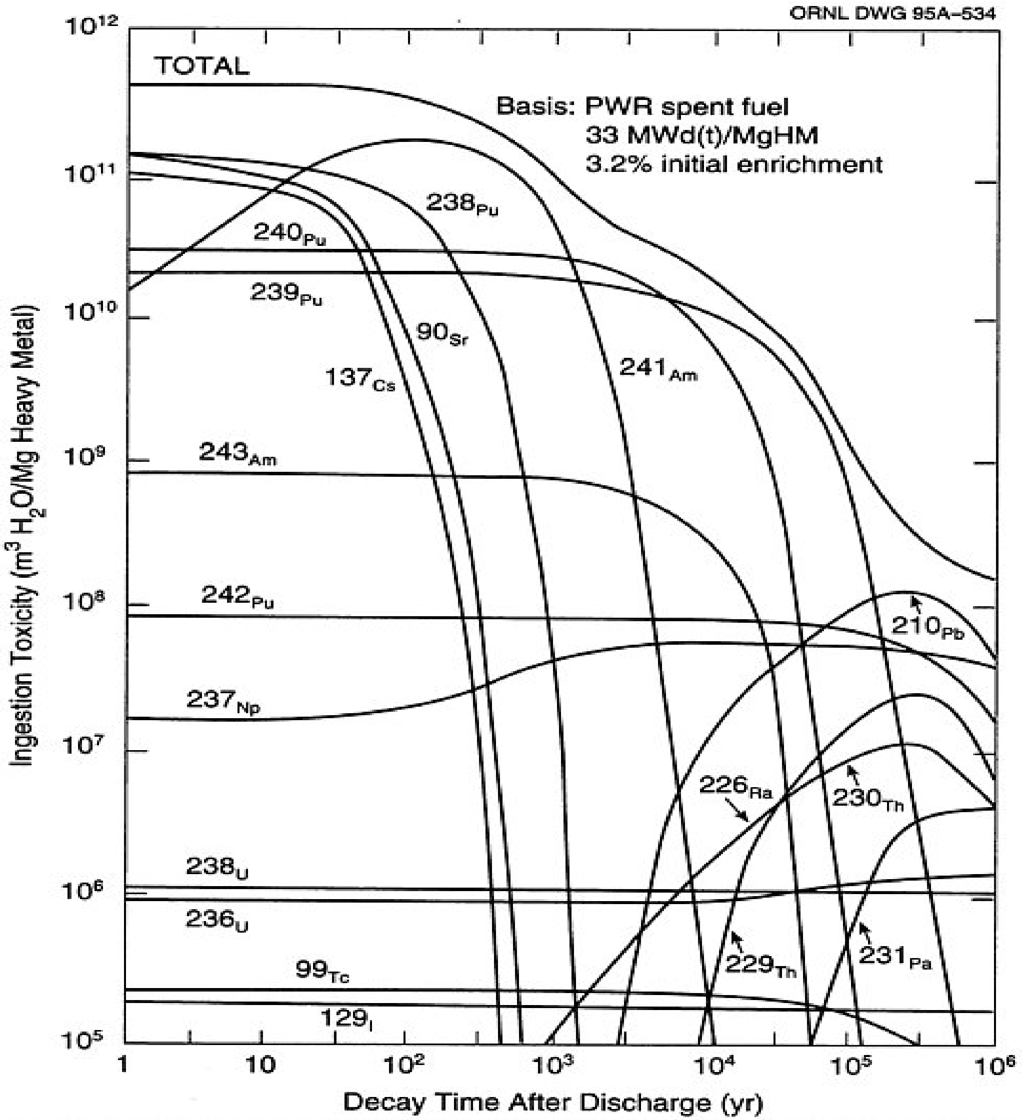
Radioactivity of Fission Products and Actinides in High-Level Wastes Produced in 1 Year of Operation of a Uranium-Fueled 1000 Mwe PWR

Benedict, Manson et al, Nuclear Chemical Engineering, 1981



Toxicity from ingestion as a function of decay time for a number of nuclides in spent LWR fuel.

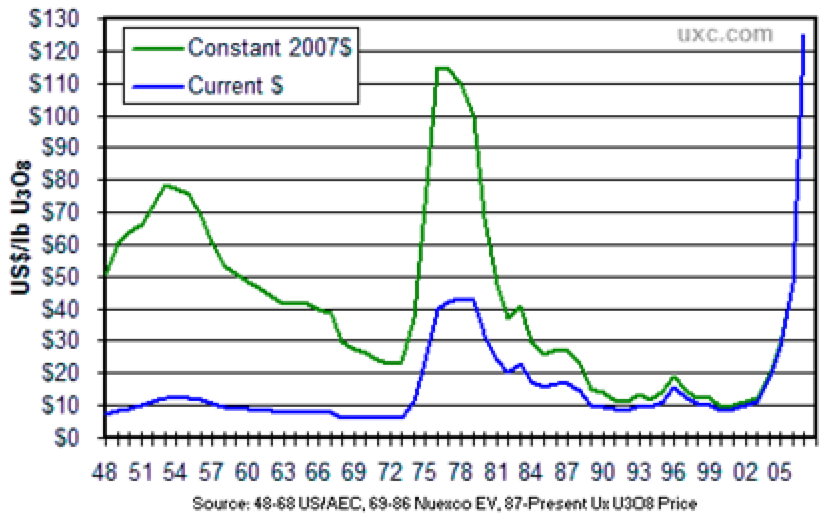
SOURCE: Oak Ridge National Laboratory (1995)
Nuclear Waste:Technologies for Separations and Transmutation NAS, 1996



MINING-SURFACE, SUB-SURFACE AND IN-SITU LEACHING

Constant 2007 US$ vs. Current US$ Spot U3O8 Prices

http://www.uxc.com/review/uxc_g_hist-price.html



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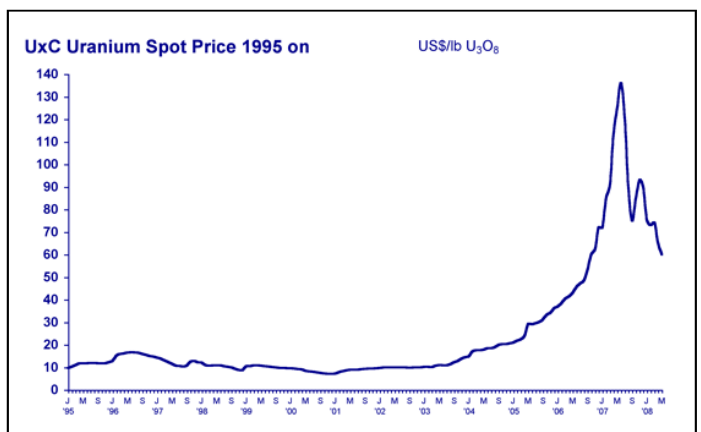


http://www.cameco.com/investor_relations/ux_history/historical_ux.php

USA Uranium Recovery Licensing Activities

Larry W. Camper, NMA/NRC April 29, 2008

http://adamswebsearch2.nrc.gov/idmws/doccontent.dll?library=PU_ADAMS^PBNTAD01&ID=081440220

Facility	Quantity
New ISL Facility	14
New Conventional Mill	7
Combined ISL-Conv.	1
ISL Expansion	7
ISL Restart	1
Conventional Restart	1
TOTAL	**31**

Higher Potential for Ground Water Contamination

Uranium Mining Methods Worldwide

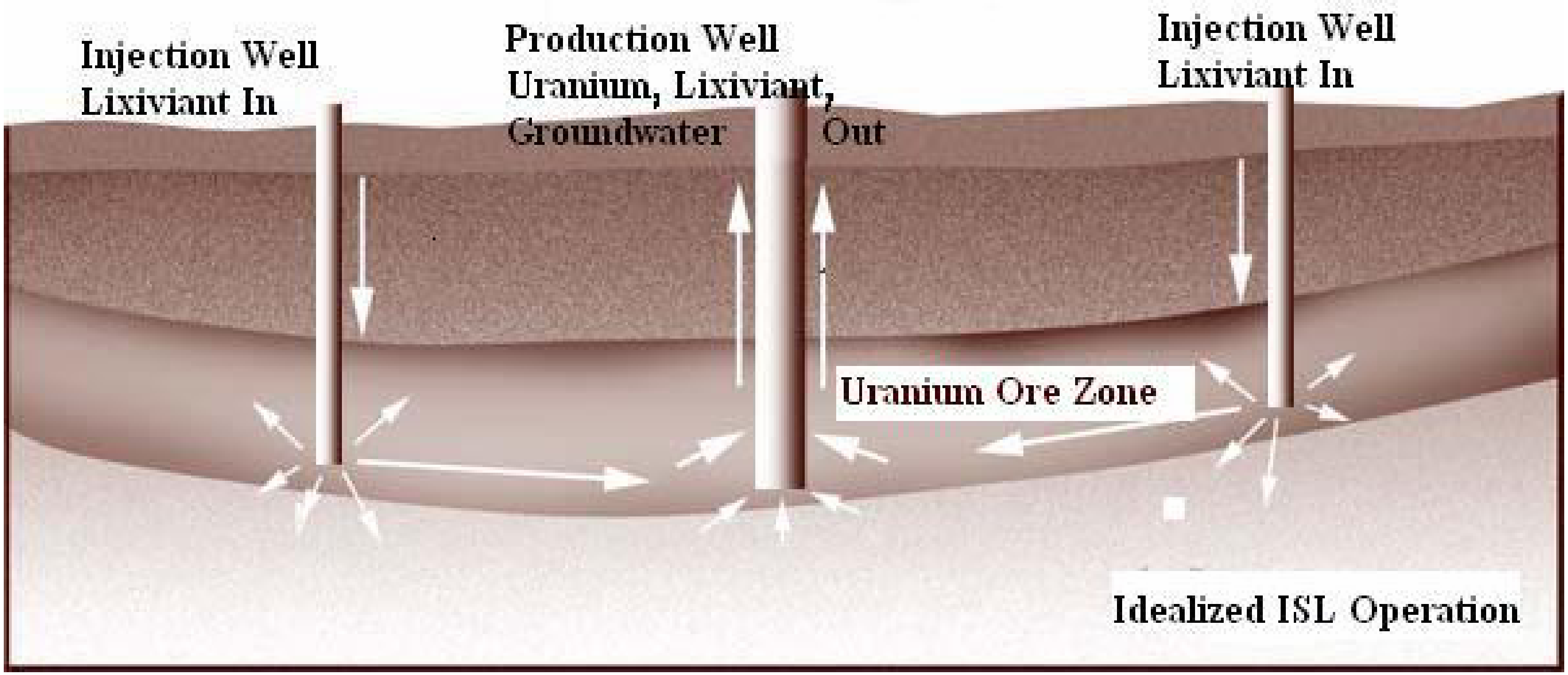
http://www.world-nuclear.org/info/inf23.html?terms=uranium+mining+usa

Uranium Mining Method	2007 Production Percent
Conventional Underground and Open Pit	62
In-Situ Leaching	29
By-product	10

Waste Uranium Rock “Pyramids" Ronneburg, Germany

http://www.wise-uranium.org/uwai.html#UMIN

Idealized Version of In Situ Leaching



Simplified version of how ISL solution mining works. Lixiviant is injected into the ground through a well on the left and far right. The fluid flows underground dissolving Uranium and carrying it in solution until it reaches a production well in the center. The fluid carrying dissolved uranium is returned to the surface from the production well, then is piped to a production facility for refinement into yellowcake.

Assumes complete capture of lixiviant with no ground water contamination

Impacts from Abandoned USA Uranium Mines-Uncertainties

1. **Actual Exposure of People**

   Many mines are on **federal lands**. Therefore, **mostly recreational use except** for **Native Americans** who live and may work around the site. Not all reclaimed nor if nearby buildings are contaminated.

2. **Actual Effect on Groundwater** and Its Use

   Drinking water wells withdraw from **deep aquifers**. May not be **contaminated**. Mines are in mineralized areas. **Difficult to differentiate between mine effluent and naturally occurring uranium**.

3. **Concentration of Contaminants**

   Ra-226, U and As may be problems but can only be determined on a site specific basis.

Technologically Enhanced Naturally Occurring Radioactive Materials from Uranium Mining, Vol. 2 Investigation of Potential Healt,Geographic, and Environmental Issues of Abandoned Uranium Mines, [EPA 402-R-08-005] April 2008

Overview of Representative Ecological Risk Assessments Conducted for Sites with Enhanced Radioactivity, November 2007-Uranium Mining

McArthur River, Canada

- Almost all of the predicted increases in the body burden or **dose in receptors** are related to the release of **treated mine water**. Few to no effects are predicted to result from air.
- The only valued **ecological component** predicted to exceed the benchmark radiological dose was the **scaup duck** primarily due to **ingestion of Po-210**. The risk is **limited** to the area near the discharge point and should **return to background** after the end of operations.
- The dose to **benthic invertebrates** (chironomid) exceeds the reference dose of 10 mGy/d only when a radiation weighting factor of 40 is assumed for alpha radiation. For the more realistic factor of 10, the **reference dose is not exceeded.**

http://www.world-nuclear.org/uploadedFiles/org/reference/position_statements/pdf/wna-senes.pdf

URANIUM MILLING AND TAILINGS

Only I mill, White Mesa, operating in USA but Shootaring Mill is changing its license to operational status.

Doses as a Result of Milling Operations, UNSCEAR 2000			
Milling		Average Annual Dose, mSv	
	Monitored Workers, thousands	Monitored Exposed Workers	Measurably Exposed Workers
	6	3.3	

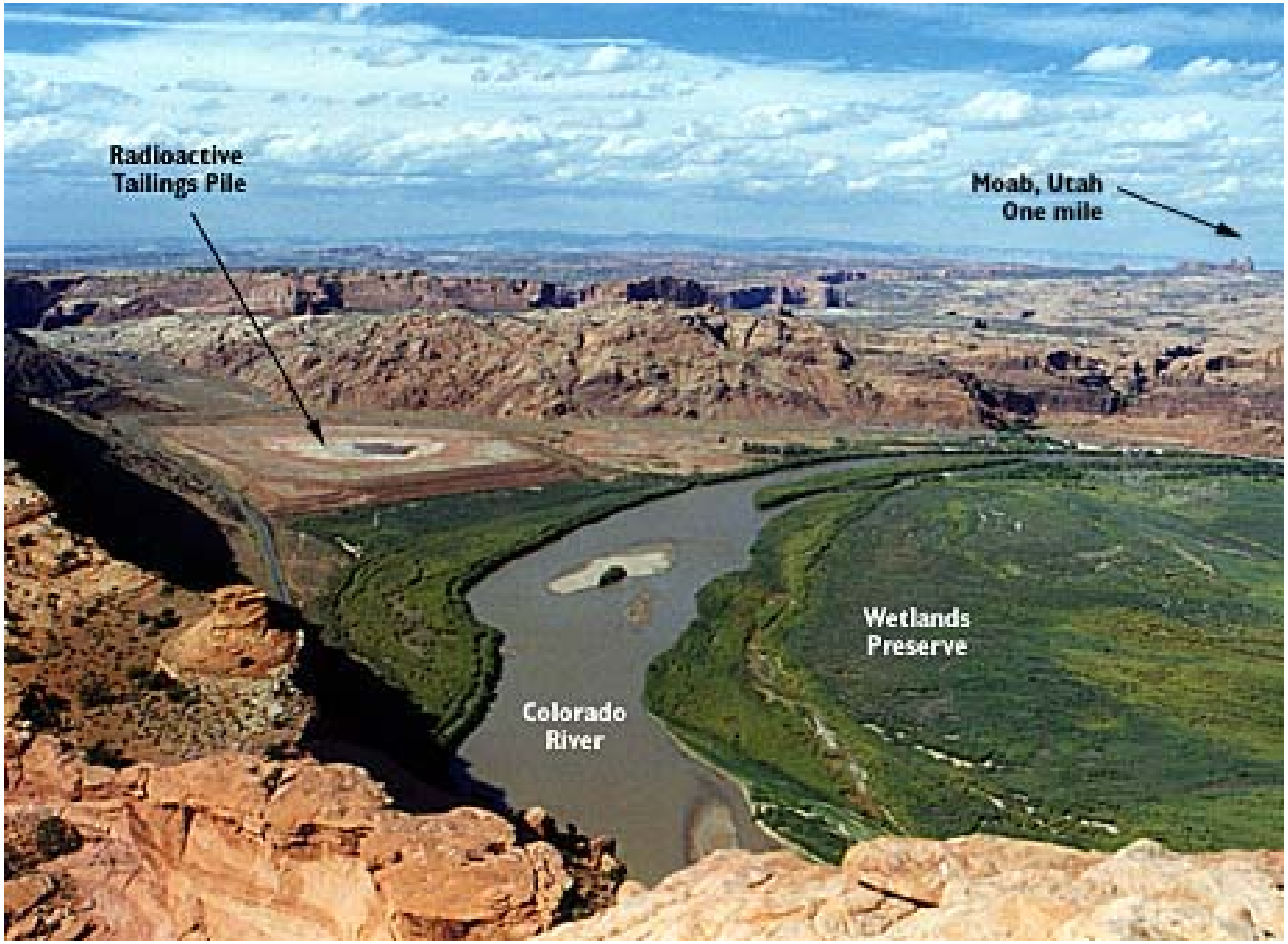
Summary-Mill Tailings Sites

All U.S. sites are closed except for Grand Junction, that is only receiving residues, and the Moab site tailings that are being removed from the Colorado River bank.

Costs of closure greatly underestimated; $1.5 billion USD spent to date

Cover designs need to accommodate environmental change and natural processes

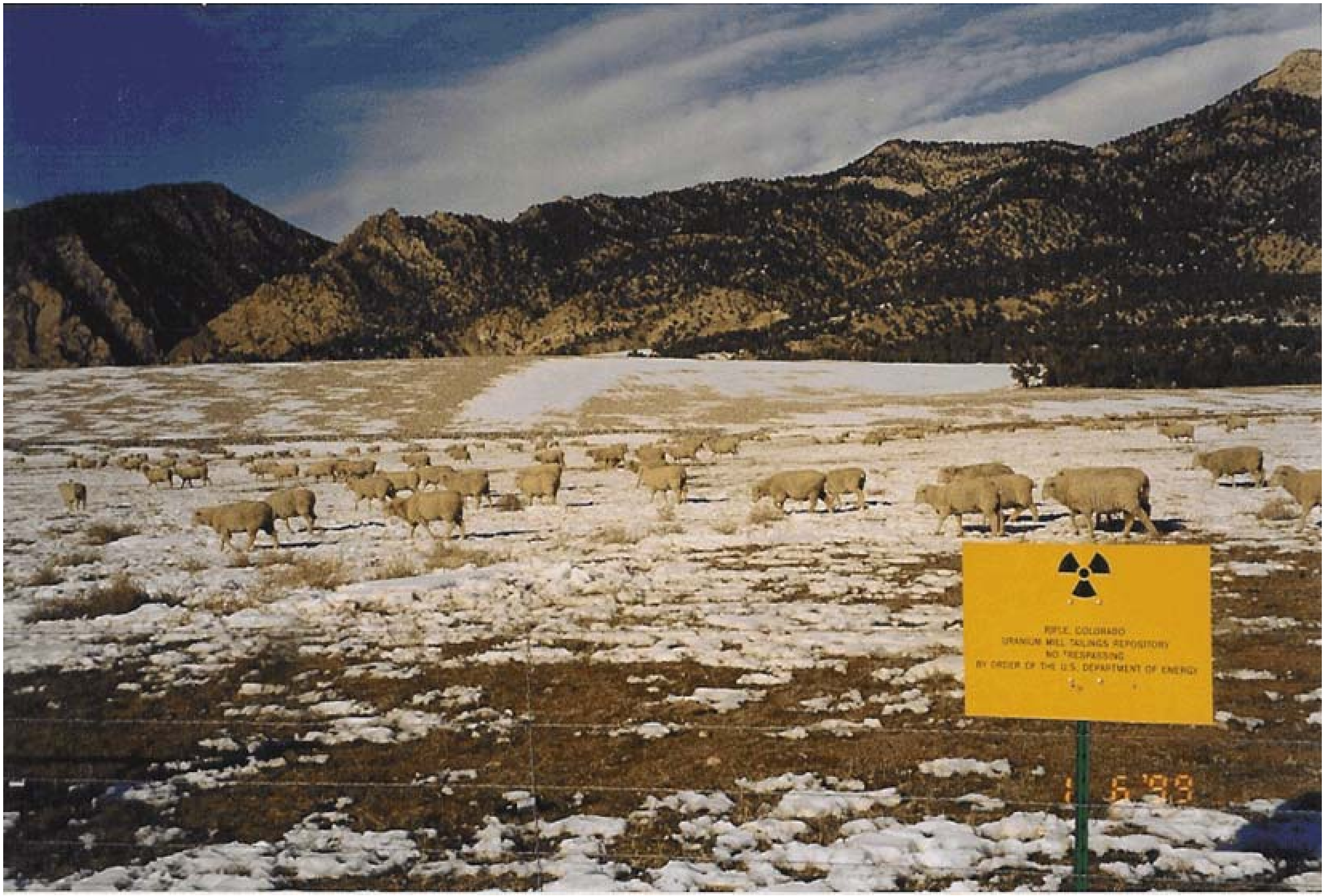
Atlas Mines Tailing Pile near Colorado River, Moab, Utah



URANIUM MILL TAILINGS DISPOSAL

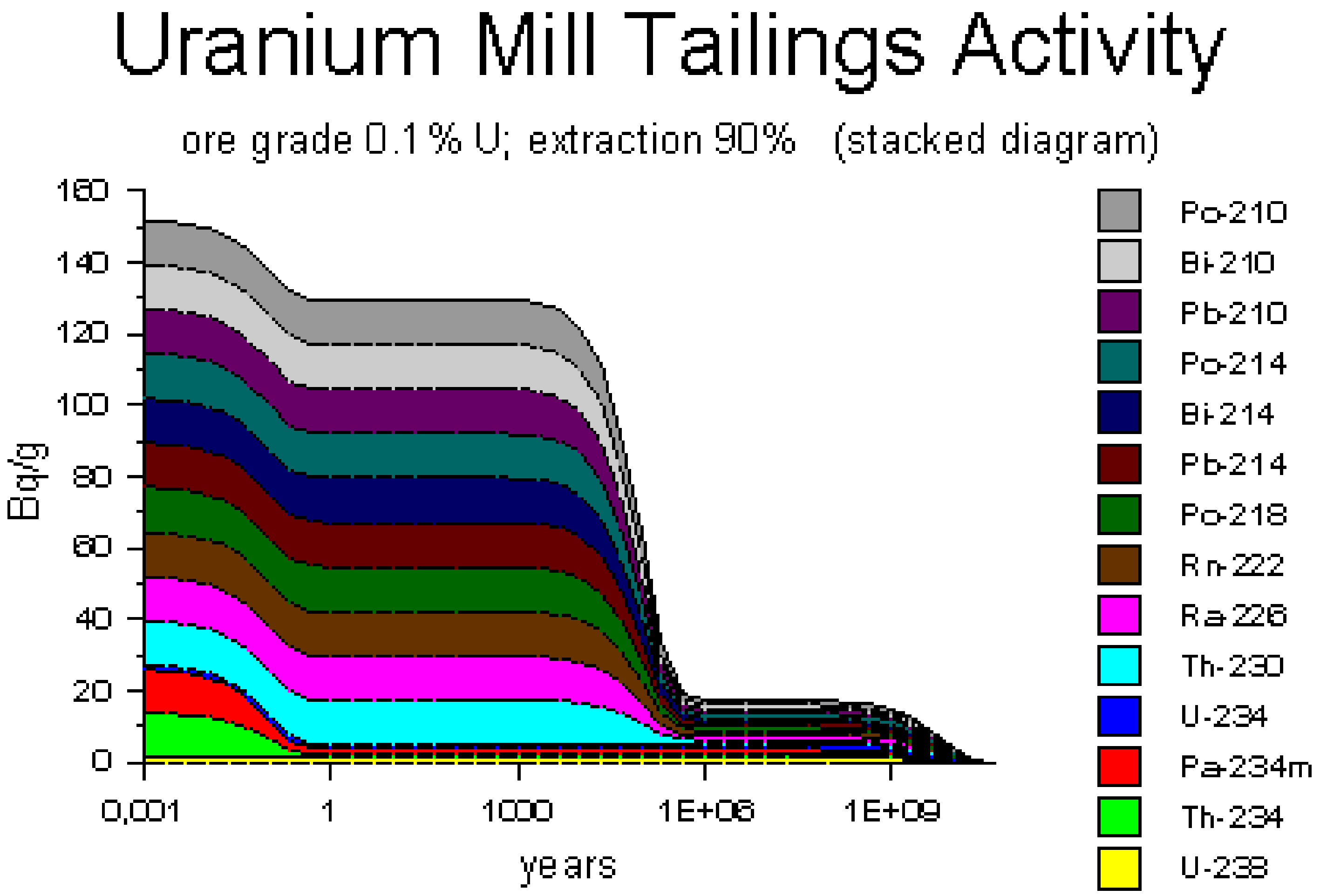
Burrell Mill Tailings Site

SHEEP GRAZING ON RIFLE MILL TAILINGS SITE



WISE Uranium Project

http://www.wise-uranium.org/rup.html December 13, 2006



Relative Risk and Uranium Recovery-Douglas B. Chambers

NMA/NRC Uranium Recovery Workshop April 29, 2008

http://adamswebsearch2.nrc.gov/idmws/doccontent.dll?library=PU_ADAMS^PBNTAD01&ID=081440199

- **From a Study of Colorado Populations Near Uranium Mining/Milling Operations**

- **No statistically significant increases for any cause of death except Lung Cancers in males (associated with historical occupational exposures); no increase in females**

- **No evidence that residents experienced increased risk of death due to environmental exposures from uranium mining and milling**

Depleted Uranium Fluoride in Cylinders

http://web.ead.anl.gov/uranium/mgmtuses/storage/index.cfm

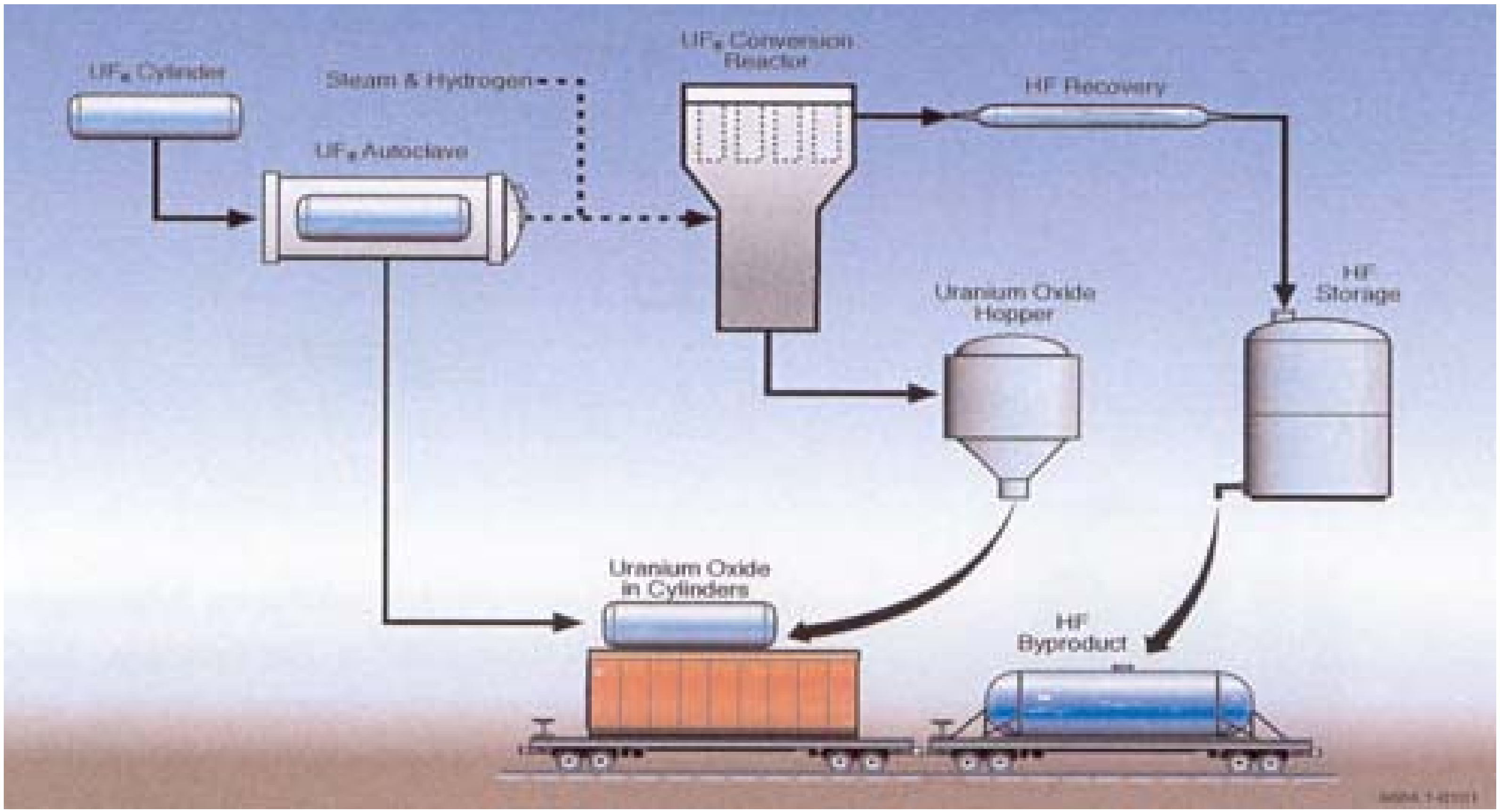
Location	Total Cylinders	Total Depleted UF_6 Metric tonnes
Paducah, KY	36,191	436,400
Portsmouth, Ohio	16,109	195,800
Oak Ridge, TH	4,822	54,300
Total	57,122	685,500

When UF6 is released to the atmosphere, it reacts with the moisture in the air to produce UF that is highly toxic.

Depleted Uranium Hexafluoride Conversion toUO_2

Portsmouth, Paducah and Oak Ridge Gaseous Diffusion Enrichment Plants

http://www.uds-llc.com/duf_conversion.htm



$UF_6 + 2\ H_2O \Rightarrow UO_2F_2 + 4HF$

$UO_2F_2 + H_2 + H_2O \Rightarrow UO_x + HF$

Full Operations scheduled 2010-11

700,000 metric tons of DUF6

Enrichment

http://www.silex.com.au/

	SILEX	CENTRIFUGE	GAS DIFFUSION
DEVELOPED	2000's	1940's	1940's
ENRICHMENT EFFICIENCY	2 to 0(1)	1.3	1.004
COST COMPARISON	Potentially Attractive	Capital Intensive	Very expensive
% OF EXISTING MARKET(2)	0%	54%	33%
STATUS	**STATUS** Under Development 3rd Generation	Proven 2nd Generation	Obsolescent 1st Generation

(1) This number is Business Classified - the range indicated is dictated by the technology Classification Guide
(2) Approximately 13% supplied via Russian HEU material

NUCLEAR POWER PLANTS
GENERATION OF REACTORS

GENERATIONS OF REACTORS

GEN I Only six still in operation. Less than 250 MWe* and all in UK

GEN II (1960s-1970s) Most commercial power reactors in operation today are light water reactors (LWR), Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR). There are a small number of Heavy Water Reactors (HWR) all derived from Canadian models (CANDU) and Russian graphite reactors (RBMK) (Реактор Большой Мощности Канальный)

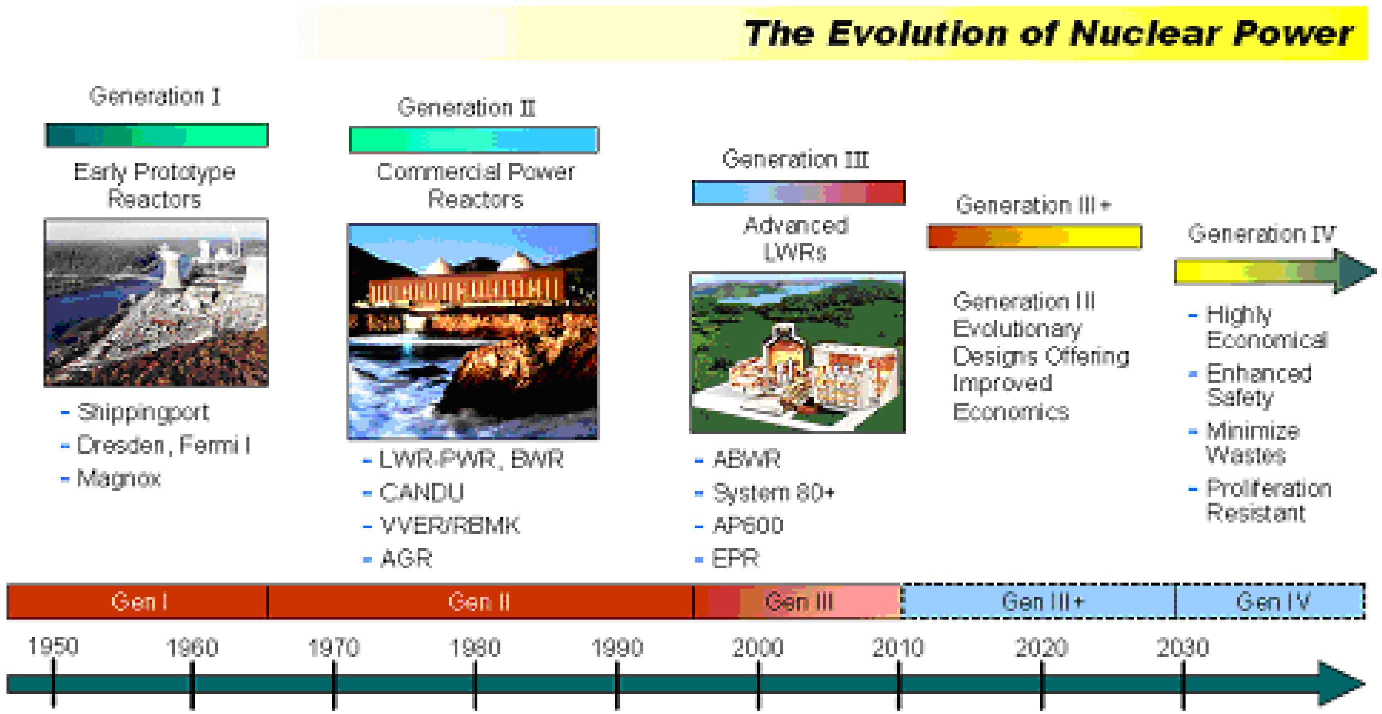
GEN III (1990s) Mostly in France and Japan. **Standardized & improved GEN II**

GEN III+ Is being used in the **current expansion of nuclear power**

GEN IV Future reactors-now limited to the 6 most likely

*Megawatts electricity

A TECHNOLOGY ROADMAP FOR GENERATION IV NUCLEAR ENERGY SYSTEMS-EXECUTIVE SUMMARY, March 2003 USDOE



Overview of Representative Ecological Risk Assessments Conducted for Sites with Enhanced Radioactivity, November 2007-Nuclear Power Plants

Loire River, France

- **14 nuclear power plants on the River releasing (only β and γ emitting isotopes) 54Mn, 58Co, 60Co, 110mAg, 63Ni, 123mTe, 124Sb, 125Sb, 131I, 134Cs, 137Cs, 3H and 14C. Only 5, 3H, 14C, 131I and 134, 137 Cs were important in the assessment of chronic exposure.**
- **The estimated dose rates to freshwater organisms in the Loire River and its estuary are at least 5 orders of magnitude lower than those at which effects have been reported. The main contribution to the estimated dose rate is internal cesium exposure.**

http://www.world-nuclear.org/uploadedFiles/org/reference/position_statements/pdf/wna-senes.pdf

Review of DOE's Nuclear Energy Research and Development Program-Executive Summary, 2007

The National Academies (http://www.nap.edu/catalog/11998.html)

"…all committee members agree that the **GNEP** (Global Nuclear Energy Partnership) program **should not go forward** and that it should be replaced by a less aggressive research program."

The Future of Nuclear Power, MIT, 2003

(http://web.mit.edu/nuclearpower)

- The prospects for nuclear energy as an option "are **limited** by four unresolved problems: **high** relative **costs**; **perceived adverse safety, environmental, and health effects**; potential **security risks** stemming from **proliferation**; and unresolved challenges in **long-term management of nuclear wastes."**

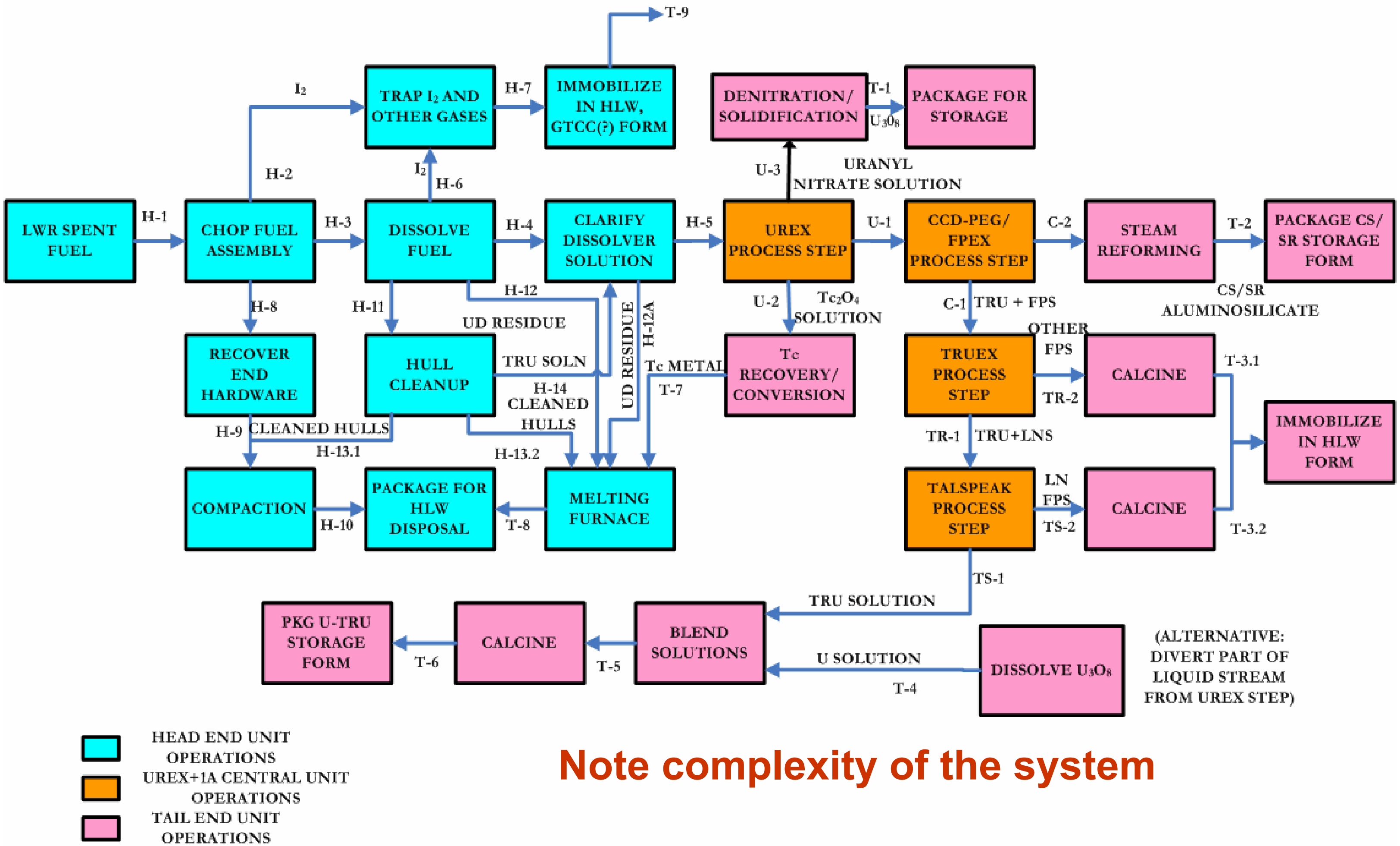
- Place "increased emphasis on the **once-through fuel cycle** as best meeting the **criteria of low costs and proliferation resistance";**

- DOE should "..perform the analysis necessary to evaluate alternative reactor concepts and fuel cycles using the criteria of cost, safety, waste, and proliferation resistance. **Expensive development projects should be delayed pending the outcome of this multi-year effort."** (emphasis added)

REPROCESSING

UREX +1A PROCESS

Spent Nuclear Reactor Fuel Reprocessing-Where Have We Been and Where Are We Going? Raymond G. Wymer, Vanderbilt University, January 29, 2007



Note complexity of the system

Overview of Representative Ecological Risk Assessments Conducted for Sites with Enhanced Radioactivity, November 2007, Nuclear Spent Fuel Reprocessing Plants

La Hague, France

The predicted dose rates to marine biota attributable to radioactive discharges to the sea from the La Hague facility are small, well below comparison guidance levels at which deleterious and observable health effects to populations of marine biota might be expected and well below dose rates from background radioactivity in the region.

http://www.world-nuclear.org/uploadedFiles/org/reference/position_statements/pdf/wna-senes.pdf

RADIOACTIVE WASTE

U.S. RADIOACTIVE WASTES

WASTE CATEGORY	MASS (MTHM)	VOLUME (m^3)	RADIOACTIVITY 10^{16} Bq	10^6Ci
SPENT NUCLEAR FUEL	34,253	13,808	N.A.	
HIGH LEVEL WASTE		347,350	3337	902
TRU (DOE)		238,015	9.6	2.6
LOW LEVEL WASTES		320,764	N.A.	
URANIUM MILL TAILINGS		146,700,000	N.A.	
MIXED LOW LEVEL WASTES		147,254	N.A.	

MTHM = METRIC TONS HEAVY METALS   N.A. = NOT AVAILABLE

DOE "INTEGRATED DATA BASE REPORT-1966: US NUCLEAR SPENT FUEL AND RADIOACTIVE WASTE INVENTORIESK PROJECTIONS, ND CHARACTERISTICS" DECEMBER 1997

US CONTAMINATED ENVIRONMENTAL MEDIA*

SOLIDS 79×10^6 m^3

SOILS 75×10^6 m^3

WATER $1{,}800 \times 10^6$ m^3

(GREATER THAN 99 % IS GROUNDWATER)

REMEDIATION COSTS**

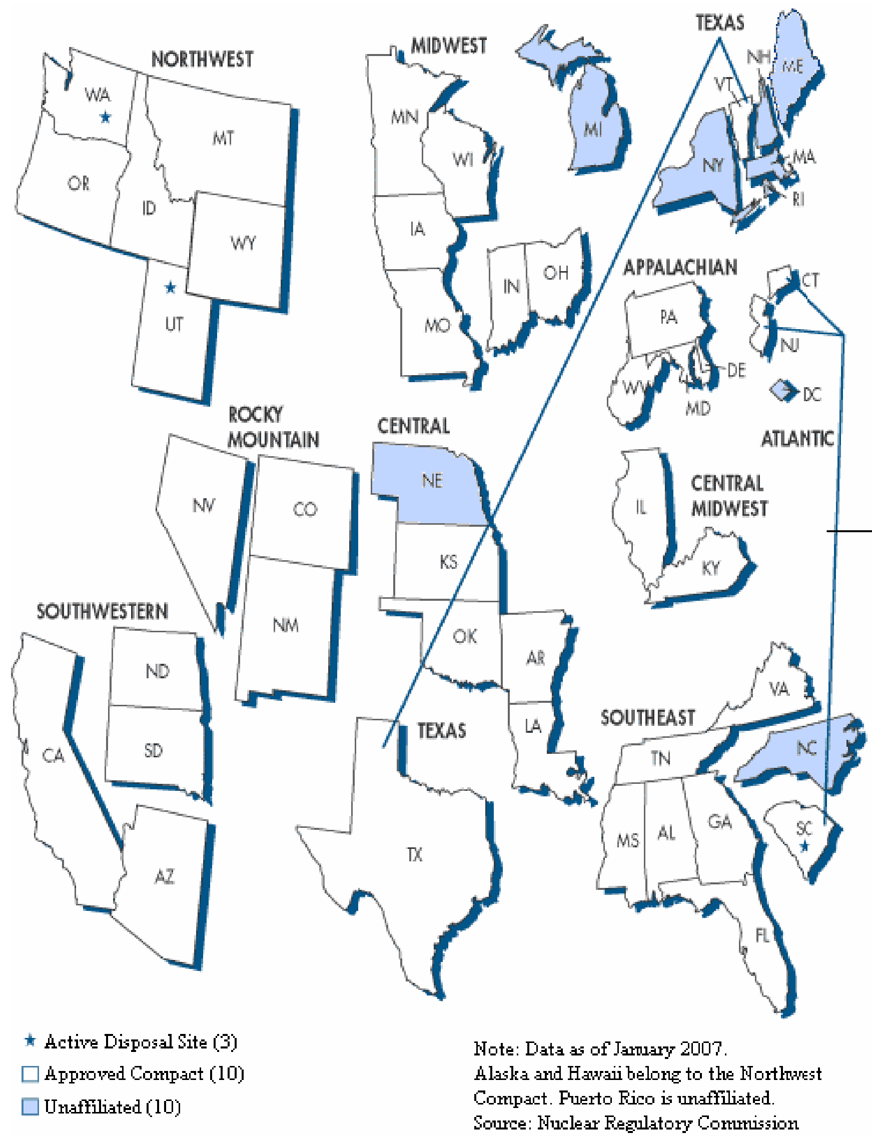
$147.3 BILLION (CONSTANT 1998 DOLLARS)
($57 B 1997-2006; $90.3 B 2007-2070)

*LINKING LEGACIES: CONNECTING THE COLD WAR NUCLEAR WEPONS PRODUCTION PROCESSES TO THEIR ENVIRONMENTAL CONSEQUENCES; DOE JANUARY 1997 DOE/EM-0319
**ACCELERATING CLEANUP: PATHS TO CLOSURE; DOE JUNE 1998 DOE/EM-0362

LOW LEVEL WASTE DISPOSAL FACILITIES

Low-Level Waste Compacts

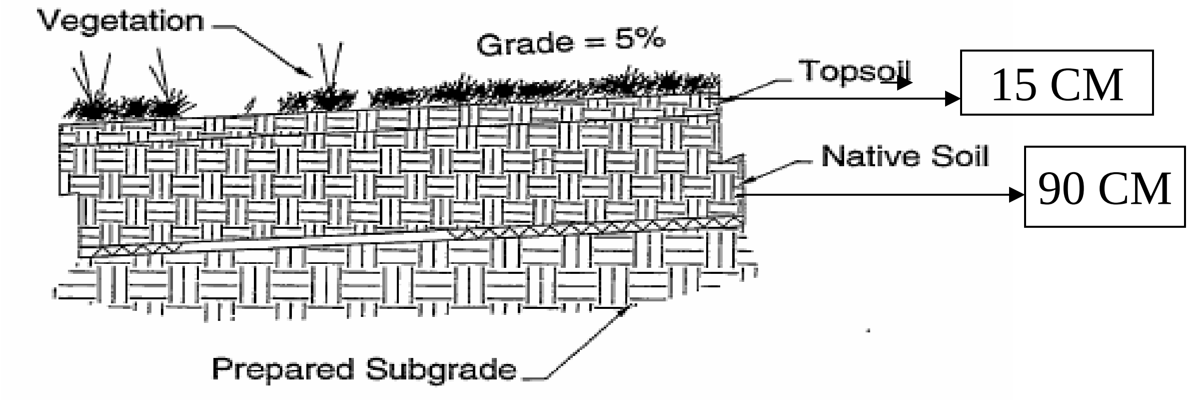
http://www.nrc.gov/waste/llw-disposal/compacts.html



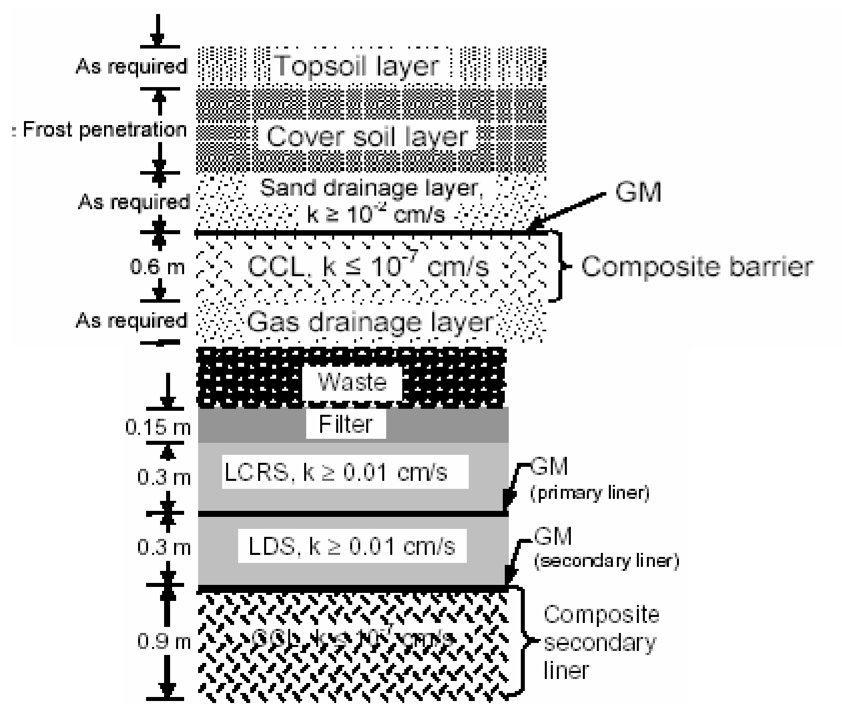
Atlantic Compact, Barnwell, as of July 1, 2008, no longer accepts out of Compact waste.

Boxes containing low-level radioactive waste lie in a shallow land burial trench at the Savannah River Site. Alternative methods for the disposal of low-level waste are being developed by the Department. *Savannah River Site, South Carolina. January 7, 1994.*

EVAPOTRANSPIRATION COVER



RCRA Type C Landfill Covers and Liners



OAK RIDGE HDPE RCRA CAP

Overview of Representative Ecological Risk Assessments Conducted for Sites with Enhanced Radioactivity, November 2007, Surface Radioactive Waste Disposal Site

For radioactive waste management and disposal sites, although higher dose rates can be sometimes found in the immediate proximity of radioactive wastes within the site boundaries, further away from the source of radioactivity or beyond the site boundaries, dose rates are below the reference dose rates.

http://www.world-nuclear.org/uploadedFiles/org/reference/position_statements/pdf/wna-senes.pdf

HIGH LEVEL WASTE TANK STORAGE

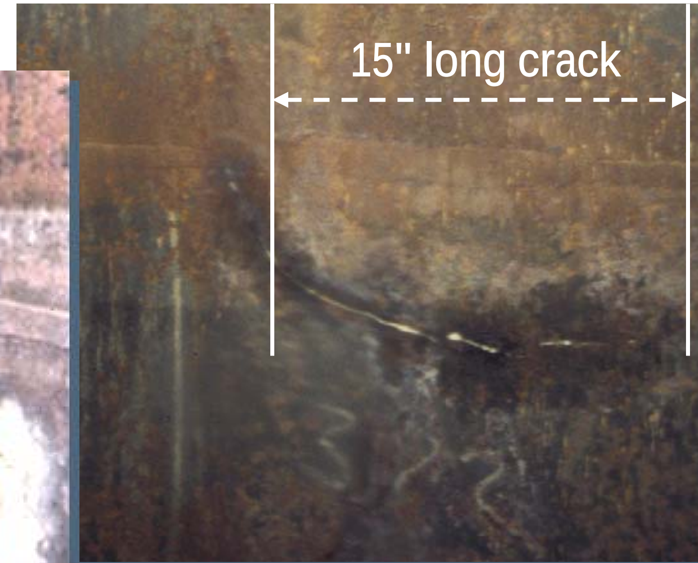
Cooling Coils in SRS Tank

Tank Waste Retrieval, Processing, and on-Site Disposal at Three Department of Energy Sites, National Research Council, 2006

Salt Waste in Tank Annulus at SRS

Tank Waste Retrieval, Processing, and on-Site Disposal at Three Department of Energy Sites, National Research Council, 2006

Tank 14



Tank 15

Outside of primary tank wall

Salt waste that leaked from tank and is contained in annulus pan

Ventilation duct

SRS WASTE TANK SLUDGE

Tank Waste Retrieval, Processing, and on-Site Disposal at Three Department of Energy Sites, National Research Council, 2006

STATISTICS OF CLEANUP OF TANK SITES

Tank Waste Retrieval, Processing, and On-Site Disposal at Three Department of Energy Sites: Final Report, The National Academies Press, 2006

	Hanford	Savannah River	Idaho
Reprocessing Methods	3	2	1
Number of Tanks (Total)	177	51	7 Bin Sets
Single Shell	149	8 (Type IV)	
Double Shell	28	43 (Types I-III)	
Number of Tanks Closed		2 (~1% OF Total)	

Defense Waste Processing Facility SRS

Terrel J. Spears, 2008

http://www.em.doe.gov/pdfs/SRS-Spears%20SR%20to%20Natl%20Academies%20Brief%201-08-08.pdf

- Began radioactive operations in March 1996
- 2,430 canisters filled At beginning of 2008
- Projected to produce more than 5,000 canisters by 2019 containing 417 million curies

WIPP(WASTE ISOLATION PILOT PLANT) TRANSURANIC WASTE DISPOSAL

Disposal at WIPP-November 24, 2008

http://www.wipp.energy.gov/shipments.htm

Total Shipments to WIPP

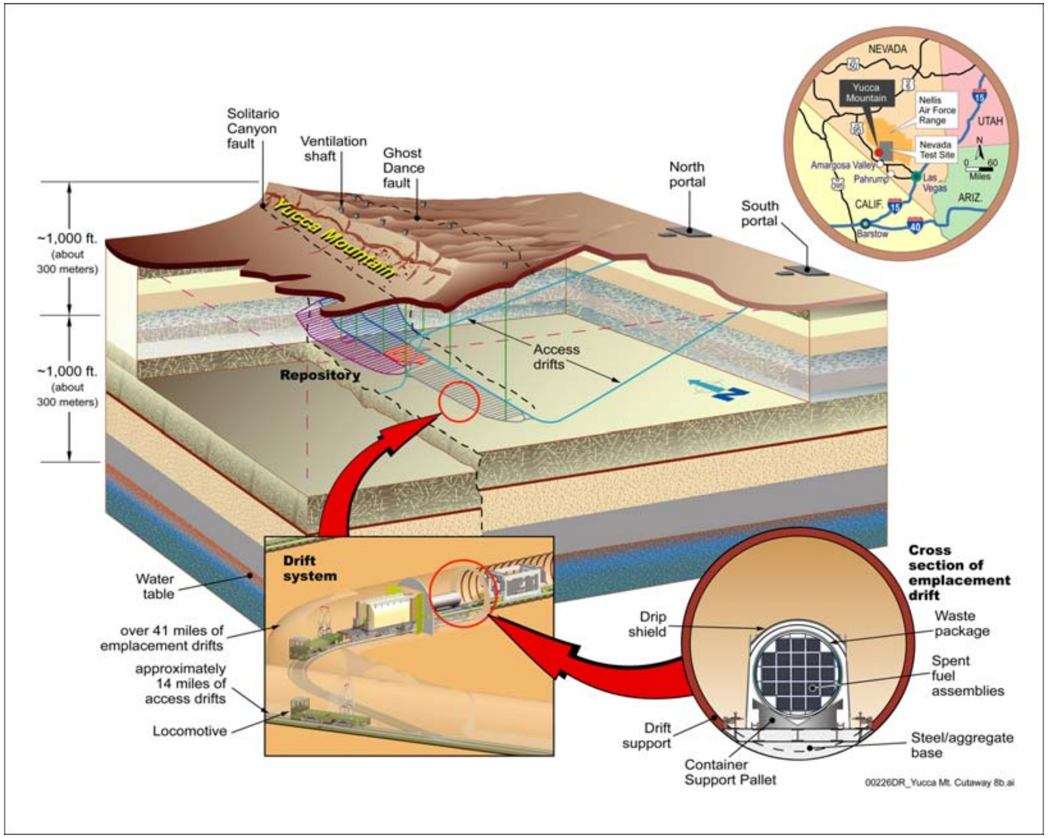
- **Contact-handled Transuranic Waste Volumes-57,790 cubic meters**

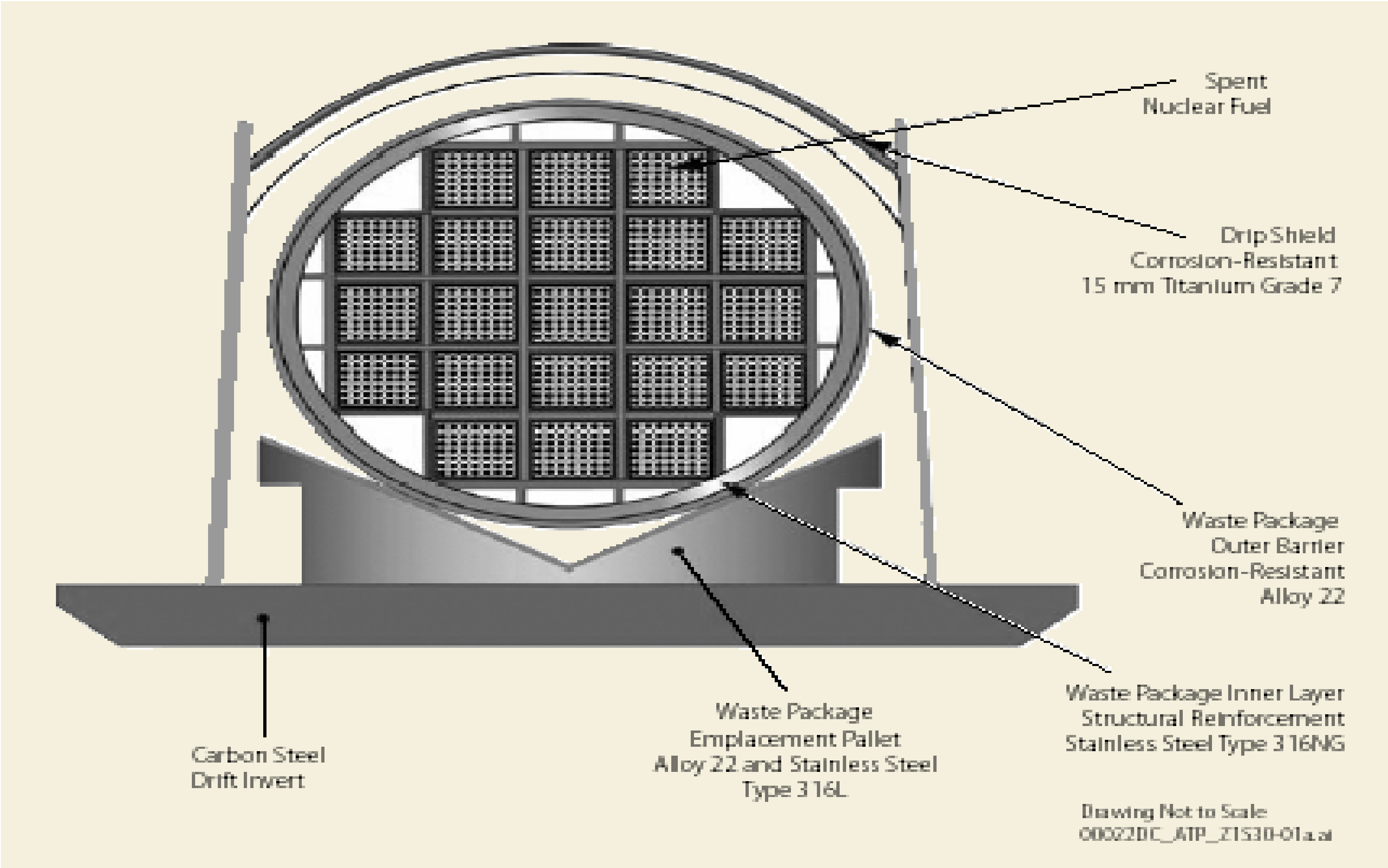
- **Remote-handled transuranic waste volumes-83 cubic meters**

PROPOSED HIGH LEVEL WASTE DISPOSAL FACILITY-YUCCA MOUNTAIN

Site Characterization

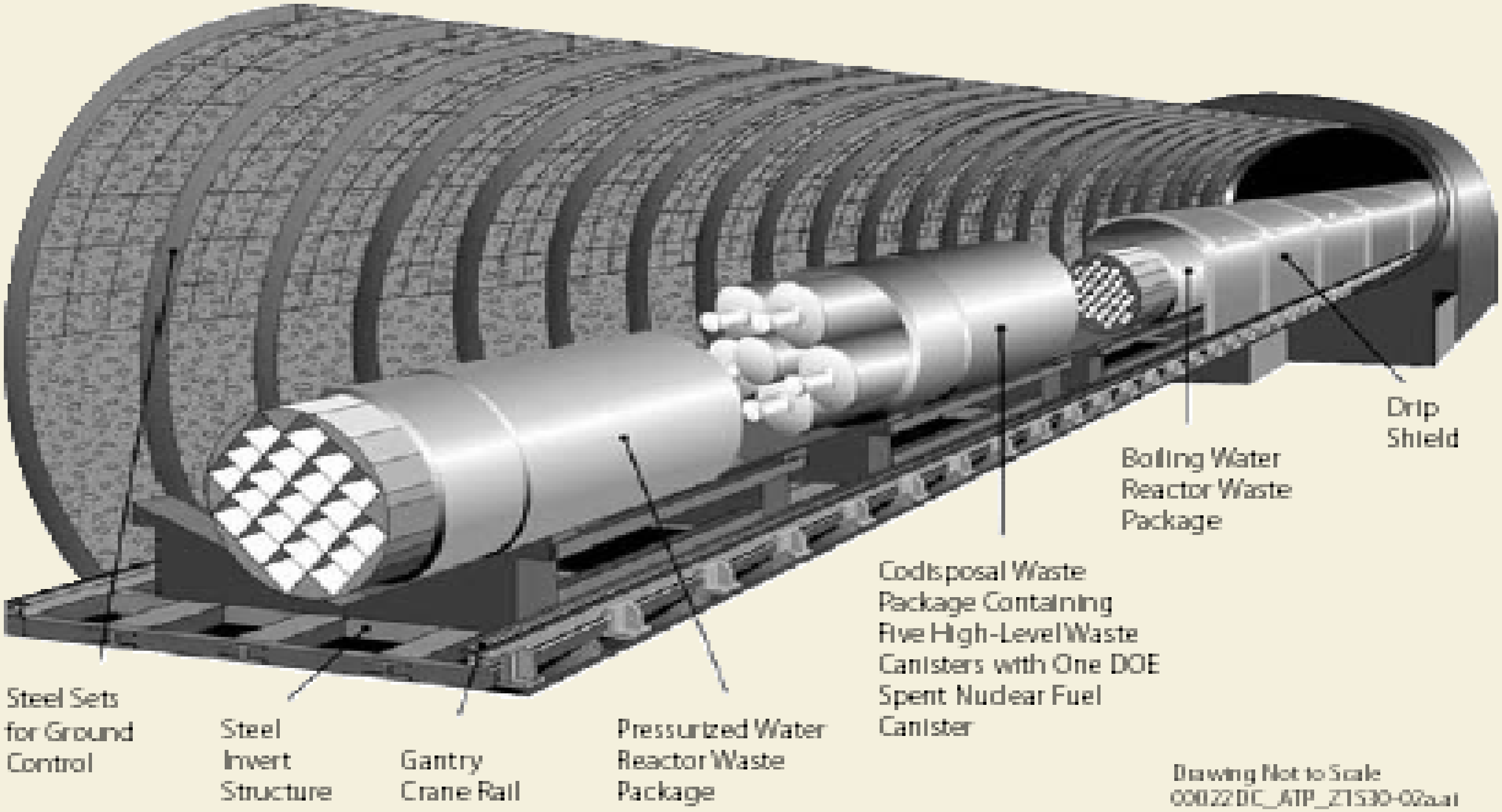
- **1987 – 1997: Characterization of Yucca Mountain site**
- **1997: Excavation of 5-mile Exploratory Studies (ESF) tunnel completed**
- **2008: License Application Submitted to USNRC**





THE FUTURE OF NUCLEAR POWER, MIT 2003

Figure A-7.B.4 Views of the Engineered Barriers at Yucca Mountain



THE FUTURE OF NUCLEAR POWER, MIT 2003

Total Estimated Cost of Project

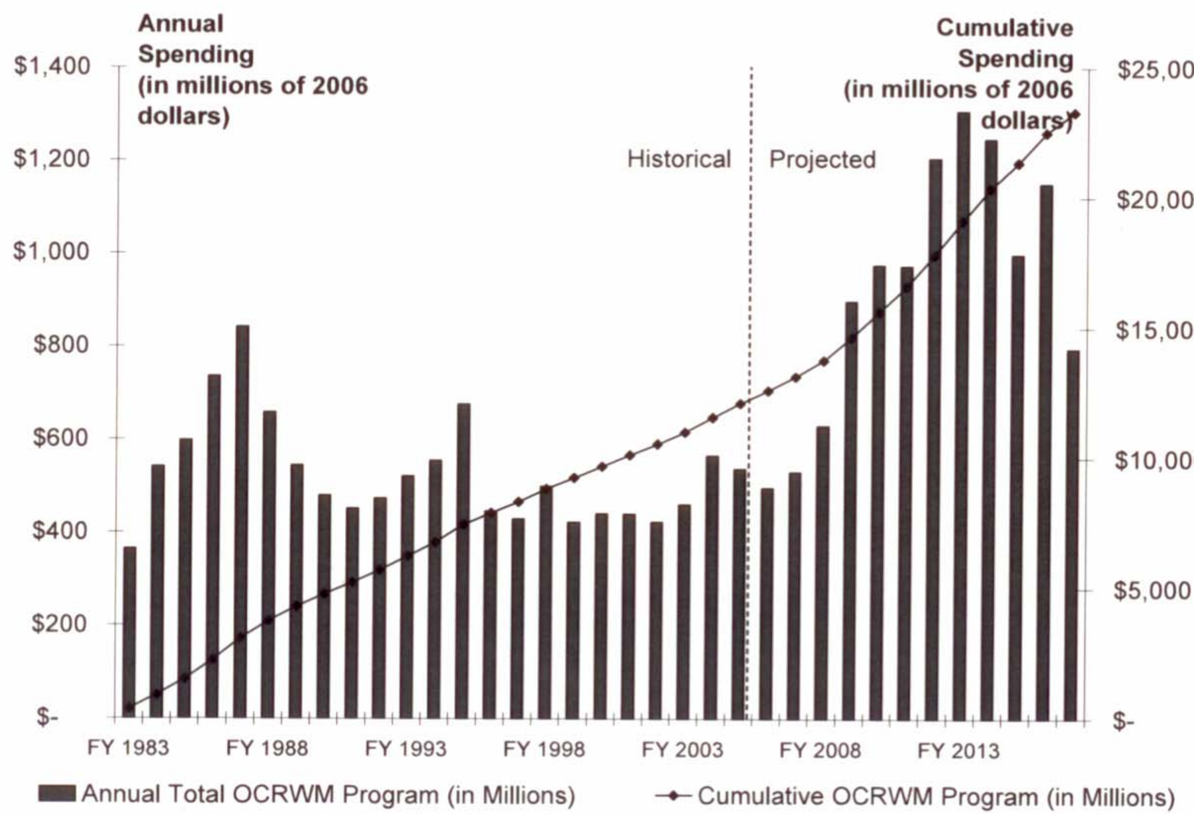
DOE's best current estimate to complete Yucca Mountain with a 2017 opening date is about $23 billion (FY 2006 dollars)

Historical cost, FY 1983-2005: $12.1 billion (in FY 2006 dollars)

Estimated future cost, FY 2006-2017: $11.2 billion (in FY 2006 dollars)

DOE plans to release updated estimates in 2007

- Cash flow analysis expected mid-to-late November 2006
- Integrated project plan expected early 2007
- Life-cycle cost analysis expected early to mid-2007



Source: GAO analysis of data and estimates provided by DOE

GAO
Accountability * Integrity * Reliability

RELATIVE COST-BACK END OF FUEL CYCLE

Some idea of the scale of part of the back end of the fuel cycle can be understood from these costs:

- **Manhattan Project to the present, 300 billion dollars on nuclear weapons research, production, and testing (in 1995 dollars)**
- **Cost to research, construct and operate Yucca Mountain: 2007 total system life cycle cost estimate, $96 Billion from the beginning of the program in 1983 through closure and decommissioning in 2133. $14 Billion to date, 14%. OCRWM established in 1982.**
- **Together with the approximately $300 Billion for cleanup = ~ $400 Billion**
- **Iraqi War direct US costs ~$600 Billion Dollars to date and estimates of total costs as high as $5 Trillion to 2017**
  The Three Trillion Dollar War,Joseph E. Stiglitz and Linda J. Bilmes, 2008
- **Bailout of the investment and banking institutions ~ 1 Trillion Dollars to date**

Long Term Stewardship-In Perpetuity Limitations

- The Roman Republic lasted from 509-27 BC and the Roman Empire lasted from 27 BC-476 AD.
- The Persian Empire lasted from 559 BC-330 BC From Cyrus the Great until Alexander the Great
- Only the Catholic Church has a long operating history, approximately 2000 years.
  - There were periods of instability.
- We can see that depending upon present day institutions to provide caretaker services into the far distant future is not reasonable.

Perspectives on Perpetuity

- **The decay of radioactive materials can be calculated till infinity.**
  - **The doses resulting from these concentrations ignore the reality of exogenous events.**
- **However you cannot predict with accuracy:**
  - **What happens during the next ice age or with global warming**
  - **advances in medicine to eliminate or reduce the effects of cancer**
  - **life style changes**
  - **new technology to immobilize radioactive materials**
  - **the importance of the few people affected by radioactive materials relative to much greater societal needs**
  - **the impact of nuclear wars or dirty bombs, etc.**

BACKUP SLIDES

In-Situ Facilities Operating USA Sept. 2008

Energy Information Administration May 13, 2008
http://www.eia.doe.gov/cneaf/nuclear/dupr/qupd.pdf

Six in-situ-leach plants operating

1 Alta Mesa Project

2 Crow Butte Operation

3 Kingsville Dome

4 Rosita

5 Smith Ranch-Highland Operation

6 Vasquez

Potential for Ground Water Contamination

Laser Enrichment

http://www.world-nuclear.org/info/inf28.html

The Atomic Vapour Laser Isotope Separation (AVLIS) and the SILVA processes have been abandoned after $2 Billion USD spent on R&D. The SILEX process is the only laser process still under development. The details are business classified. However, it is known to be a molecular photo-dissociation of UF_6 to produce UF_5 that can be separated from the ^{238}U in the UF_6.The process will be examined in a test loop test before proceeding to full scale production with commercial licensing underway. The two largest US nuclear utilities have already signed letters of intent to contract for uranium enrichment from the Global Laser Enrichment (GLE) consortium.

UF_6 Conversion to UO_2

The UF_6, in solid form in containers, is heated to gaseous form, and the UF_6 gas is chemically processed to form LEU uranium dioxide (UO_2) powder. The powder is then pressed into pellets, sintered into ceramic form, loaded into Zircaloy tubes, and constructed into fuel assemblies.

URANIUM MILLING AND TAILINGS

Only I mill, White Mesa, operating in USA but Shootaring Mill is changing its license to operational status. The mill uses sulphuric acid leaching and a solvent extraction recovery process to extract and recover uranium and vanadium. The mill is licensed to process an average of 2,000 tons per day of ore and produce 8.0 million pounds of U3O8 per year.

Doses as a Result of Milling Operations, UNSCEAR 2000			
Milling		Average Annual Dose, mSv	
	Monitored Workers, thousands	Monitored Exposed Workers	Measurably Exposed Workers
	6	3.3	

Mining Statistics

Estimated Overburden Produced by Open-Pit and Underground Mining

	Estimated Total Overburden Produced (MT), 1948-1996		
Mining Method	**Low Estimate**	**High Estimate**	**Average**
Surface Mining	1,000,000,000	8,000,000,000	3,000,000,000
Underground Mining	5,000,000	100,000,000	67,000,000

Source: Otton 1998

Waste to Ore Ratios

Mining Method	Low	High	Average
Surface Mines			30:1 early 1980s; lower later
Underground Mines	1:1	20:1	(9:1 early) 1:1 (late 1970s)
In-Situ Leaching	Small amounts deposited on site		

Technologically Enhanced Naturally Occurring Radioactive Materials From Uranium Mining Volume 1: Mining and Reclamation Background , [EPA 402-R-08-005] April 2008

Open Pit Mining

Ranger Open Pit Mine, Australia) http://www.wise-uranium.org/uwai.html#UMIN

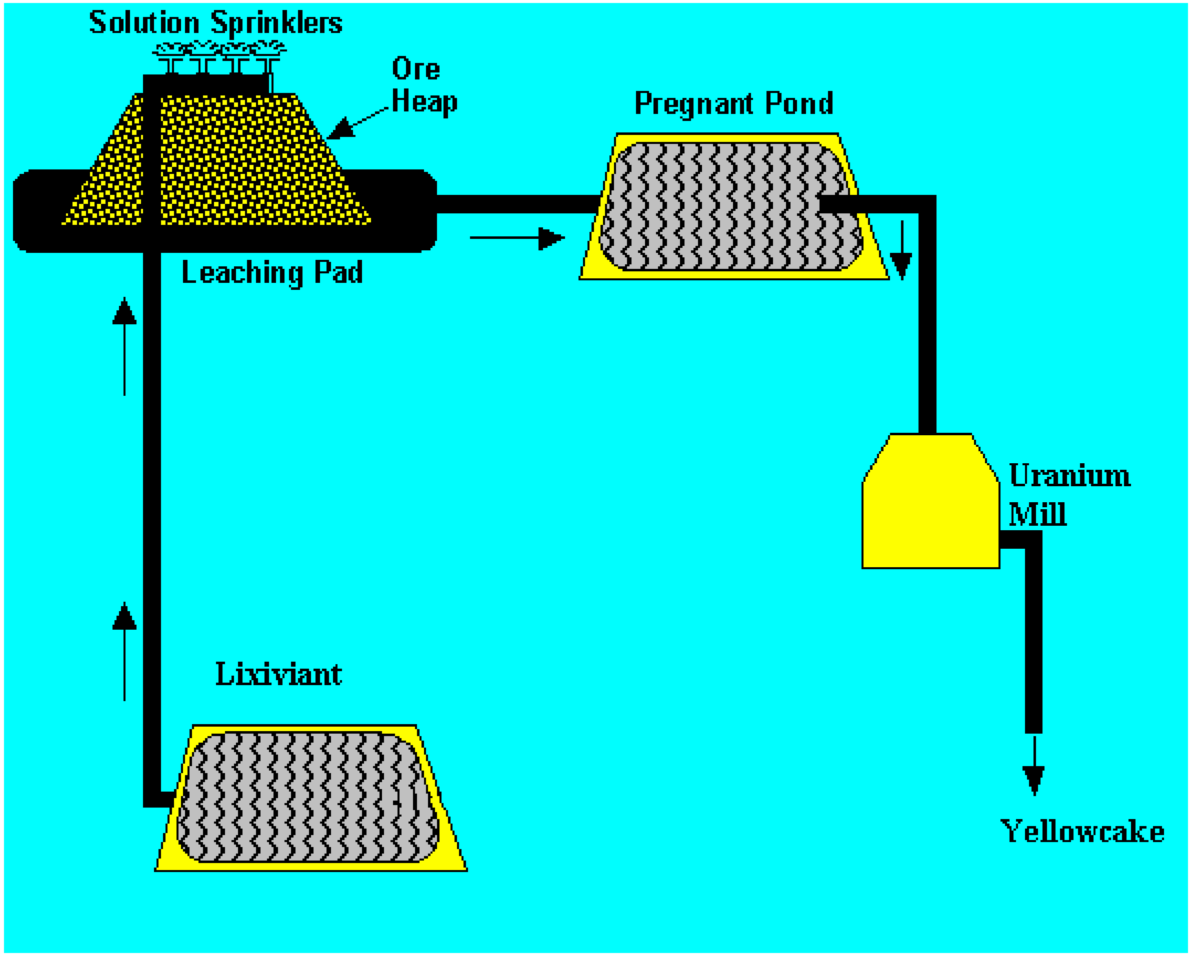
Surface Mine Nevada

Technologically Enhanced Naturally Occurring Radioactive Materials Uranium Mining Volume 1: Mining and Reclamation Background http://www.epa.gov/rpdweb00/docs/tenorm/402-r-08-005-voli/402-r-08-005-v1-cov-exec-toc.pdf

Surface Mine

Technologically Enhanced Naturally Occurring Radioactive Materials Uranium Mining Volume 1: Mining and Reclamation Background http://www.epa.gov/rpdweb00/docs/tenorm/402-r-08-005-voli/402-r-08-005-v1-cov-exec-toc.pdf

Idealized Heap Leaching Process



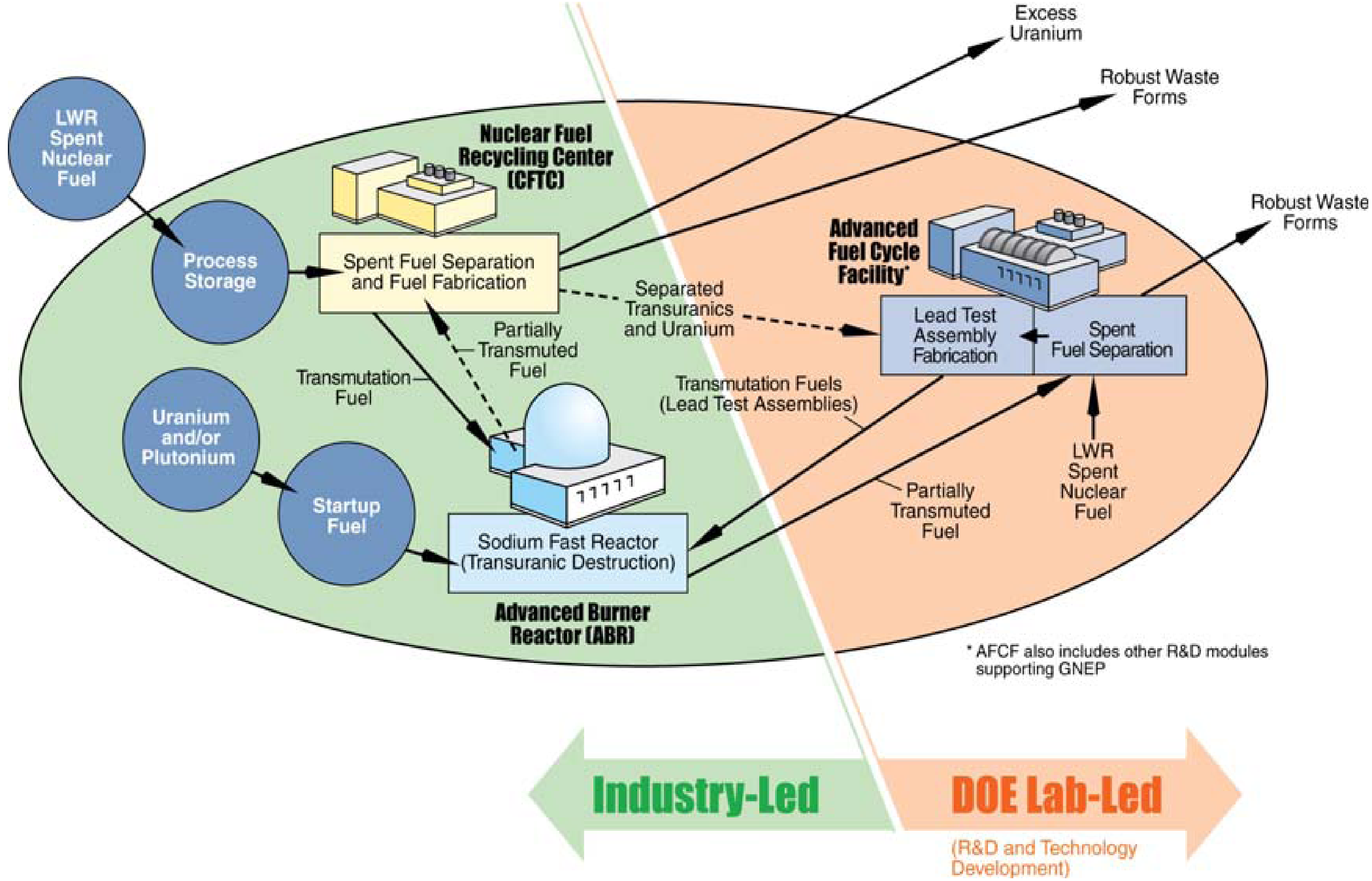
Technologically Enhanced Naturally Occurring Radioactive Materials
Uranium Mining Volume 1: Mining and Reclamation Background
http://www.epa.gov/rpdweb00/docs/tenorm/402-r-08-005-voli/402-r-08-005-v1-cov-exec-toc.pdf

Mill Tailings Pond

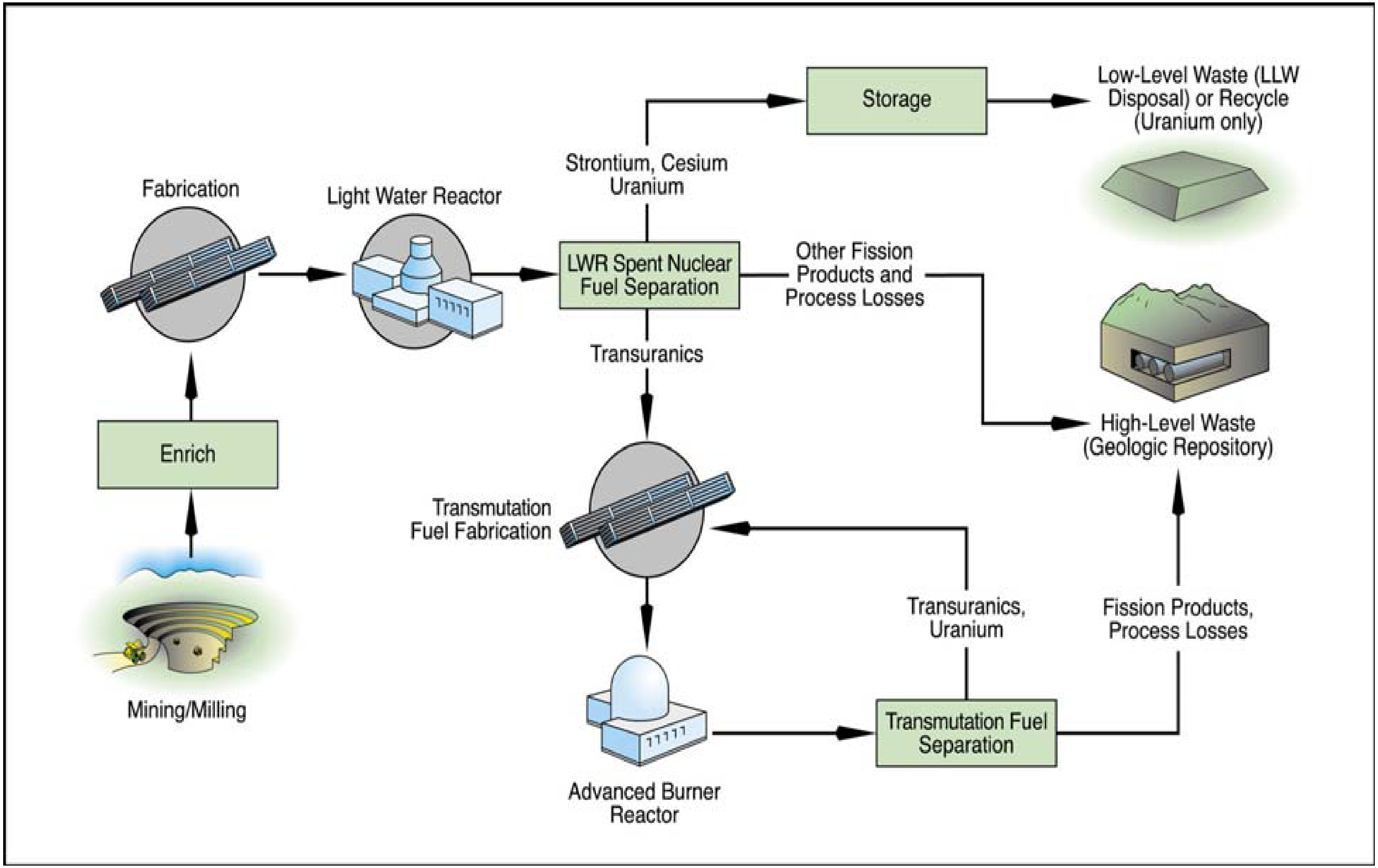
Ranger uranium mill tailings pond, Australia
http://www.wise-uranium.org/uwai.html#UMIN

The Closed Tailings Impoundment at the Split Rock, Wyoming Disposal Site

DOE-LM Annual Update and Program Overview Richard P. Bush
NMA/NRC Uranium Recovery Workshop April 29, 2008
http://adamswebsearch2.nrc.gov/idmws/doccontent.dll?library=PU_ADAMS^PBNTAD01&ID=081440235



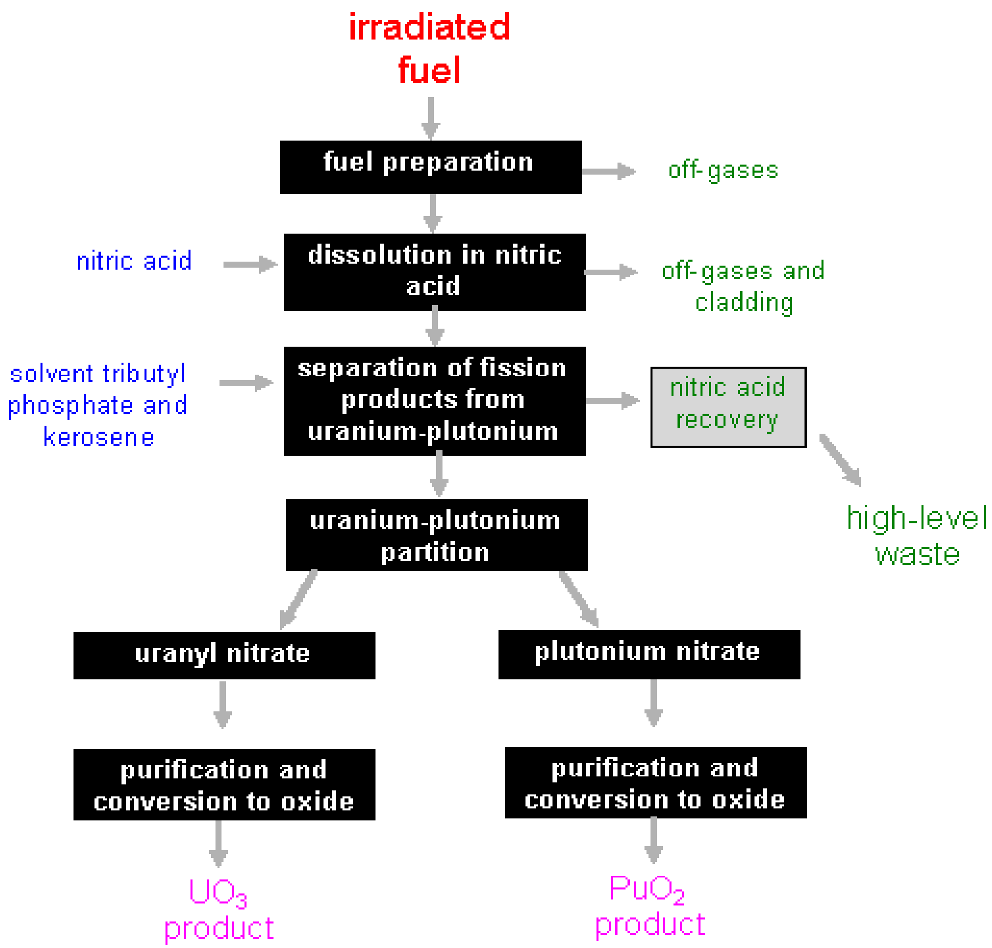
GNEP First Facilities Architecture



Initial GNEP deployment system architecture.

Simplified Purex Process

Spent Nuclear Reactor Fuel Reprocessing-Where Have We Been and Where Are We Going? Raymond G. Wymer, Vanderbilt University, January 29, 2007



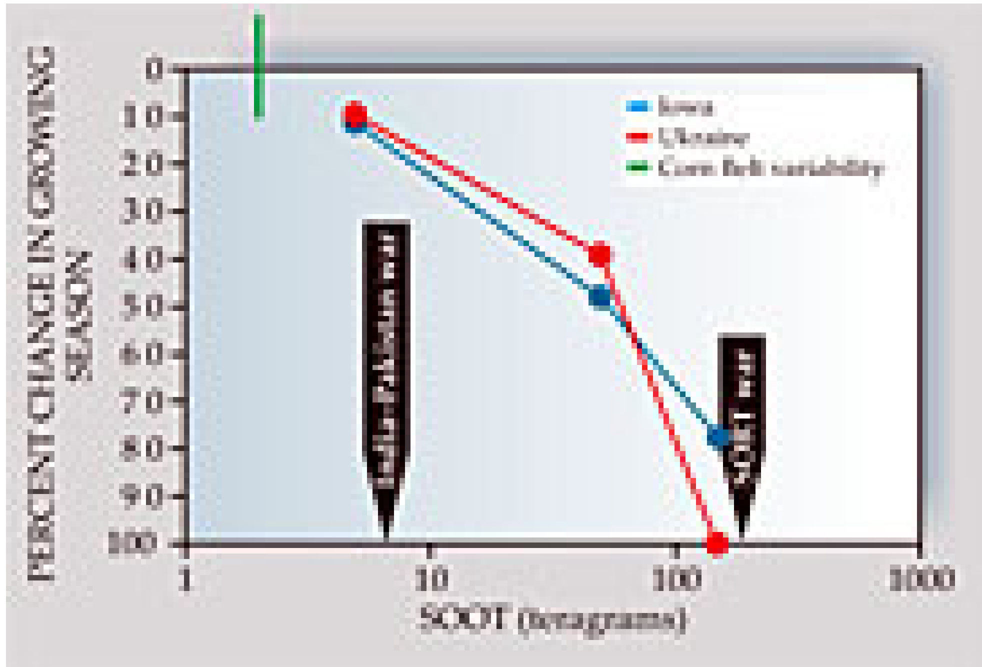
Duke Energy's CNO Said Opening Yucca Mountain Was Not Necessary to Advance Nuclear Power in the US

www.ustransportcouncil.org/documents/SummitV/meeting

Brew Barron posed the question to the United States Transport Council April 25, 2007 of whether the US needs Yucca Mountain to advance nuclear power and answered, "in my opinion, the answer quite simply is no."

NUCLEAR WEAPONS PROLIFERATION

Environmental Consequences of Nuclear War
Toon, Owen B., Alan Robock and Richard P. Turco, Physics Today, December 2008



Decline in growing season in Iowa (blue) and Ukraine (red) as a result of townhe amount of soot injected into the upper atmosphere. Impact of Indo-Pakistan and Sort Wars shown. Green line indicates the natural variability of the growing season in USA corn belt

PROLIFERATION

THE FUTURE OF NUCLEAR POWER, MIT 2003

(http://web.mit.edu/nuclearpower)

The **current international safeguards regime** is inadequate to meet the **security challenges** of the **expanded nuclear deployment** contemplated in the global growth scenario.

The **reprocessing system now used** in Europe, Japan, and Russia that involves separation and recycling of plutonium **presents unwarranted proliferation risks.**

DIRTY BOMBS

Radioisotope Thermoelectric Generator

Radioisotope Medical and Commercial Sources

Radioactive Wastes

NUCLEAR ACCIDENTS

10 Energy-Related Accidents (1969-1996) (ranked by cost)

Energy Carrier	Date	Country	Energy Chain stage	Fatalities	Injured	Evacuees	Costs (10^6 USD1996)
Nuclear	**26.04.86**	**Ukraine**	**Power Production**	**31**	**370**	135,000	**339,200**
Nuclear	28.03.79	USA	Power Production	0	0	144,000	**5427.2**
Oil	24.03.89	USA	Transport to Refinery	0	0	0	**2260**
Hydro	05.06.76	USA	Power Production	14	800	35,000	**2219**
Oil	28.01.69	USA	Extraction	0	0	0	**1947**
Oil	07.07.88	UK	Extraction	167	0	0	**1800**
Hydro	11.08.79	India	Power Production	2500	--	150,000	**1024**
Oil	30.05.87	Nigeria	Refinery	5	--	0	**916.4**
Oil	20.12.90	Bahamas	N.A.	0	0	0	**742**
Natural Gas	06.10.85	Norway	Exploration	0	0	0	**622**

Source: Project GaBE, 1998

SECURITY OF SUPPLY INCLUDING TOTAL COSTS (MARKET AND EXTERNAL) PLUS PUBLIC ACCEPTANCE ISSUES

External costs of electricity supply, EuroCent/KWh

(based on DLR, ISI 2006; study commissioned by the German Ministry of the Environment)

Combined Cycle Thermal Efficiency	PV(2030) photovoltaic	Wind 2,5 MW	Lignite CC 48%	Gas CC 57%	Nuclear
Climate change	**0,38**	**0,06**	**6,1**	**2,7**	**…**
Health effects	**0,2**	**0,03**	**0,27**	**0,17**	**…**
Ecosystem impacts	🟢	🟢	🟡	🟡	**…**
Material damage	**0,006**	**0,001**	**0,008**	**0,005**	**…**
Crop losses	**0,004**	**0,0004**	**0,005**	**0,005**	**…**
Major accidents	🟢	🟢	🟢	🟢	🔴
Proliferation	🟢	🟢	🟢	🟢	🔴
Security of supply	🟢	🟢	🟢	🟡	🟡
Geo-political effects	🟢	🟢	🟢	🟡	🔴
	~ 0,58	**~ 0,09**	**> 6,4**	**> 2,9**	**>> x**

🟡 = **non-negligible effects are expected, leading to potential externalities**

🔴 = **potential for significant effects, leading to potential conflicts with sustainability requirements**

🟢 = **no significant effects (assuming operation of facility according to good practice)**

PERSPECTIVE

CONCLUSIONS

As I have indicated,