Economics of Plutonium Recycle

Thomas B. Cochran, Ph.D.
Natural Resources Defense Council, Inc.

Policy Review Panel on Nuclear Fuel Recycling
Global Energy and Environment Initiative (GEEI)
Johns Hopkins University
School of Advanced International Studies (SAIS)

Washington, D.C.
11 December 2009

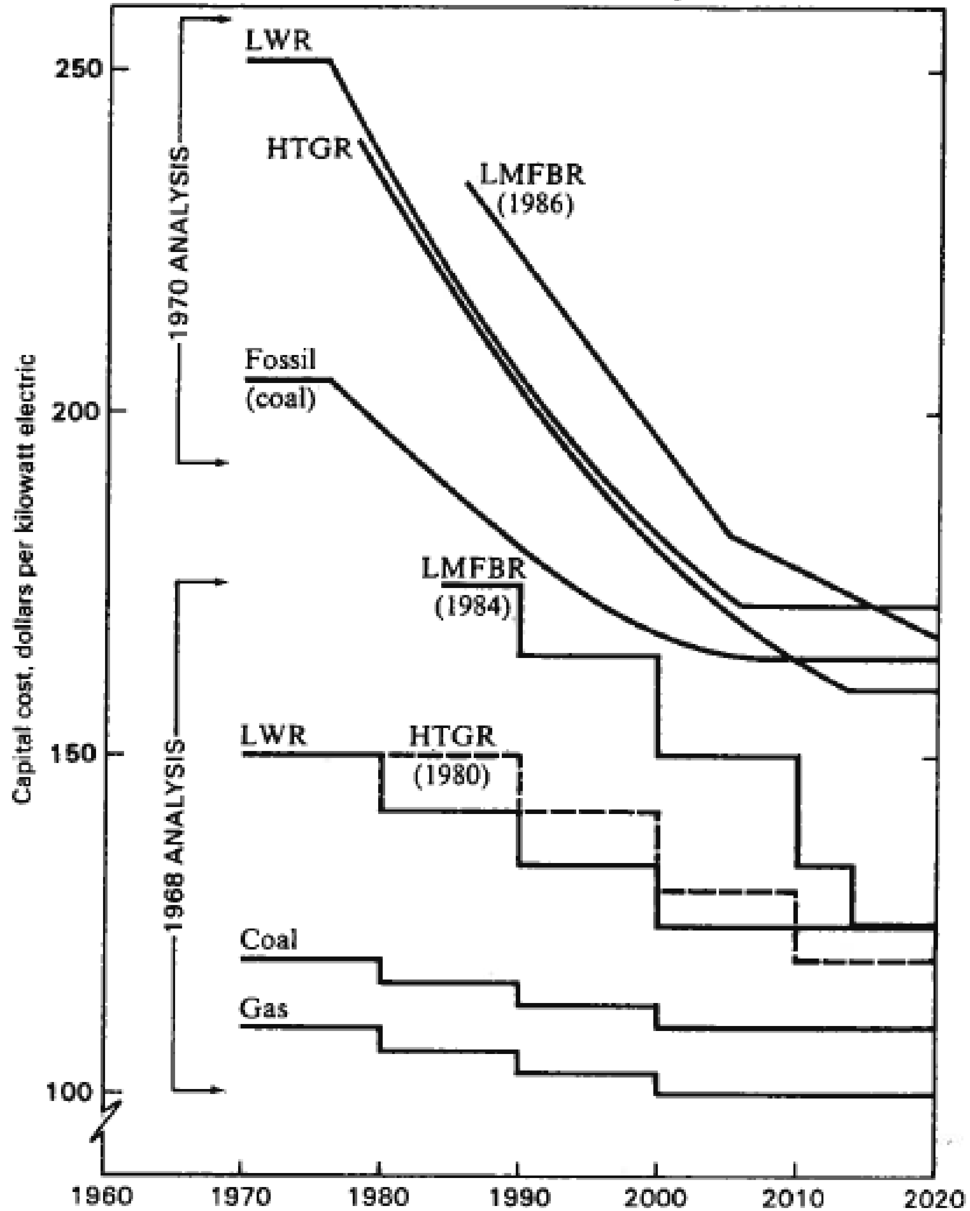
Nuclear Fuel Cycle Options

- 1) Once-through cycle
- 2) Single-pass recycle in thermal reactors (the French/Areva option)
- 3) Balanced closed cycle with transmutation in fast reactors (the GNEP vision)

Historical Background

- April 26, 1944: gathering of Fermi, Szilard, Wigner, Weinberg and others at the Met Lab to discuss the possibilities for using nuclear fission to heat and light cities; they believed uranium was scarce and would need breeders
- 1944-1969: no serious consideration given to economics of recycle or breeders
- 1944-1974: no serious consideration given to proliferation
- 1969-1974: AEC badly misjudged nuclear power economics; projected:
  - LWRs would cost ~ $150/kW
  - LMFBR would cost about 20% higher, i.e., $30/kW more than LWR, decreasing to $15/kW by 1990, and to zero by 2015
  - Reprocessing would cost ~$34-50/kg (LWR); $38/kg (LMFBR)

FIGURE 4. Projected Power Plant Capital Costs Used in AEC's Cost-Benefit Analysis



SOURCE: AEC, *Updated (1970) Analysis*, WASH 1184, p. 37.

TABLE 10. AEC Estimate of Representative Fuel Fabrication and Reprocessing Costs Used in 1970 Cost-Benefit Analysis of the LMFBR Program

Reactor	Fabrication cost including fuel preparation, $/kg[a]		Reprocessing cost including conversion, $/kg[a]	
	Initial	Year 2020	Initial	Year 2020
LWR (without Pu recycle)	$ 83	$ 42	$ 34	$ 22
LWR (with Pu recycle)	147	48	50	22
HTGR (with LMFBR)	243	89	62	34
LMFBR (intro. 1986)	316	115	38	30

SOURCE: U.S. Atomic Energy Commission, *Updated (1970) Cost-Benefit Analysis of the U.S. Breeder Reactor Program*, WASH 1184 (Jan. 1972), p. 41.

TABLE 9. Reactor Fuel Cycle Costs

(a) 1000-Mw LMFBR equilibrium cycle fuel cost

Cost component		Cost, mill/kwh
Fabrication		0.334
Reprocessing and reconversion		0.166
Shipping		0.038
Plutonium carrying charge of which		0.546
Inpile	0.432	
Outpile	0.114	
Fabrication carrying charge		0.061
Reprocessing carrying charge		−0.042
Plutonium credit		−0.348
Total		0.755

(b) Estimated fuel cycle costs for a model 1000-Mw light-water reactor today

Cost component	Cost, mill/kwh
Mining and milling	0.38
Conversion to UF_6	0.07
Enrichment	0.58
Reconversion and fabrication	0.33
Spent-fuel shipping	0.02
Reprocessing	0.12
Waste management	0.04
Plutonium credit	−0.25
Uranium credit (includes a 0.03 mill/kwh cost of reconverting to UF_6)	−0.12
Fuel inventory carrying charge	0.57
Total	1.74

SOURCE: Part (a), U.S. Atomic Energy Commission, *An Assessment of the Liquid Metal Fast Breeder Reactor*, WASH 1100 (unpublished), p. 124. Part (b), U.S. Atomic Energy Commission, *The Nuclear Industry*, WASH 1174-71 (1971), p. 92.

Using GDP Deflator Index to convert from 1970 to 2010 dollars

- 2010$ = 4.65 x 1970$
- In 2010$ the AEC estimates of 1970:
  - LWRs would cost ~ $700/kW
  - LMFBR would cost about 20% higher, i.e., $140/kW more than LWR; decreasing to $70/kW by 1990, and zero by 2015
  - Reprocessing would cost ~$160-230/kg (LWR); ~$180/kg (LMFBR)

Current Costs Estimates

- LWRs: \$4,000/kW (MIT II) to 8,000/kW (Harding-mid) (overnight) (~6-12 times greater)
- LMFBR-LWR cost difference: ~several times \$1,000/kW (more than 10 times greater)
- Reprocessing: \$2,000/kg to 4,0000/kg (more than 10 times greater)
- LEU fuel cost: (decreased)
  - U_3O_8: ~\$50/kg (no significant change)
  - Enrichment: \$150/kgSWU (decreased 2.5 times)

Single-pass Recycle

- Makes reprocessing appear more attractive by storing spent MOX fuel assemblies indefinitely—delay reprocessing spent MOX assemblies until the Pu in the MOX assemblies is needed to fuel fast breeder reactors
  - Treats spent MOX as an asset, rather than a liability.
  - Avoids half the heat loading of the repository and thus reduces the perceived repository capacity requirement.

MIT-Future of Nuclear Power (2003)

Table A-5.D.1 Once-through UOX Fuel Cycle Cost

	M_i	C_i	ΔT_i (yr)	DIRECT COST $M_i \cdot C_i$ ($)	CARRYING CHARGE $M_i \cdot C_i \cdot \phi \cdot \Delta T_i$ ($)
Ore purchase	10.2 kg	30 $/kg	4.25	307	130
Conversion	10.2 kg	8 $/kg	4.25	82	35
Enrichment	6.23 kg SWU	100 $/kg SWU	3.25	623	202
Fabrication	1 kgIHM	275 $/kgIHM	2.75	275	76
Storage and disposal	1 kgIHM	400 $/kgIHM[30, a]	–2.25	400	-90
			Total	1686	353
			Grand Total	2040	

a. The cost of waste storage and disposal is assumed to be paid at the end of irradiation, even though the unit cost of $400/kgIHM is a proxy for the 1 mill/kWehr paid by utilities during irradiation.

MIT-Future of Nuclear Power (2003)

Table A-5.D.2 Single Recycle MOX Fuel Cycle Cost

	M_i (kgIHM)	C_i ($/kgIHM)	ΔT_i(yr)	DIRECT COST $M_i \cdot C_i$ ($)	CARRYING CHARGE $M_i \cdot C_i \cdot \phi \cdot \Delta T_i$ ($)
Credit for UOX SF	5.26	–400	4.25	–2105	–895
Reprocessing	5.26	1000	4.25	5263	2237
HLW storage and disposal	5.26	300	3.25	1579	513
MOX Fabrication	1	1500	3.25	1500	488
MOX Storage and disposal	1	400	–2.25	400	–90
			Total	6637	2253
			Grand Total	8890	

MIT-Future of Nuclear Power (2003)

Once-through cycle:

$2040/kg = 0.515 cents/kWh

Single-pass recycle:

$8890/kg = 2.24 cents/kWh

Increase in electricity cost (assuming 16% of fuel is MOX is 0.791 cents/kWh

Incremental Cost to US consumer: ~$6.4 billion/y (809 billion Kwh produced by nuclear in US in 2008);

$0.25 trillion over 40 years

MIT-Future of Nuclear Power (2003)

Table A-5.D.3 Breakeven Values

COST COMPONENT	ORIGINAL VALUE	REQUIRED VALUE	REQUIRED/ORIGINAL
Natural uranium	$30/kgU	$560/kgU	19
Reprocessing	$1,000/kgIHM	$90/kgIHM	0.09
MOX fabrication	$1,500/kgIHM	Impossible	N/A
Waste storage and disposal	$400/kgIHM (SF)	$1,130/kgIHM	2.8
	$300/kgIHM (HLW)	$100/kgIHM	0.33

Balanced Closed Cycle with Fast Reactors

- 1.27cents/kwh per $1,000/kW LWR-FR capital cost differential, assuming FR achieve 90% capacity factor
- Assuming one-third of nuclear capacity from fast reactors and 1,000 billion kWh/y nuclear capacity, incremental cost to US consumer = >$10 billion/y
  - $4.2 billion/y per $1,000/kW cost differential
  - >$6.4 billion for recycle

Actinide Recycle is Doomed to Fail

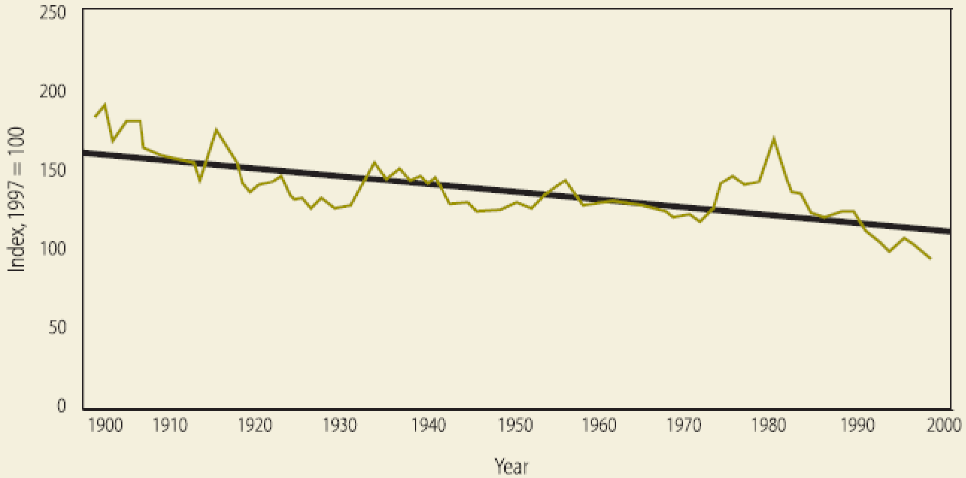
About 1/3 of the deployed reactor capacity must be from fast reactors

- Fast reactors currently **cost considerably more** than thermal reactors, and seem likely to stay that way.
- Commercial/naval fast reactor development **programs failed** in the: 1) United States; 2) France; 3) United Kingdom; 4) West Germany; 5) Italy; 6) Japan; 7) Russia 8) U.S. Navy and 9) the Soviet Navy; and the program in India is showing no signs of success. The Soviet Union/Russia never closed the fuel cycle and never fueled its fast reactors with MOX. (China is starting a fast reactor development program).
- After spending tens of billions of dollars on fast reactor development there is **only one** operational commercial-size fast reactor out of about 436 operational commercial power reactors worldwide and even this one (BN-600 in Russia) is not fueled with plutonium
- Fast reactors have proven to be **less reliable** than thermal reactors

Conclusion

- No evidence that single pass or fast reactor recycle costs will break-even with once-through cycle cost
- Like all major minerals the improving efficiency of uranium extraction outpaces depletion of the resource

Figure A-5.E.2 Composite mineral price index for 12 selected minerals, 1900 to 1998, in constant 1997 dollars. Selected mineral commodities include 5 metals (copper, gold, iron ore, lead, and zinc) and seven industrial mineral commodities (cement, clay, crushed stone, lime, phosphate rock, salt, and sand and gravel).



Conclusion (cont.)

- Why separate the plutonium?
- USG has 34 tonnes of excess weapon-grade plutonium; it cannot give it away; separated Pu has a negative economic value for energy use
- To get Pu for one MOX assembly, one needs to reprocess 6-8 spent LEU fuel assemblies
- Even taking credit for recovery of unused uranium, a MOX assembly will cost several times (MIT estimate is 4.5 times) the cost of a fresh LEU assembly

Conclusion (cont.)

But if one advocates storing spent MOX fuel indefinitely, a better strategy is to:

- Store spent fuel indefinitely;
- Postpone reprocessing until recycle is clearly economical (which will not happen any time soon, and may never happen)
- Defer major closed cycle R&D commitments until the international control regime can provide adequate safeguards (which is clearly not the case today).

Single-pass Recycle

- Reduces uranium mining requirements ~20-25%
- But at great cost
- We could also reduce uranium requirements by operating enrichment plants at very low tails assay; also at great cost and consequently an equally dumb idea
- Better strategy is to minimize the cost of the fuel cycle

Single-Pass Recycle is the Wrong Strategy

- Proliferation risks associated with plutonium separation in non-weapon states of concern
- High costs; massive federal subsidies
- Safety risks
- High, intermediate and low-level radioactive waste
- Air, sea/groundwater pollution
- Decommissioning
- No reduction in repository requirements

Proliferation is the Biggest Concern
International Safeguards are Inadequate

"the objective of safeguards is the **timely detection of diversion of significant quantities of nuclear material** from peaceful activities to the manufacture of nuclear weapons or of other explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."

IAEA, INFCIRC/153; Emphasis supplied

In Non-Weapon States
This IAEA Objective
Cannot be Met Today at:

- Nuclear Fuel Reprocessing Plants
- Mixed-Oxide Fuel Fabrication Plants
- Storage Facilities for Separated Plutonium and Highly-Enriched Uranium
- Commercial Gas Centrifuge Plants

Conclusion (cont.)

The current open fuel cycle is likely to remain less costly than closed fuel cycles indefinitely. Therefore, the US should renew the search for alternative repository sites.

Dry Cask Storage at a U.S. Power Plant

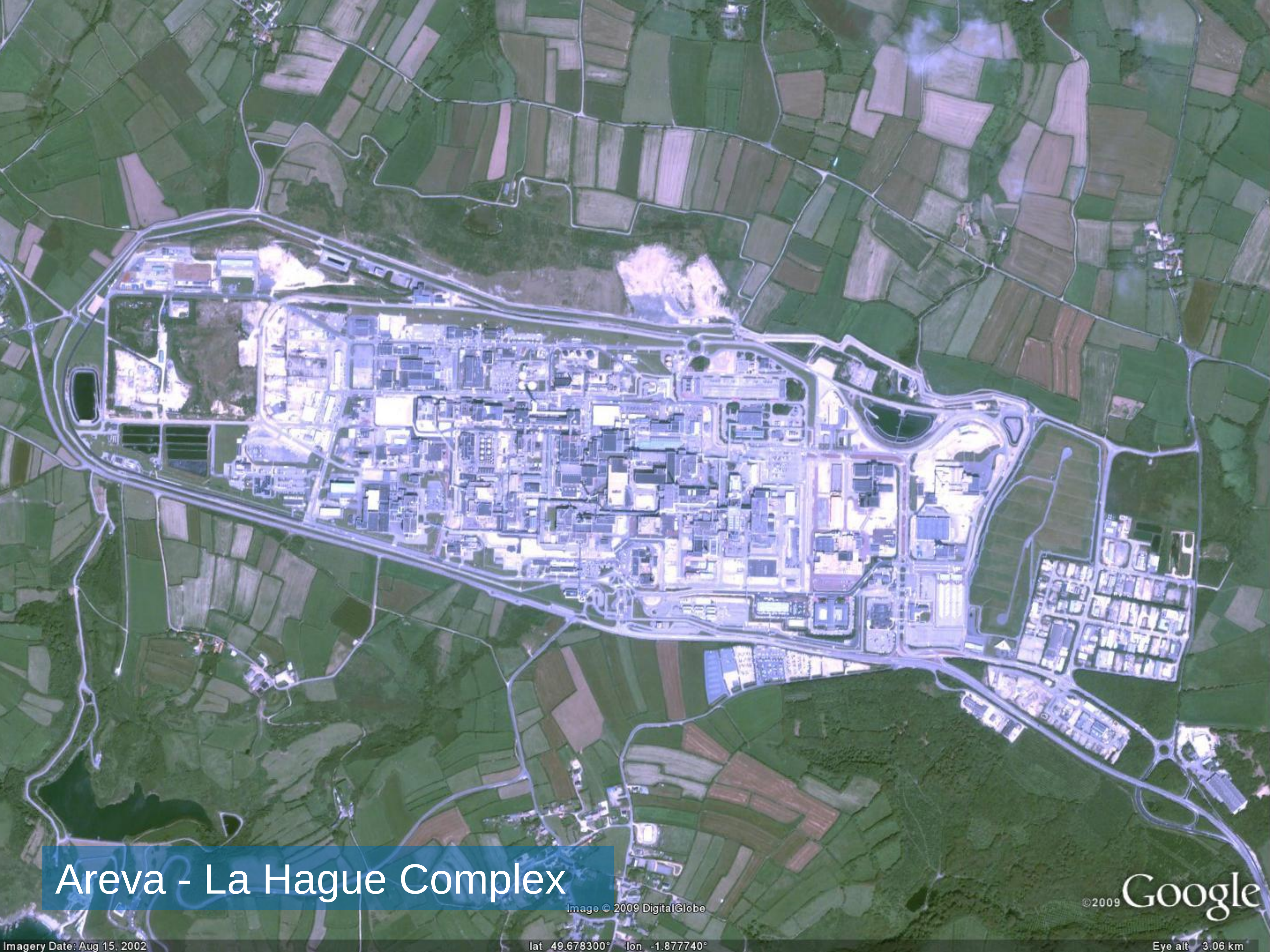
Maine Yankee Dry Cask Storage Installation

Dry Cask Storage at a Site in Germany

Ahaus Spent Fuel Storage Facility

Reprocessing Complex in France

Areva - La Hague Complex



La Hague Complex:

Area: 300 hectares = 3 million square meters (m^2)

~2 million m^2 within the outer fence

Processing Area: ~373,000 m^2

Capacity: 1,600 tonnes of spent fuel (t SF) per year

(~0.0043 t of SF/year-m^2)

Ahaus Spent Fuel Facility:

Building Area: ~7,680 m^2

Capacity: 3,960 tonnes of spent fuel

(~0.5 t of spent fuel per m^2)

Maine Yankee Dry Cask Storage Facility:

Pad Area for 64 casks: ~2,580 m^2

Assumption: 12 t SF/cask

Capacity: 768 tonnes of SF

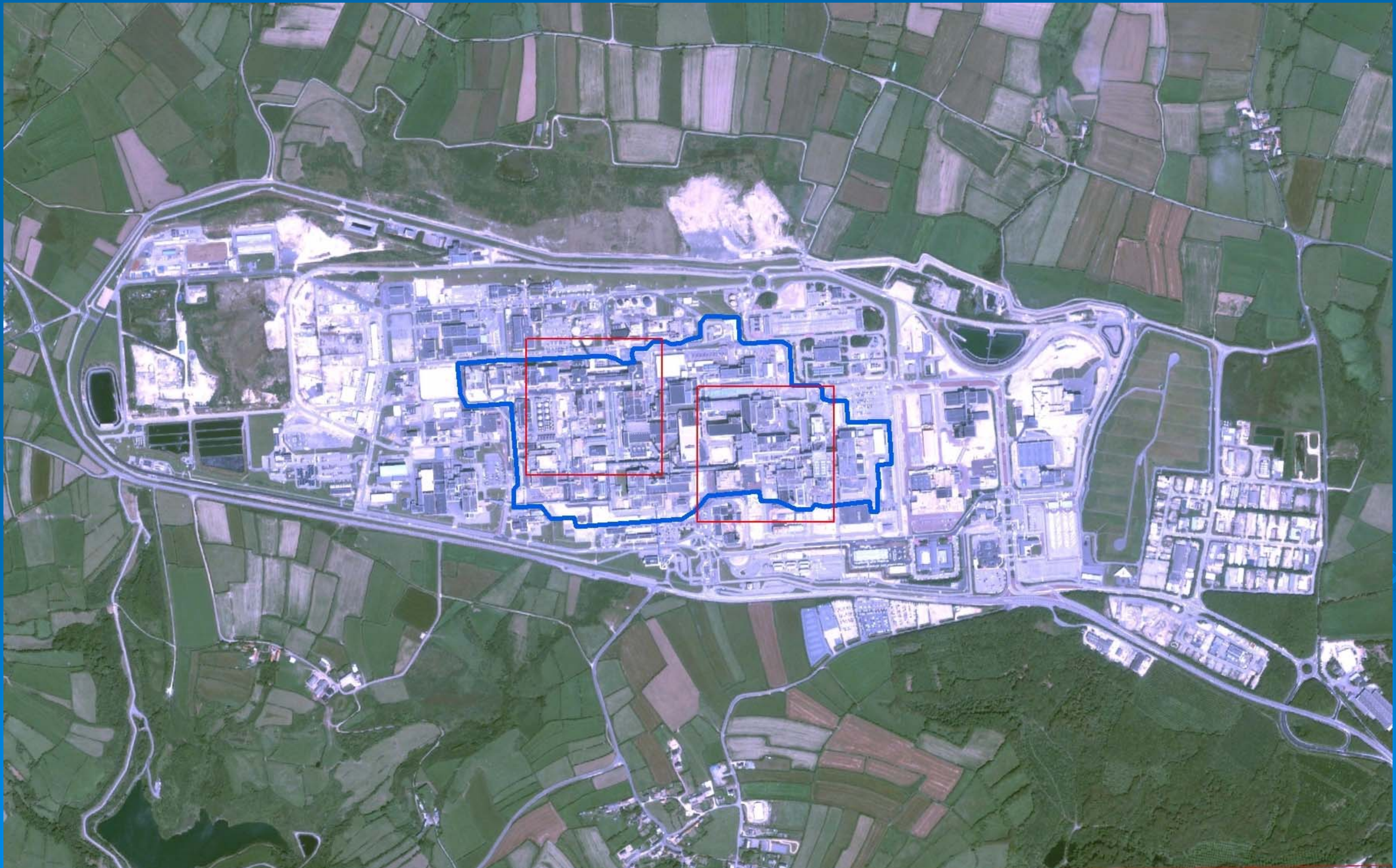
(~0.3 t of SF per m^2)

Area required for dry cask storage of 60,000 t spent fuel:

one red square (60,000 t SF / 0.5 t SF/m^2 = 120,000 m^2)

La Hague Complex – chemical processing area:

blue polygon (~373,000 m^2)



Dry Cask Central Storage

- Consolidated central storage of spent fuel from shut down reactors makes sense.
- Consolidated storage of spent fuel from operating reactors does not make sense.

END

Extra Slides

President Gerald R. Ford on October 28, 1976 announced his decision that

... the reprocessing and recycling of plutonium should not proceed unless there is sound reason to conclude that the world community can effectively overcome the associated risks of proliferation ...

that the United States should no longer regard reprocessing of used nuclear fuel to produce plutonium as a necessary and inevitable step in the nuclear fuel cycle, and that we should pursue reprocessing and recycling in the future only if they are found to be consistent with our international objectives.

If one wants to minimize:

- Fuel cycle costs
- Proliferation risks
- Waste volumes
- Safety risks
- Radioactive releases
- Occupational exposures

Don’t reprocess spent fuel