GEM✵STAR* Consortium
Staging and Demonstration

**a technology from*

ADNA Corporation
(Accelerator Driven Neutron Applications)

presented by

Dr. Charles Bowman, ADNA president

with

Dr. R. Bruce Vogelaar, Professor of Physics
Virginia Tech

Dr. Ganapati Myneni, Accelerator Science
The Jefferson Lab

for

1st International Workshop on Accelerator-Driven Subcritical systems & Thorium Utiization
September 27-29, 2010, Blacksburg, VA

Nuclear Energy's Fundamental Problem ….
Too Few Fission Neutrons

Neutron shortage leads to

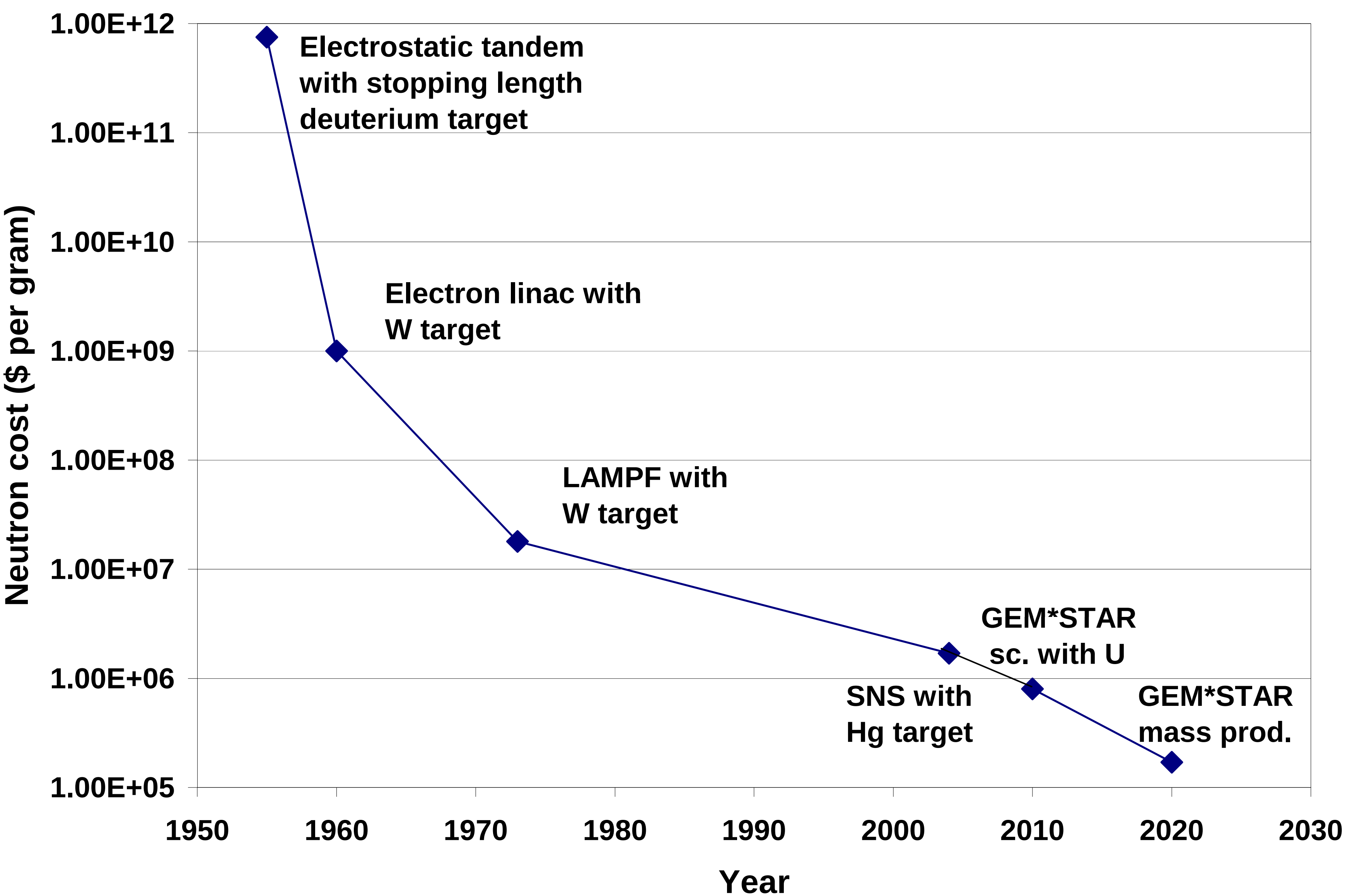
- Enrichment
- Reprocessing and therefore near term waste storage requirement
- Expensive fast reactors with safety issues

Shortage consequences

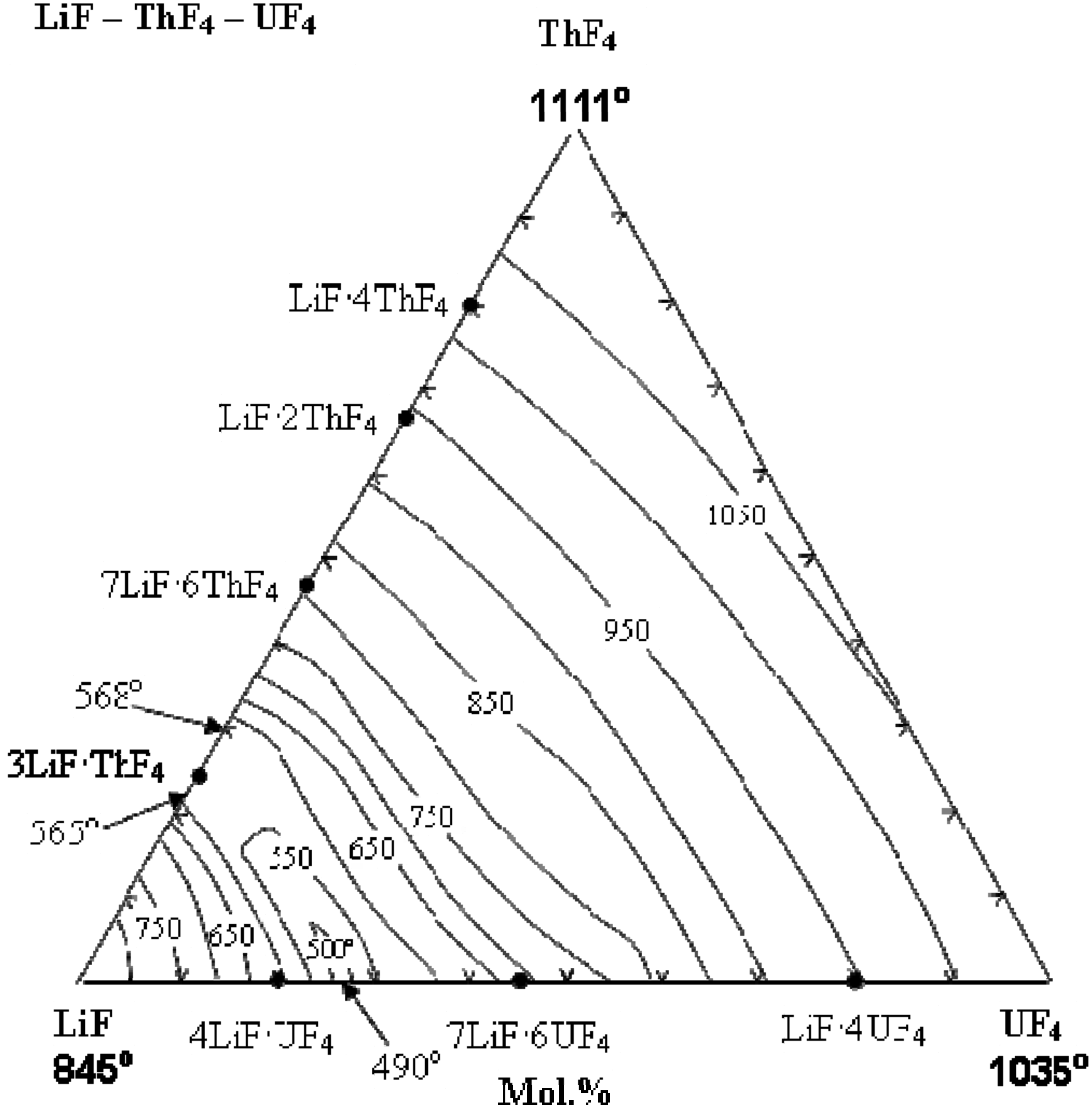
- Extraordinary technological complexity (GNEP)
- Serious proliferation burden
- Onerous international controls
- Near term storage for high level waste
- Unnecessarily high cost for nuclear energy

The GEM*STAR solution

- Improve the reactor neutron economy (graphite and control rods)
- Add supplemental neutrons from accelerators
- Use liquid fuel and recycle without chemical separations (reprocessing)
- Make energy generation cheaper, simpler, and safer
- Reduce waste and delay permanent disposition for centuries

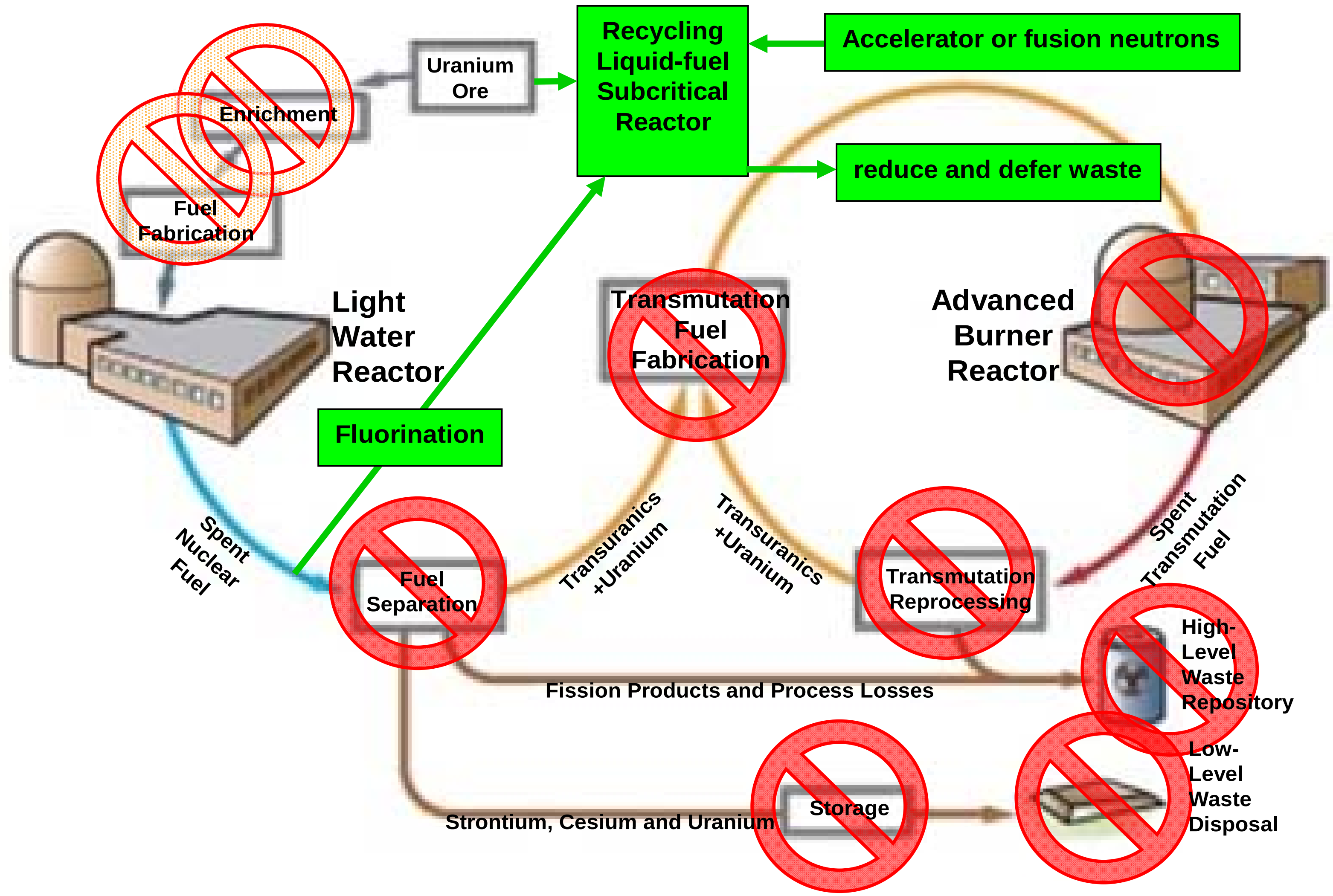

1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
Neutron cost ($ per gram)
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year
Electrostatic tandem with stopping length deuterium target
Electron linac with W target
LAMPF with W target
GEM*STAR sc. with U
SNS with Hg target
GEM*STAR mass prod.

LiF – ThF₄ – UF₄



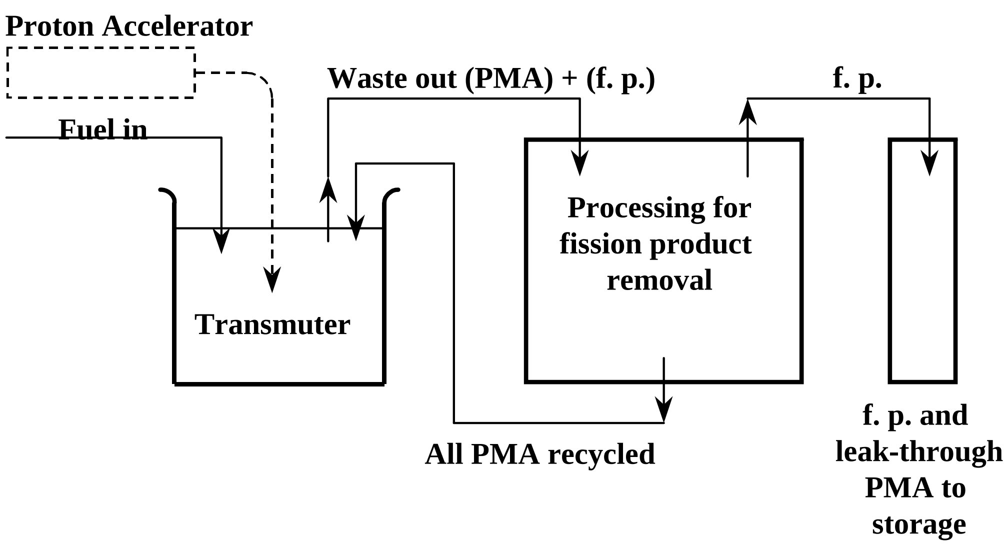
ThF4
1111°
LiF·4ThF4
LiF·2ThF4
7LiF·6ThF4
568°
3LiF·ThF4
565°
1050
950
850
750
650
550
750
650
500°
LiF
845°
4LiF·UF4
490°
7LiF·6UF4
LiF·4UF4
UF4
1035°
Mol.%

graphically…

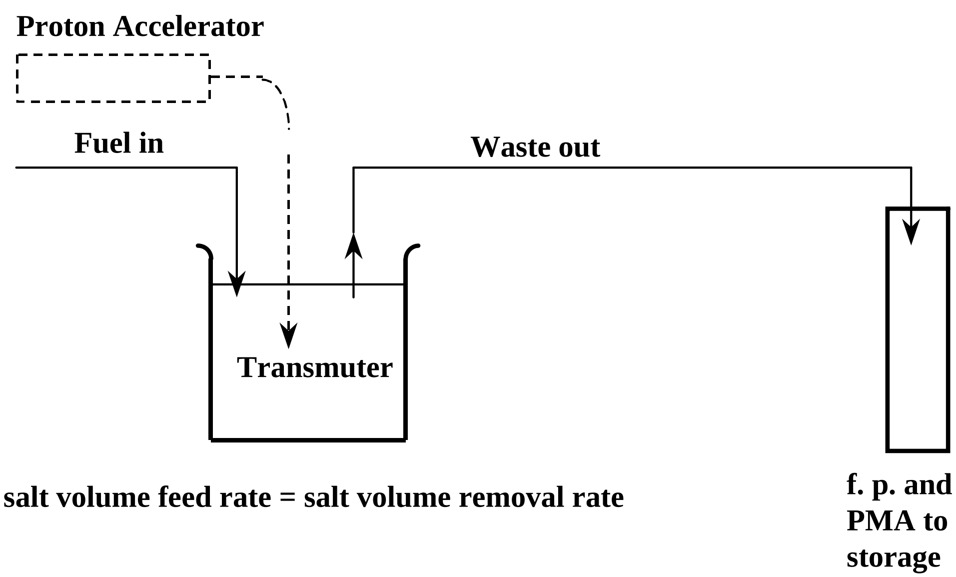


GEM STAR

CONVENTIONAL APPROACH



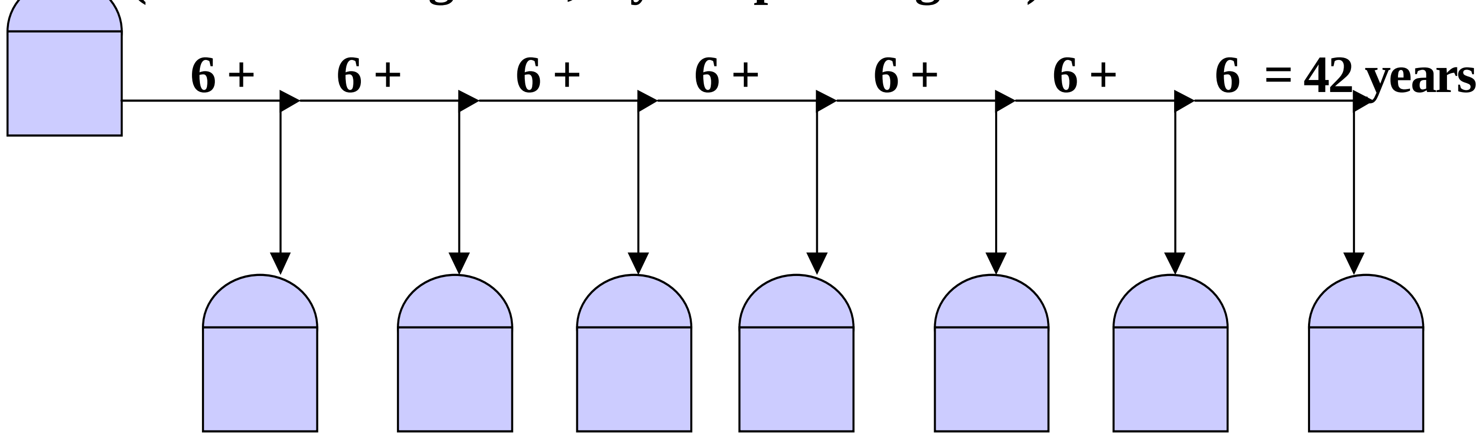
NEW APPROACH



salt volume feed rate = salt volume removal rate

Mother Fast Plutonium Breeder

(12 % breeding ratio; 6 years per daughter)



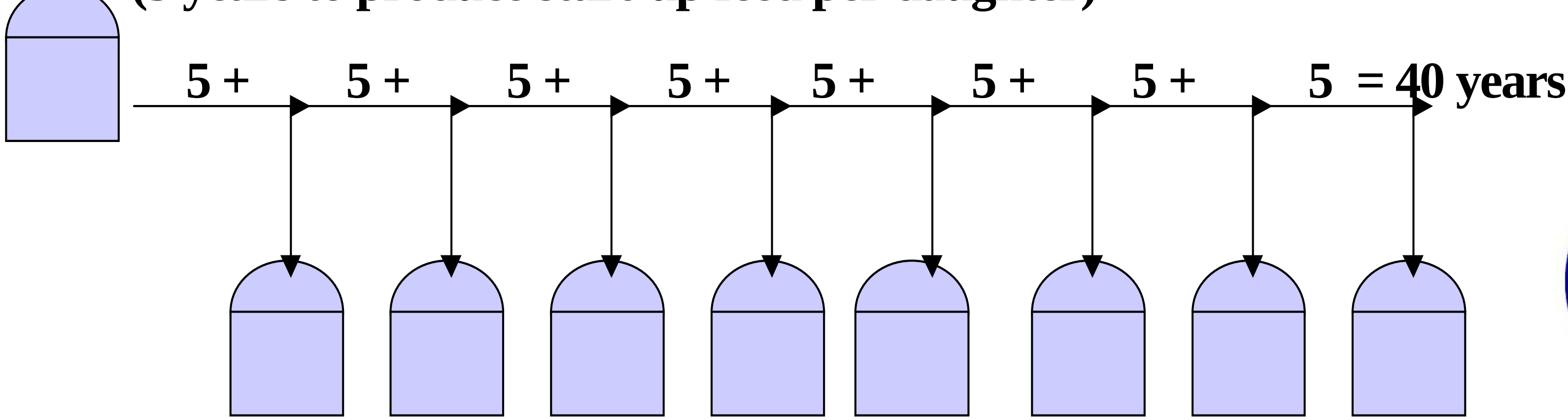
Seven daughters in 40 years

with cooling, fuel destruction, reprocessing, waste separated, and fuel refabrication

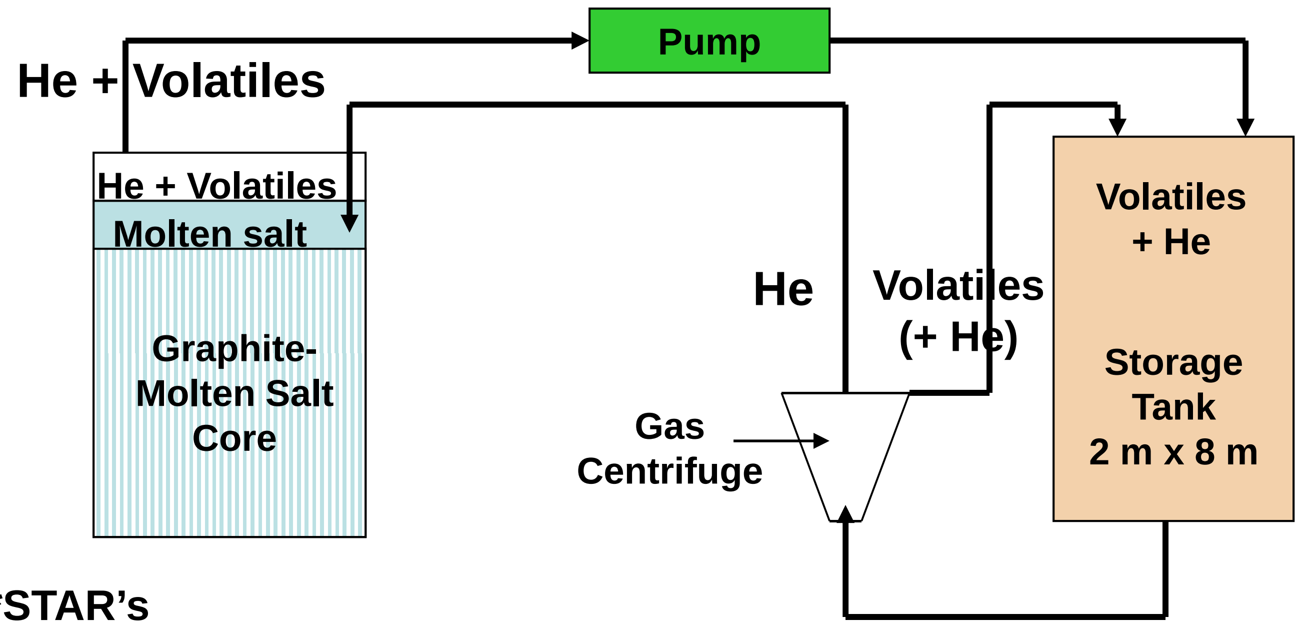
and a total of about 20,000 kg of weapons-useful ^{239}Pu from mother in 42 years

Mother Thorium-Burning Thermal-Spectrum Fluid-Fuel Unit

(5 years to produce start-up feed per daughter)



Is On-Line Removal of Volatiles the Major Advantage of Liquid fuel?



GEM*STAR's volatile inventory reduction in core for ^{85}Kr and ^{129}I = **3 minutes** (GEM*STAR)/**3 years** (LWR) = **1/ 5,000,000**

LWR present protections:
cladding,
pressure vessel,
containment vessel,
pumped water cooling

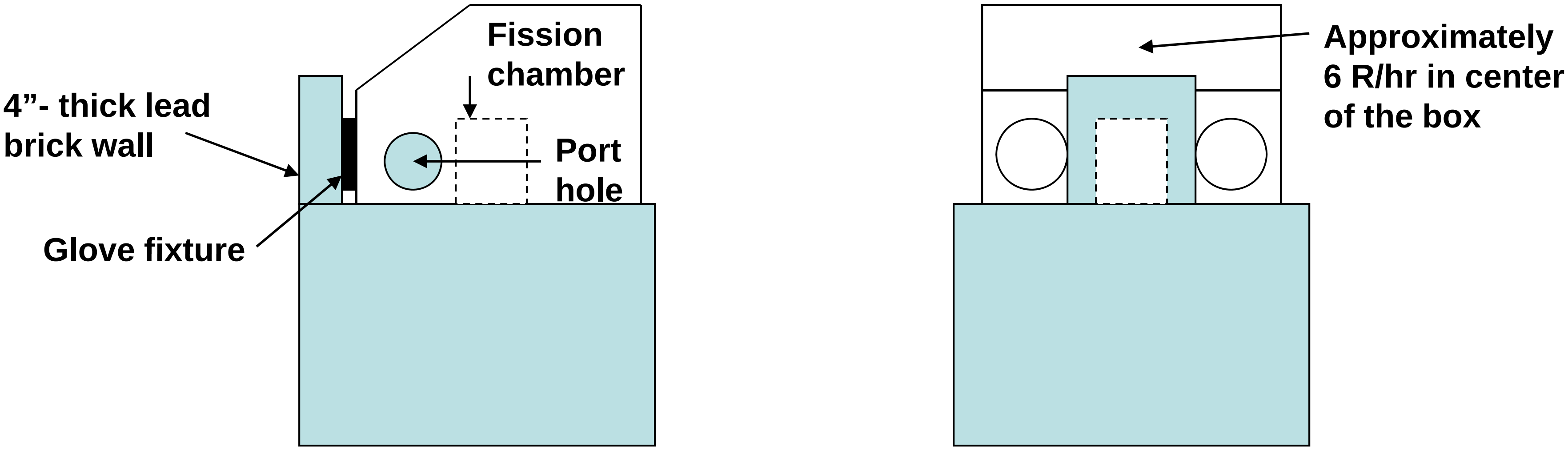
New LWR add-ons:
Gravity-fed water cooling
Air convection cooling

Add-on cost-of-scale for LWRs:
1000 MWe to1500 MWe
$6 billion to $9 billion

Assembling a ^{232}U Fission Chamber

LLNL (Auchampaugh, Bowman, and Evans)
Nuclear Physics A112, 329-336 (1968)

1. Assembling ^{233}U components not a suicide mission



Ordinary glove box under negative pressure

^{232}U chemical cleaned of decay products at ORNL about 2 months earlier

About 0.75 grams of pure ^{232}U (contaminant for approximately 1 kg of ^{233}U)

Finger ring dosimeters

Ten minutes for fission chamber assembly (finger dose about 1 R for Bowman)

Frequent unsupervised hand and body irradiations at least ten times higher per person than Bowman's at LLNL in the 1960s (Genuine Russian threat; Vietnam War)

2. Zero ^{232}U for separations done on Th for ^{233}Pa ($T_{1/2}$ = 27 days)

Practical Consequences of the GEM*STAR Breakthrough

*Burns natural uranium and produces twice as much energy from mined uranium as LWRs

*Produces as much energy from LWR spent fuel in the first pass as the LWR produced from fresh fuel

*Eliminates public concerns about enrichment, reprocessing, fast reactors

*Reduces waste stored per watt by about 5-10 and delays storage by 250-500 years

*Enhances safety; subcritical operation, low power density, low vapor pressure core materials, passive afterheat removal with air alone, fail safe operation

*Competes with the cost of nuclear power from once-through LWR even with the accelerator: lower fuel cost, afterheat costs, materials costs, heat exchanger costs, no pressure vessel, and 30% higher thermal-to-electric conversion efficiency

*Divorces nuclear power from nuclear weapons

*Burns natural U, thorium, naval spent fuel, DOE uranium, depleted-U, W-Pu, HEU

*High temperature heat enables liquid transportation fuel from coal and water

Why Electricity Cost is Lower Than LWR

(even with the accelerator and target)

- Higher thermal-to-electric efficiency (44 % vs 33 %)
- Volatile source term for accident or terrorism reduced by 1,000 to 1,000,000
- No downtime for refueling
- Less steam cooling capacity required
- Lower fuel costs by three per ton
- No control rod costs
- Graphite very cheap construction material
- No external heat exchanger
- No seven-inch pressure vessel (that must be manufactured in a foreign country)
- No back-up water cooling system for LOCA
- Simpler passive convection air cooling (low power density and vapor pressure)
- Shorter construction time (by 3) reduces interest charge on construction capital
- Improved safety reduces time and expense for siting and regulatory approval
- Improved safety may reduce interest rate on borrowed construction capital
- No near-term cost for reprocessing or waste disposition
- Ultimate waste disposition cost reduced and delayed
- Potential payment from DOE to GEM*STAR for consuming LWR spent fuel

GEM*STAR Demo Design

$10 million Required Over Two Years
Staging Facility and Engineering Design

for

60 MWe GEM*STAR electric demo costing $160 million

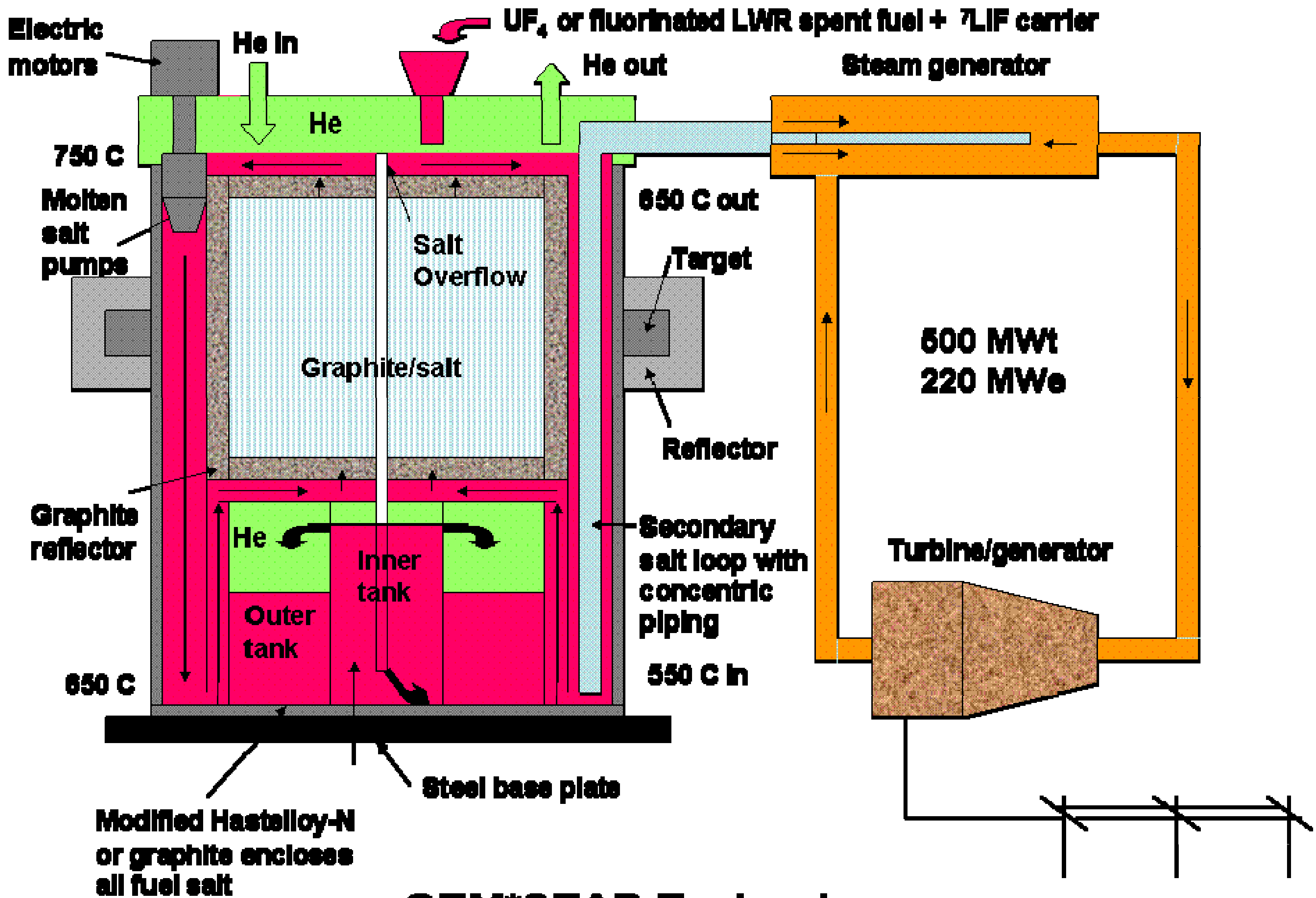
200,000 gallon/day diesel demo costing $160 million

- **Virginia Tobacco Indemnity Fund $4 million grant**
  Staging facility guiding demo design
  Location at 266 Sunflower Lane, Callaway, VA
  Involves natural uranium and radioactive sources
  $2 million/y for two years

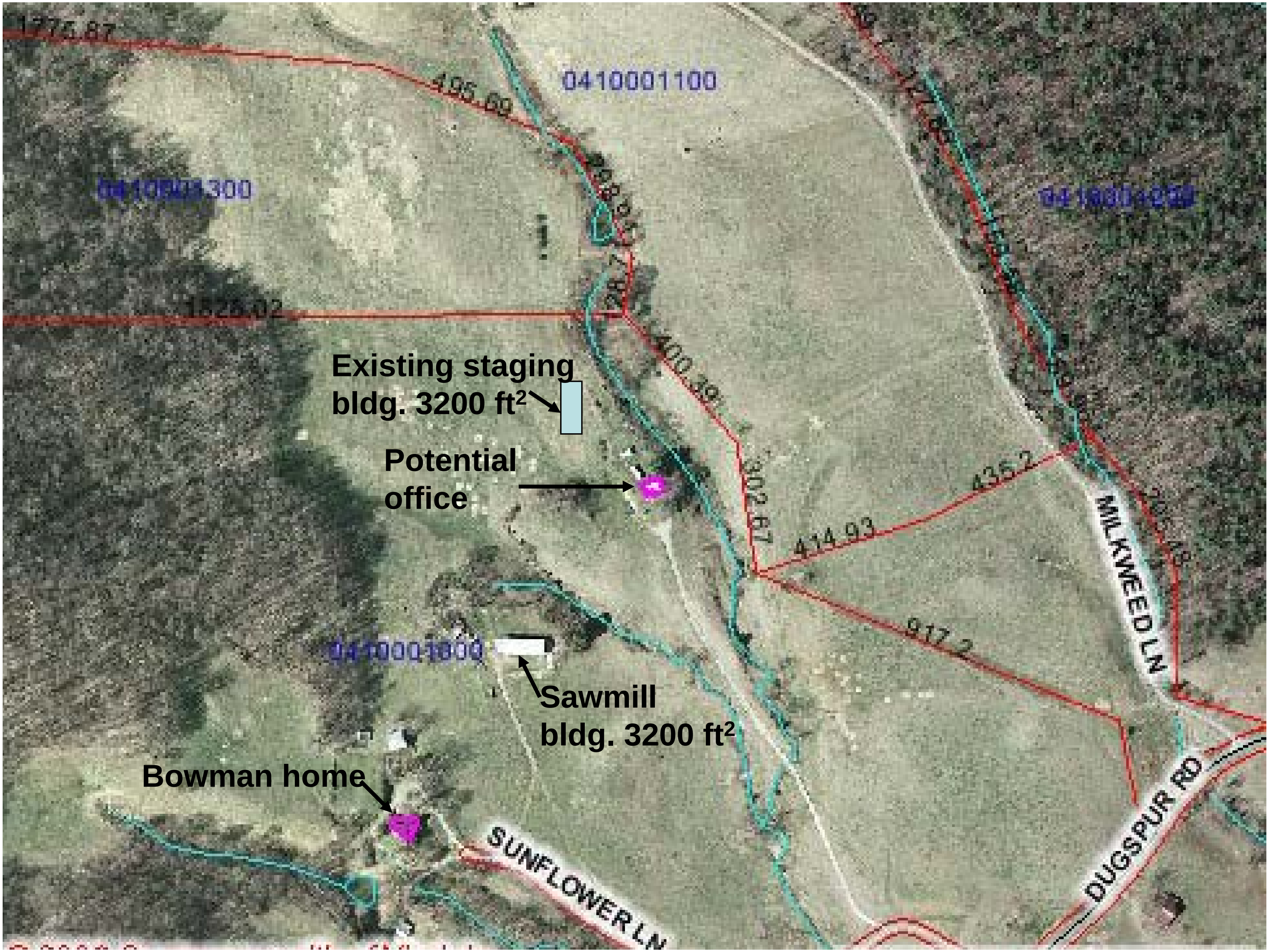
- **Los Alamos County $4 million grant**
  Engineering design of the demo in Los Alamos
  ADNA headquarters in Los Alamos
  Reservation of half of TA-21 for three years
  $2 million/y for two years

- **Other (VA and/or NM) $1 million/y for two years**
  Private investment in GEM*STAR stock
  Virginia universities contribution
  DOE via Virginia consortium

Virginia Staging Facility

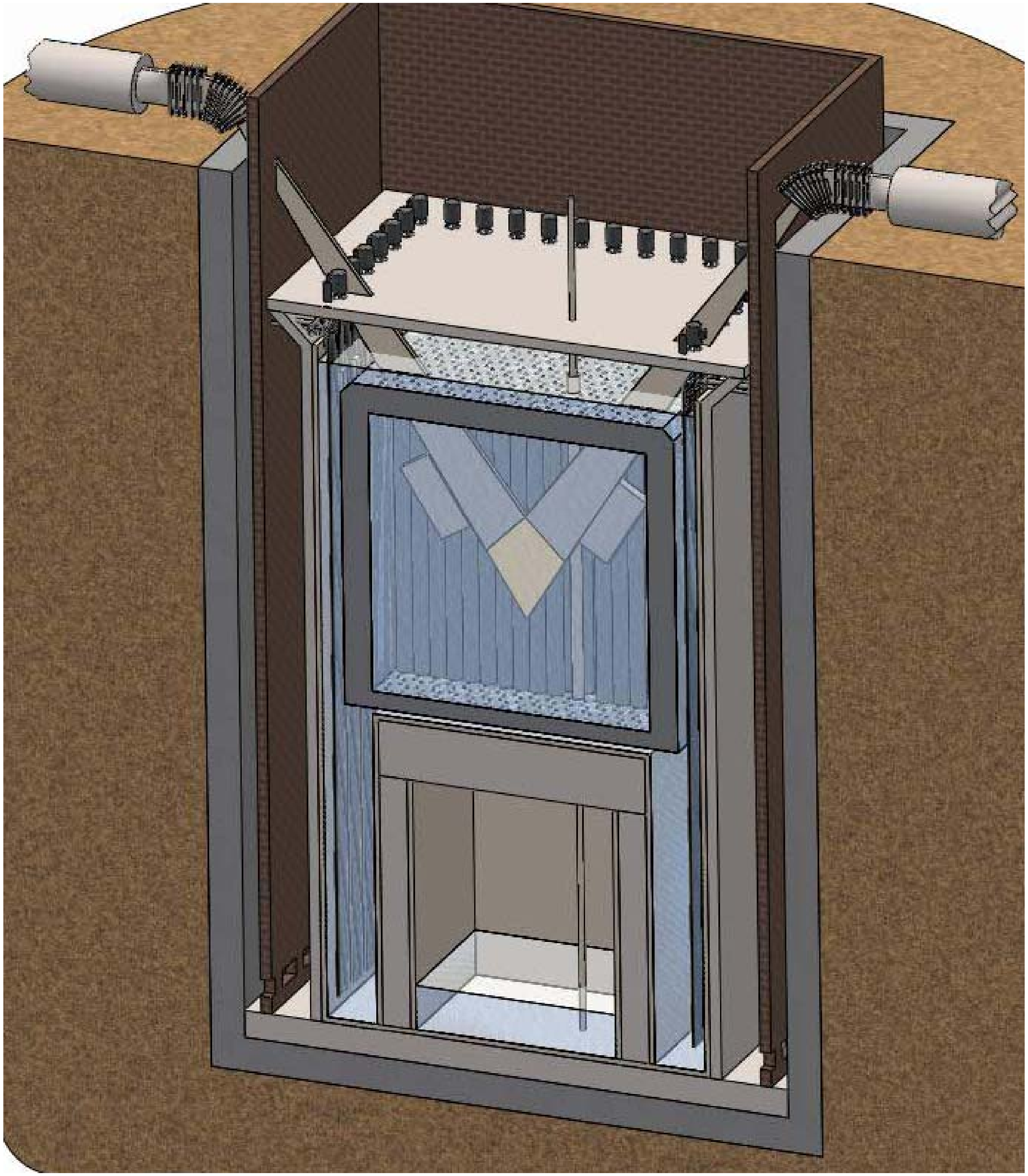


GEM*STAR Technology


0410001100
0410001300
Existing staging
bldg. 3200 ft2
Potential
office
0410001800
Sawmill
bldg. 3200 ft2
Bowman home
SUNFLOWER LN
MILKWEED LN
DUGSPUR RD
495.69
1526.02
400.39
302.67
414.93
436.2
917.2
1776.87


266 Sunflower Ln, Callaway, VA 24067
Charles and Nona Bowman
Fall-back GEM*STAR demo site
Callaway Rd
Mill Rd
© 2010 Google
Image © 2010 Commonwealth of Virginia
3895 ft
©2009

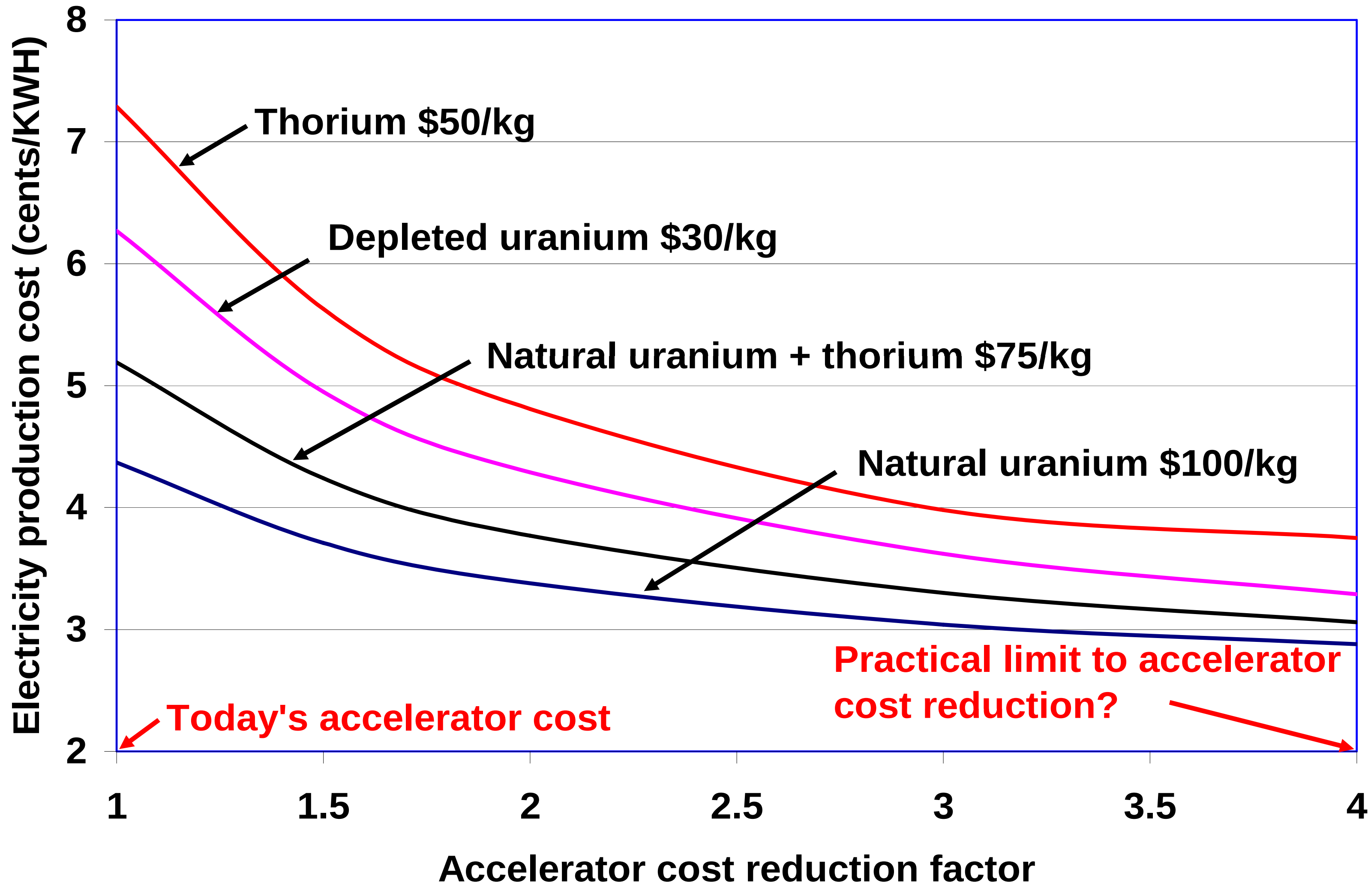
New Mexico Engineering Design



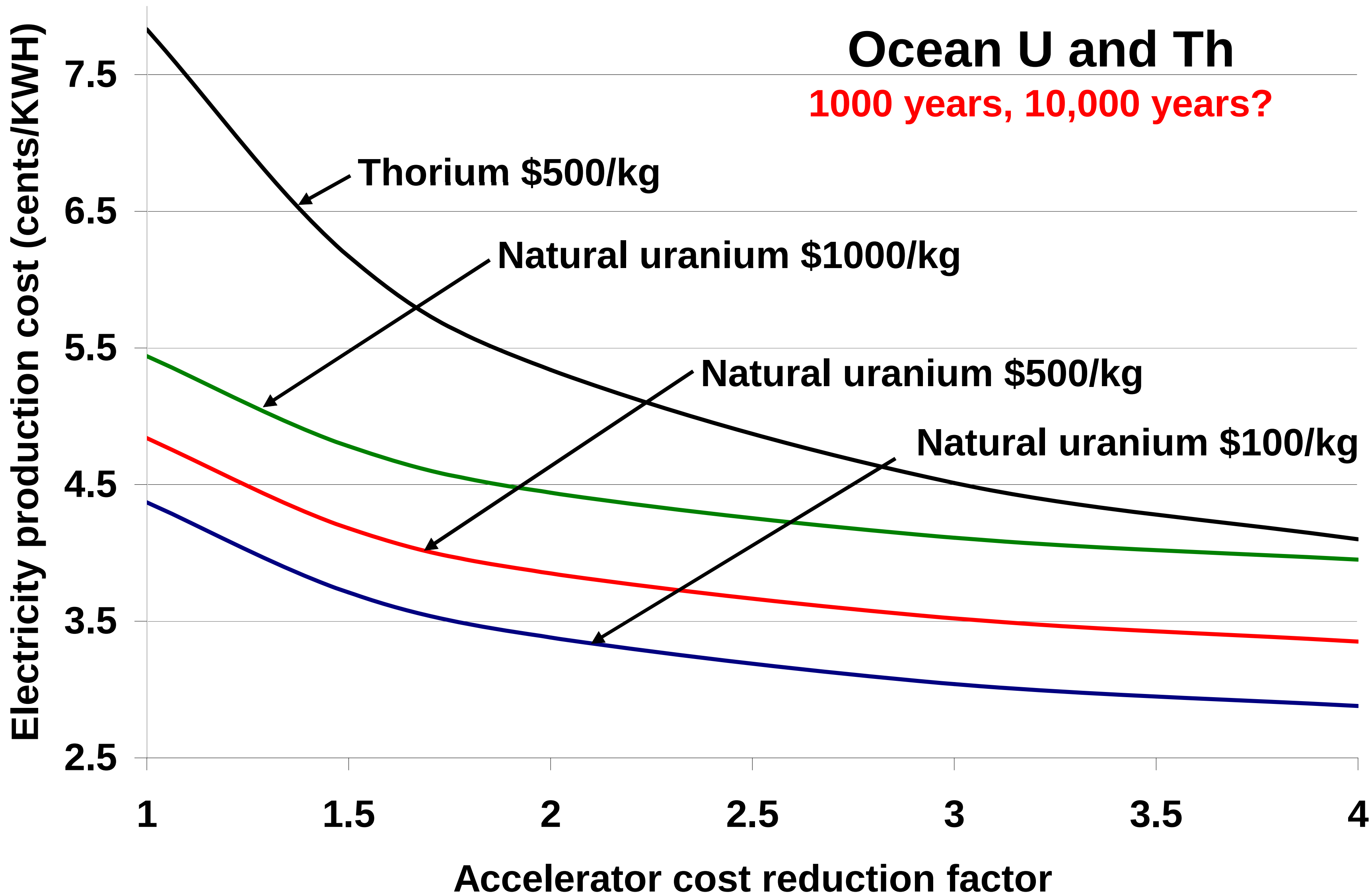
GEM*STAR Comparison on NRC and EPA Issues

Consideration	Nuclear Now and Future	GEM*STAR
Refueling radiation exposure	Significant	Zero
On-site spent fuel storage	Complex	Internal for 40 years
Longer term waste storage	Unsolved	Reuse and delay by centuries
Routine radiation release	Near zero	Near zero
Fission power density	High	Lower by ten
Accident radiation release	Large	Smaller by 1,000 – 1,000,000
Vulnerability to missile attack	Expensive barrier	Self limiting and sealing
Afterheat removal	Active by water dousing	Passive by air convection
Afterheat water requirement	Very large	Zero
Routine water requirement	Significant	Lower by 30 %
Heat release to environment	Significant	Lower by 30 %
Pressure vessel	Expensive	Thin inner containment only
Containment vessel	Heavy concrete	Thin steel outer containment
Weapons proliferation risk	Very high	Very low

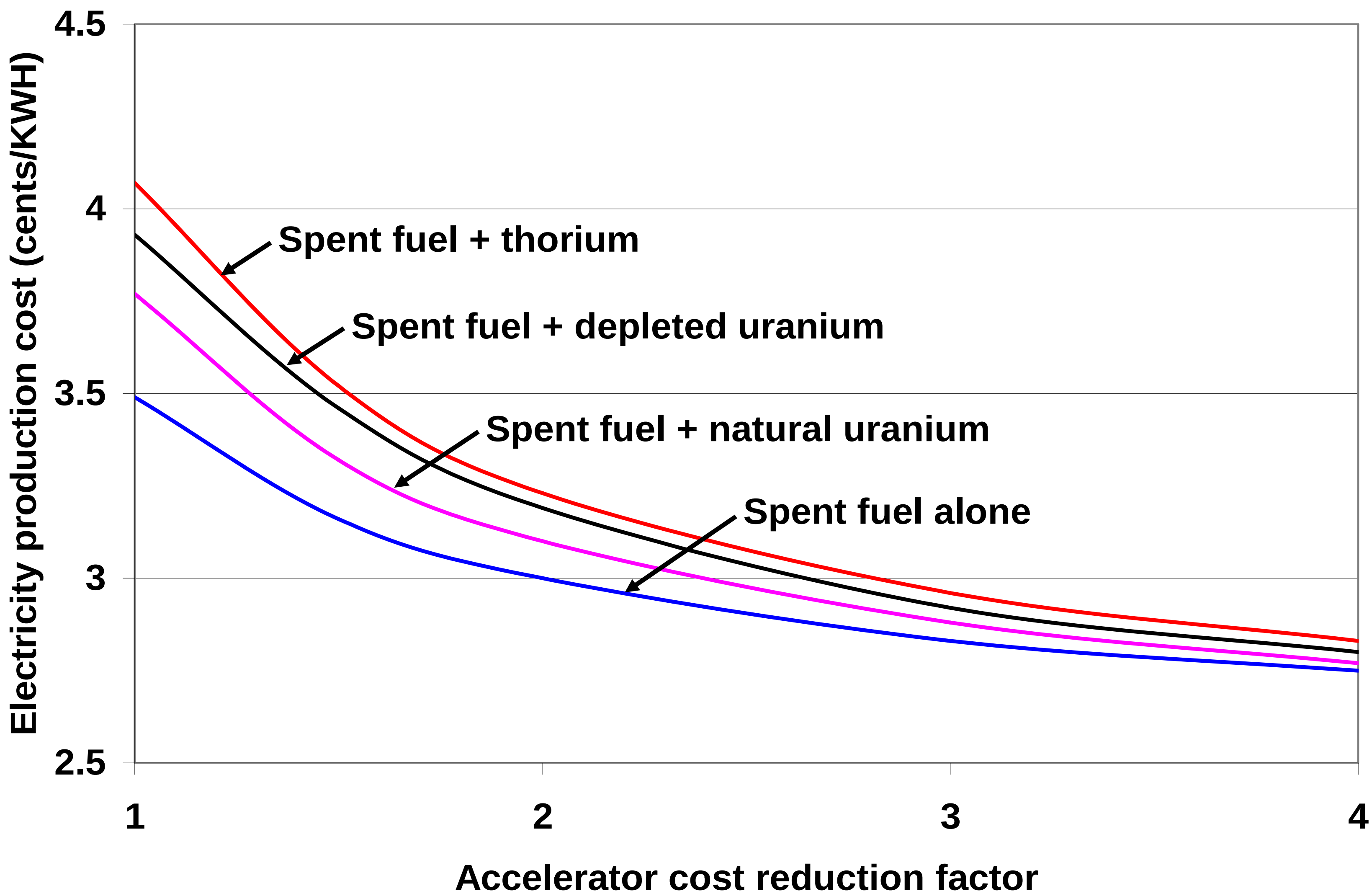
Major safety and environment simplifications for NRC and EPA



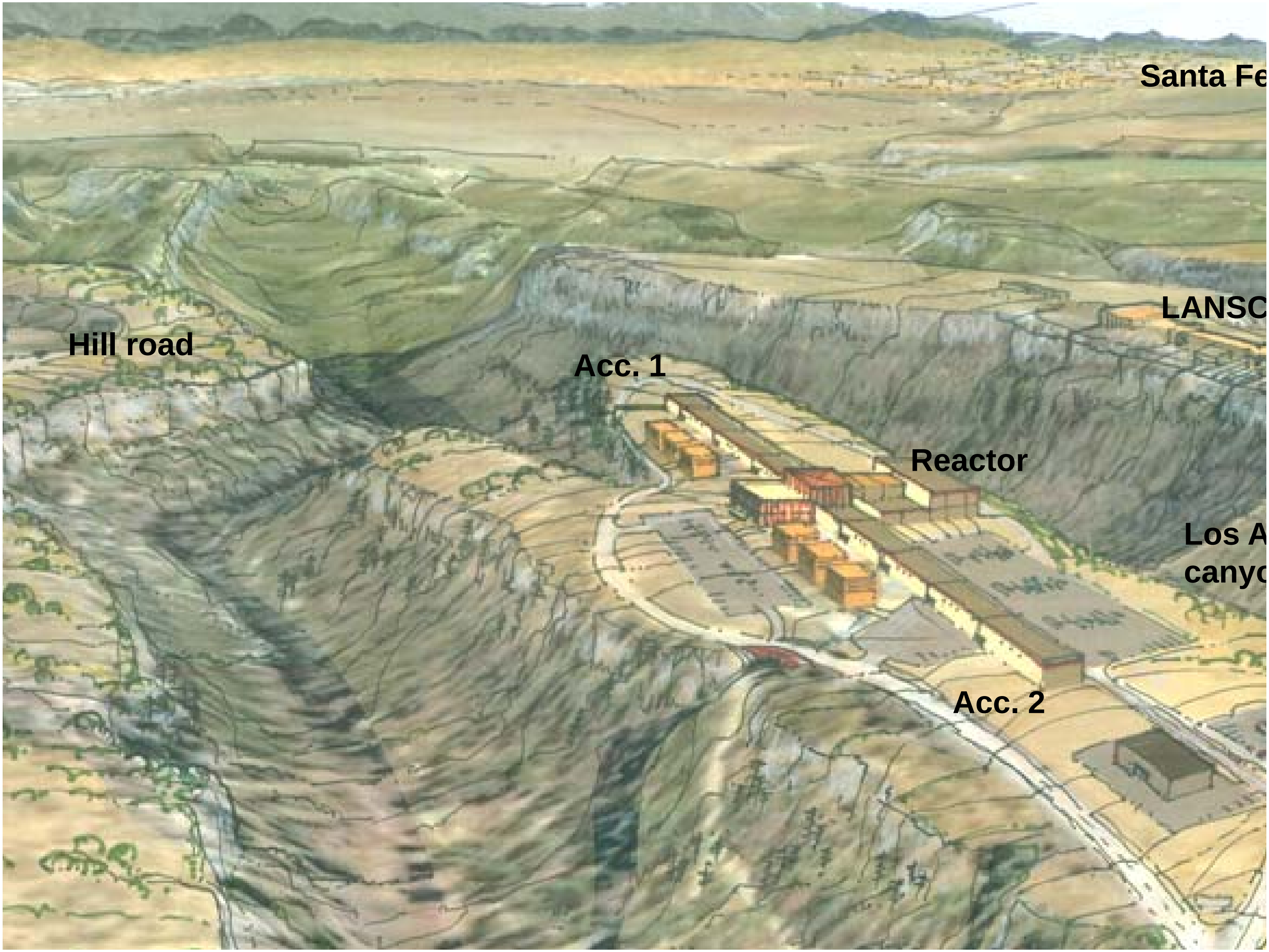
8
7
6
5
4
3
2
Electricity production cost (cents/KWH)
Thorium $50/kg
Depleted uranium $30/kg
Natural uranium + thorium $75/kg
Natural uranium $100/kg
Practical limit to accelerator cost reduction?
Today's accelerator cost
1
1.5
2
2.5
3
3.5
4
Accelerator cost reduction factor



Ocean U and Th
1000 years, 10,000 years?
Thorium $500/kg
Natural uranium $1000/kg
Natural uranium $500/kg
Natural uranium $100/kg
Electricity production cost (cents/KWH)
7.5
6.5
5.5
4.5
3.5
2.5
1
1.5
2
2.5
3
3.5
4
Accelerator cost reduction factor



4.5
4
3.5
3
2.5
1
2
3
4
Electricity production cost (cents/KWH)
Accelerator cost reduction factor
Spent fuel + thorium
Spent fuel + depleted uranium
Spent fuel + natural uranium
Spent fuel alone



Santa Fe
LANSC
Hill road
Acc. 1
Reactor
Los A
canyo
Acc. 2

Are Investment Risks Acceptable?

Safety Risks

System sealed against all emissions
Volatile inventory down by 1,000 to 1,000,000 from an LWR
Plutonium inventory down by 20 from an LWR
Fuel freezes (solidifies) if dispersed by a successful missile attack
Underground location with concrete and steel protection

Technical risk

It can be built…highly successful accelerators and a molten reactor have been built
Combustion Engineering Inc. completed a detailed design for a 1000 MWe molten salt reactor in 1970

Financial risk

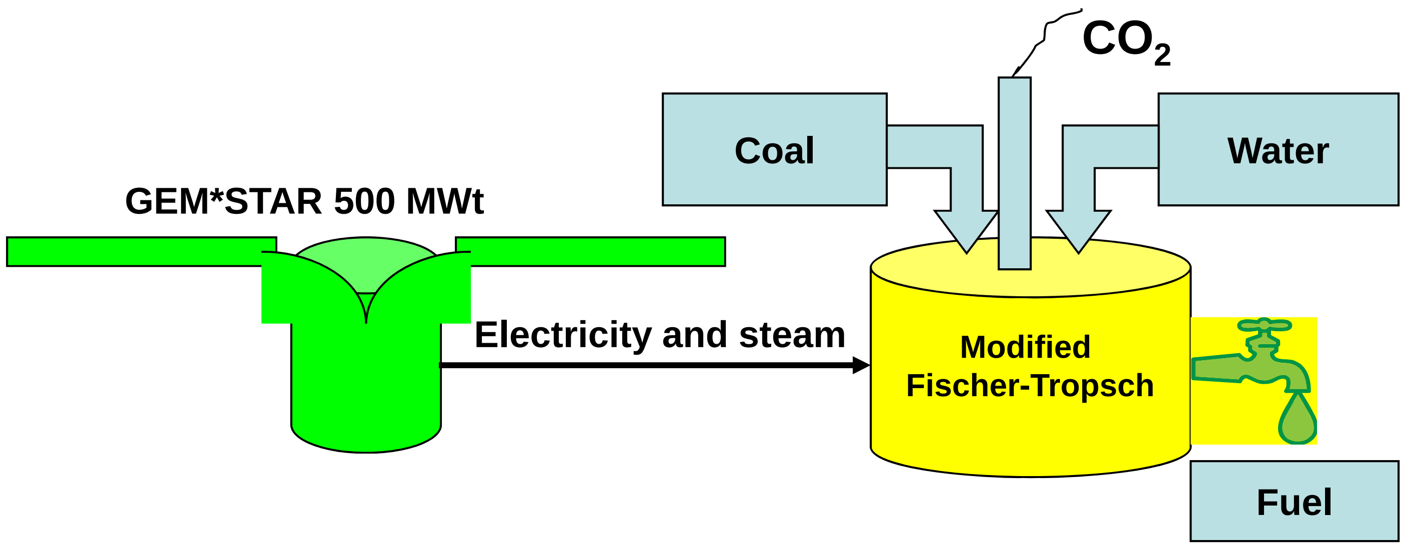
Pulling together the construction team
- **World's most attractive nuclear project by far**
- **Most compelling green (no CO_2) energy project (undercuts solar, wind, and bio electricity costs by more than four)**

First 60-MWe unit will pay for its operations and pay off capital investment
Investment come from national and world market measured in $ trillions
Future costs for GEM*STAR electricity go down, not up
No IPO sellout…..ADNA to be a long-term vertically integrated corporation

Regulatory risk

GEM*STAR is technically not a reactor so role of NRC not established by precedent but by House and Senate
Project aim is demonstrating successful operation; licensing later
A demo under DOE oversight might not require NRC oversight as well
Absence of federal funds might speed environmental approvals
Simple change to DOE missions of tritium or ^{3}He production if necessary for turn-on
Build elsewhere if U. S. approvals introduce unacceptable delays

Diesel and Gasoline from GEM*STAR



$6H_2O + 3C \rightarrow 3CO_2 + 6H_2 \rightarrow 2(-CH_2-) + 4\ H_2O + CO_2$

Water (680,000 gallons/d)
+ Coal (3000 tons/d)

↓

Diesel (680,000 gallons/d
+ CO_2 (1000 tons/d C (1/3 of feed))

Obviously railroad site required

Estimate of Diesel Price at the Pump

Steam and electricity from GEM*STAR	$ 0.53/gallon
Feed coal @ $100/ton (twice the current price)	0.37
Conversion facility operations costs	0.19
Construction mortgage payments for conv. facil.	0.15
Liquid fuel production profit @ 15 %	0.19
Wholesale price	$ 1.43/gallon
Distribution and sales	0.24
Federal excise tax*	0.25
State excise tax*	0.22
Total	$2.14/gallon

*U. S. Energy Information Administration averages for the U. S.

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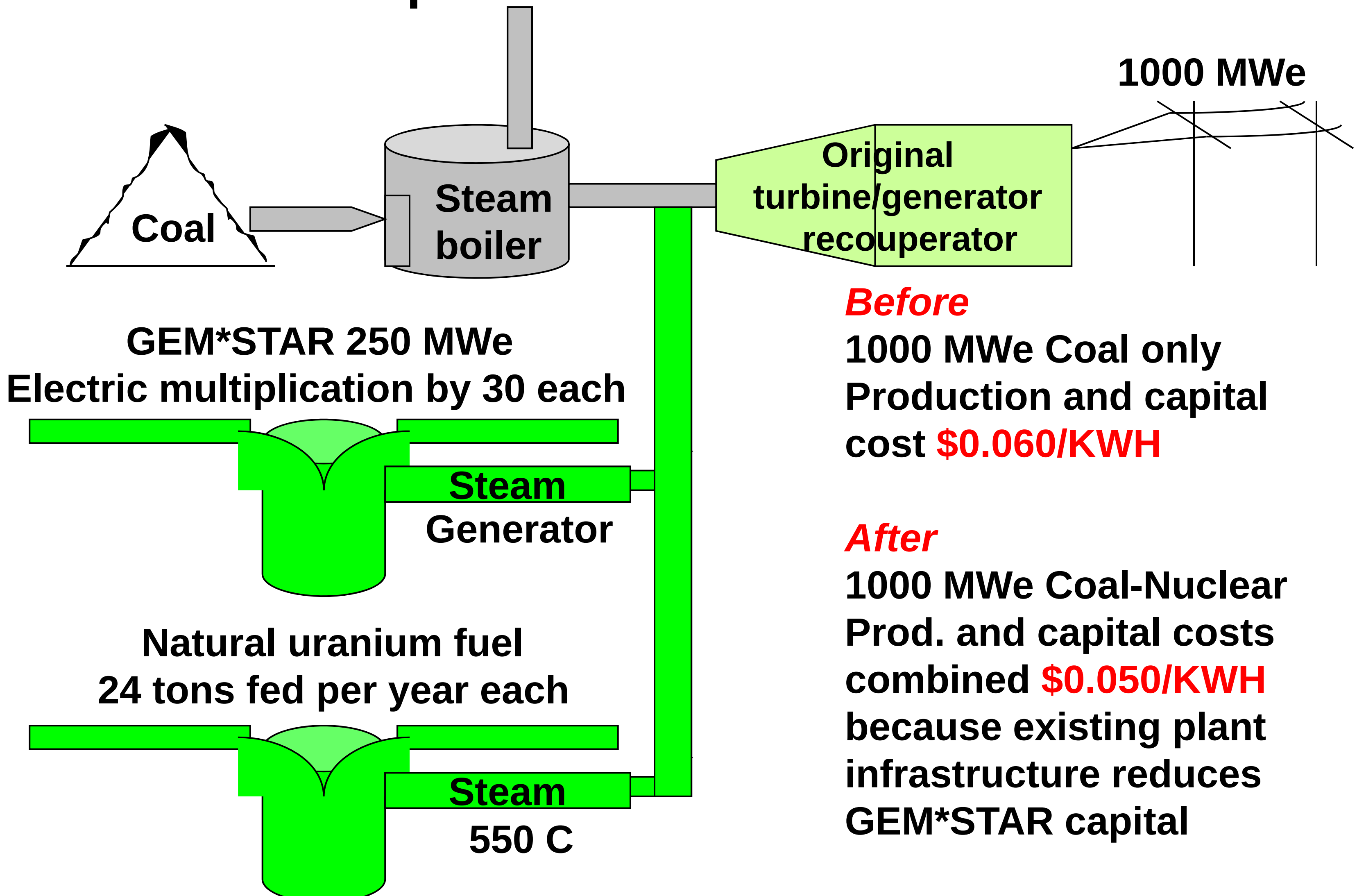
Coal-Fired Plant Conversion to Half Nuclear
Cap-and-Trade Neutralized



Natural UF_4 fuel $5.0 million/year
Electricity sales @ 7 ¢/KWH $550 million/year

Before

1000 MWe Coal only
Production and capital cost $0.060/KWH

After

1000 MWe Coal-Nuclear
Prod. and capital costs combined $0.050/KWH because existing plant infrastructure reduces GEM*STAR capital

CO_2 credits transferred internally

East-West Roles in GEM*STAR

Phase 1: Start-Up

Virginia	New Mexico
Staging facility construction, Franklin County	**ADNA Corp. design and engineering of demo**
VA University & Jefferson Lab Consortium Funding development (Calculations, design, scoping)	**NM resource draw-in (LANL, Sandia, WIPP with DOE support)**
GEM*STAR Demo site selection (Natural uranium only)	**GEM*STAR Fuel Testing Facility design**

Phase 2: Mid-Term

Demonstration steam generation with natural uranium	**GEM*STAR fuel testing facility construction**
Demo electricity production (Nat. U)	**Alternative fuel preparation (reactor spent fuel, naval spent fuel, thorium, depleted uranium, weapons plutonium, DOE legacy fuels**
Demo liquid fuel production (Nat. U)	**Demo Isotope separation for ^{7}Li**

East-West Roles in GEM*STAR (Continued)

Phase 3: Longer Term

Virginia

GEM*STAR manufacture

VA Consortium Technology extension center (advanced recycling, advanced accelerators, materials development)

^{7}Li production and fuel preparation

Virginia Focus

GEM*STAR manufacturing and technology improvement

New Mexico

Continued fuel development at fuel test facility (Initial focus on spent fuel)

Advanced GEM*STAR designs

^{7}Li production and fuel preparation

New Mexico Focus

GEM*STAR solutions to long-term DOE problems

GEM*STAR Demo at TA-21

GEM*STAR Demo	100 % borrowed capital 60 MWe		Stage I: 60 MWe Demo with 50% loan and 50% capital Investment	
	Upper Bound	Lower Bound	Upper Bound	Lower Bound
Reactor & Building	$ 50,793,235	$ 25,596,623	$ 50,793,235	$ 25,596,623
Accelerators & Building	$ 90,164,034	$ 63,856,251	$ 90,164,034	$ 63,856,251
Miscellaneous Buildings	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000
Turbines & Generator Sets (200 Mwe)	$ 30,000,000	$ 20,000,000	$ 30,000,000	$ 20,000,000
Estimated Cost without Pre-finance	$ 211,148,723	$ 137,343,449	$ 211,148,723	$ 114,452,874
Initial phase pre-start-up financing costs (7%)	$ 15,340,411	$ 9,614,041	$ 14,780,411	$ 8,011,701
Estimated Cost with Finance of Building Costs	$ 226,489,133	$ 146,957,490	$ 225,929,133	$ 122,464,575
Capital Investment (initial)	-	-	$ 105,574,361	$ 57,226,437
Revenues (Year 5)	$ 35,826,402	$ 35,826,402	35826402.49	35826402.49
Operational & Finance Costs (Year 5)	$ 39,852,192	$ 24,965,252	26180934.76	15444293.66
Profit or Loss (Year 5)	$ (4,025,789)	$ 10,861,151	9645467.734	20382108.84
Profit or Loss with GHG Credit (Year 5)	$ 4,116,575	$ 8,142,364	17787831.94	27726054.84
Generation cost per KWhr	$ 0.084	$ 0.053	0.055	0.033
Sales Price per KWhr	$ 0.070	$ 0.070	0.070	0.070
Gain or Loss per KWhr	$ (0.014)	$ 0.017	0.015	0.037
Gain or Loss per KWhr with GHG Credit $0.018/KWh	$ 0.004	$ 0.035	0.033	0.055
Margin (Profit/Loss on Revenues)	**Avg.** -20%	**2%** 24%	21%	**37%** 53%
Margin (Profit/Loss on Revenues) with GHG Credit	**Avg.** 6%	**28%** 50%	47%	**63%** 79%
Return on Invested Capital without GHG Credit	-	-	9%	**22%** 36%

Initially 60 MWe with upgrade to 120 MWe by adding a second accelerator and target and doubling the turbine-generator, but without other changes.

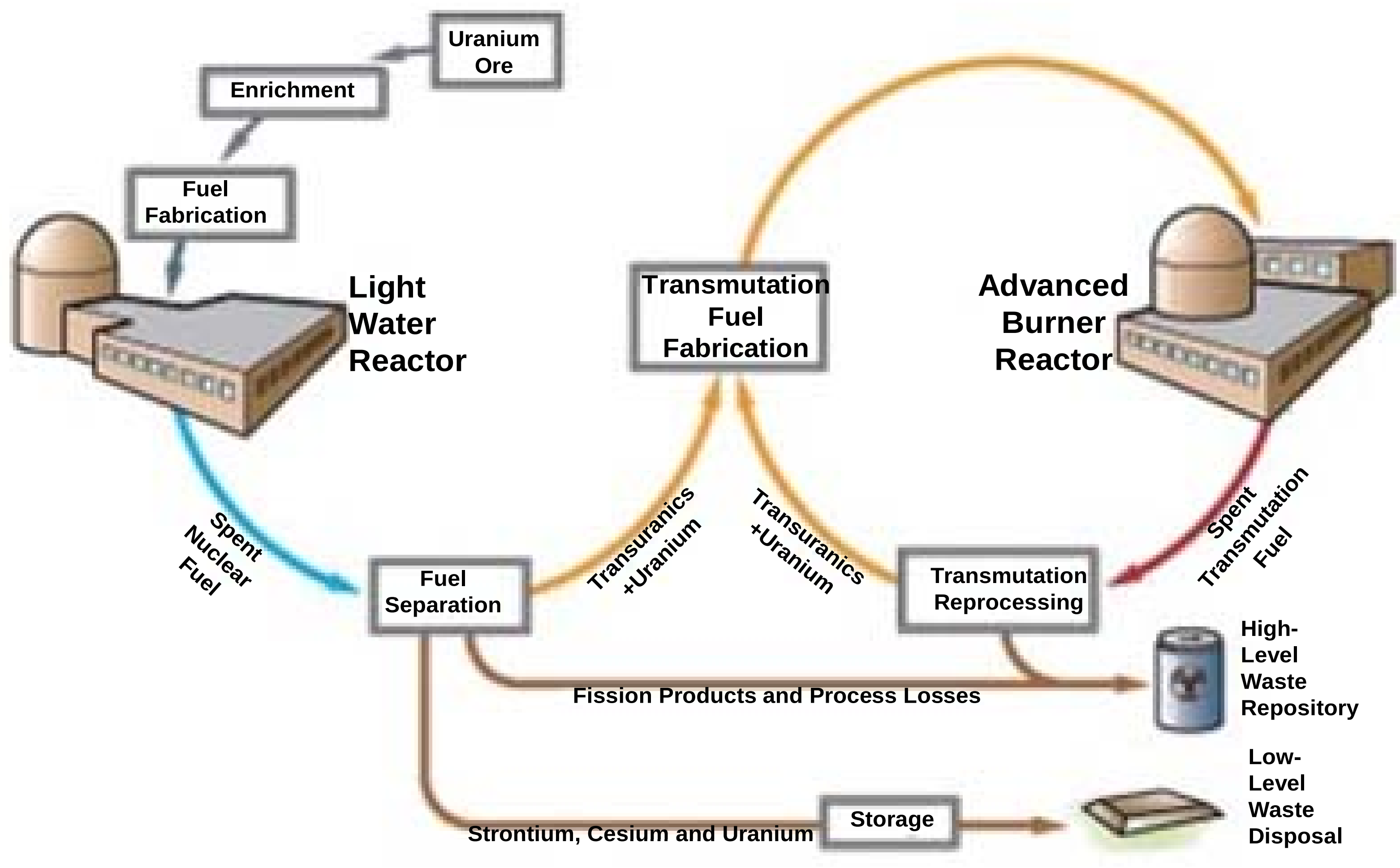
The ADNA-GEM*STAR Team

Bruce Vogelaar	**Prof. of Physics, Virginia Tech**
Ganapati Myneni	**SCT Jefferson Lab**
Eugene Smith	**Virginia Electric Power Co., retired**
Roger Smith **R.J. Ponchione**	**Zia Engineering and Design**
Tom Wangler	**Accelerator consultant**
Kieth Barras	**Mosaic Architectural Engineering and Design**
David Blond	**Chief Economist of the Pentagon, Retired**
Kevin Holsapple	**Los Alamos Community Development Corporation**
Brad Salter	**Virginia financial development consultant**
Ed Bilpuch* **Calvin Howell**** **Anton Tonchev** **Werner Tornow***	**Duke-TUNL neutron science team** ***Former TUNL director** ****Present TUNL director**
14 additional stockholders	**Assistance-in-kind**

Permitting and Regulatory Spread Sheet

Stage	Item	Permitted/Licensed Party			Regulatory Body						
		ADNA	Virginia Tech	Jefferson Laboraotory	County	Emergency Services (e.g. Fire Marshall)	State Environment	NRC	OSHA	EPA	Other
1	Zoning	x			x						
	“Source Material”	?	?	?				x			
	“Hygiene Plans”, etc	x	?			x	x		x		
	Low-Energy LINAC			x		x		x			?
2	Proton Accelerator	x		x		x		x	x		
	Reactor	x	?			x	x	x	x	?*	
	Turbine Generator	x							x		
3	Demonstrator	x				x	x*	x	x	x*	
	“Special Nuclear Materials”	x		?				x			
4	Power Generation License	x						x	x		?
5	Spent Nuclear Fuel	x						x	x		?

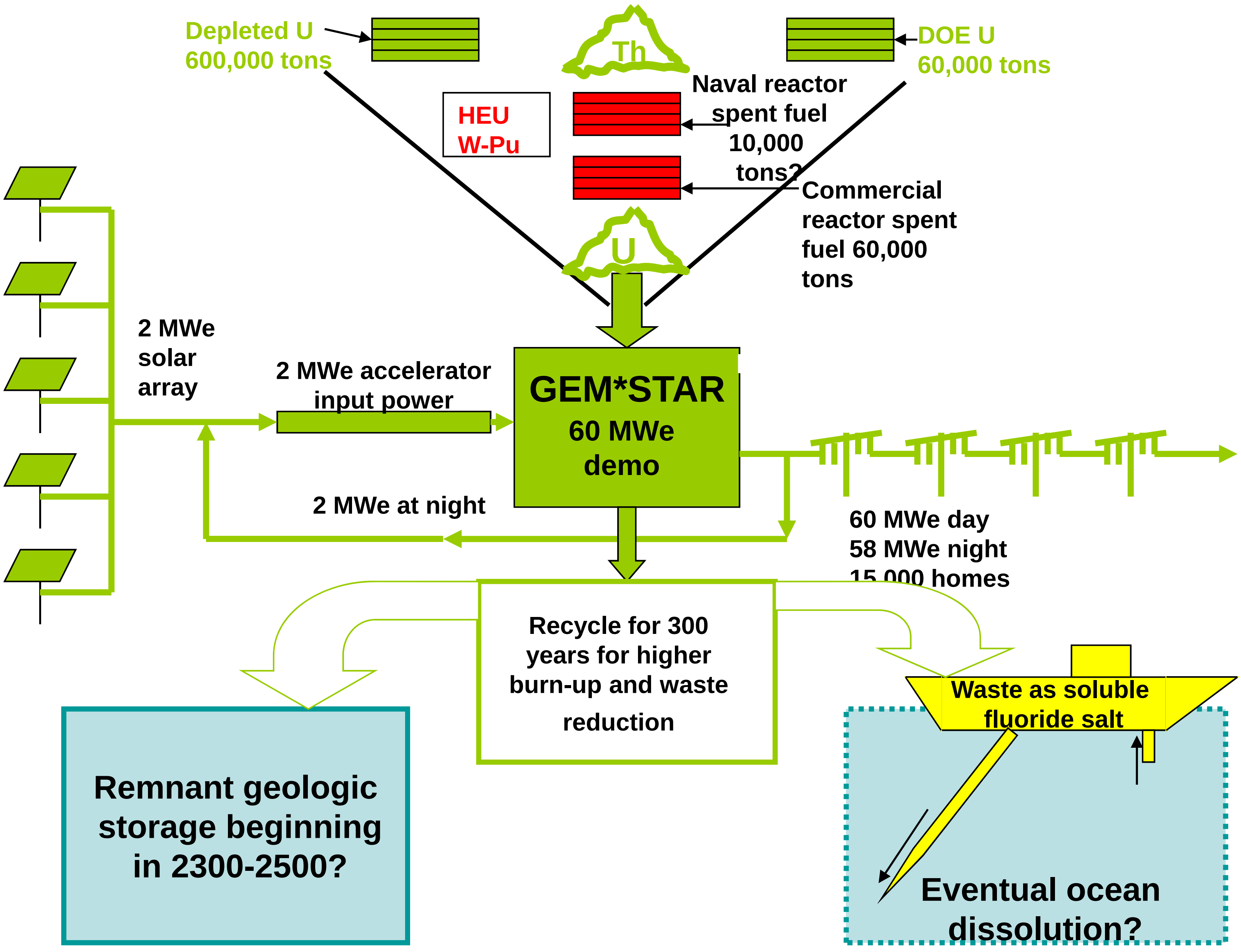
graphically…



GEM*STAR


Rocky Mt, VA
Image © 2010 Commonwealth of Virginia
© 2010 Google
8.47 mi
gery Dates: Feb 1, 2006 - Feb 1, 2007
36°59'38.44" N
79°48'54.97" W
elev 1001 ft
Eye alt 29.44 mi

GEM*STAR


Depleted U
600,000 tons
Th
DOE U
60,000 tons
HEU
W-Pu
Naval reactor spent fuel 10,000 tons?
Commercial reactor spent fuel 60,000 tons
U
2 MWe solar array
2 MWe accelerator input power
GEM*STAR
60 MWe demo
2 MWe at night
60 MWe day
58 MWe night
15,000 homes
Recycle for 300 years for higher burn-up and waste reduction
Remnant geologic storage beginning in 2300-2500?
Waste as soluble fluoride salt
Eventual ocean dissolution?