GEM STAR

Green Energy-Multiplier

Subcritical Technology for Alternative Reactors

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Topics

- Virginia Tech Kimballton Underground Research Facility (KURF)
- Virginia Tech Nuclear Engineering Program Update
- GEM*STAR

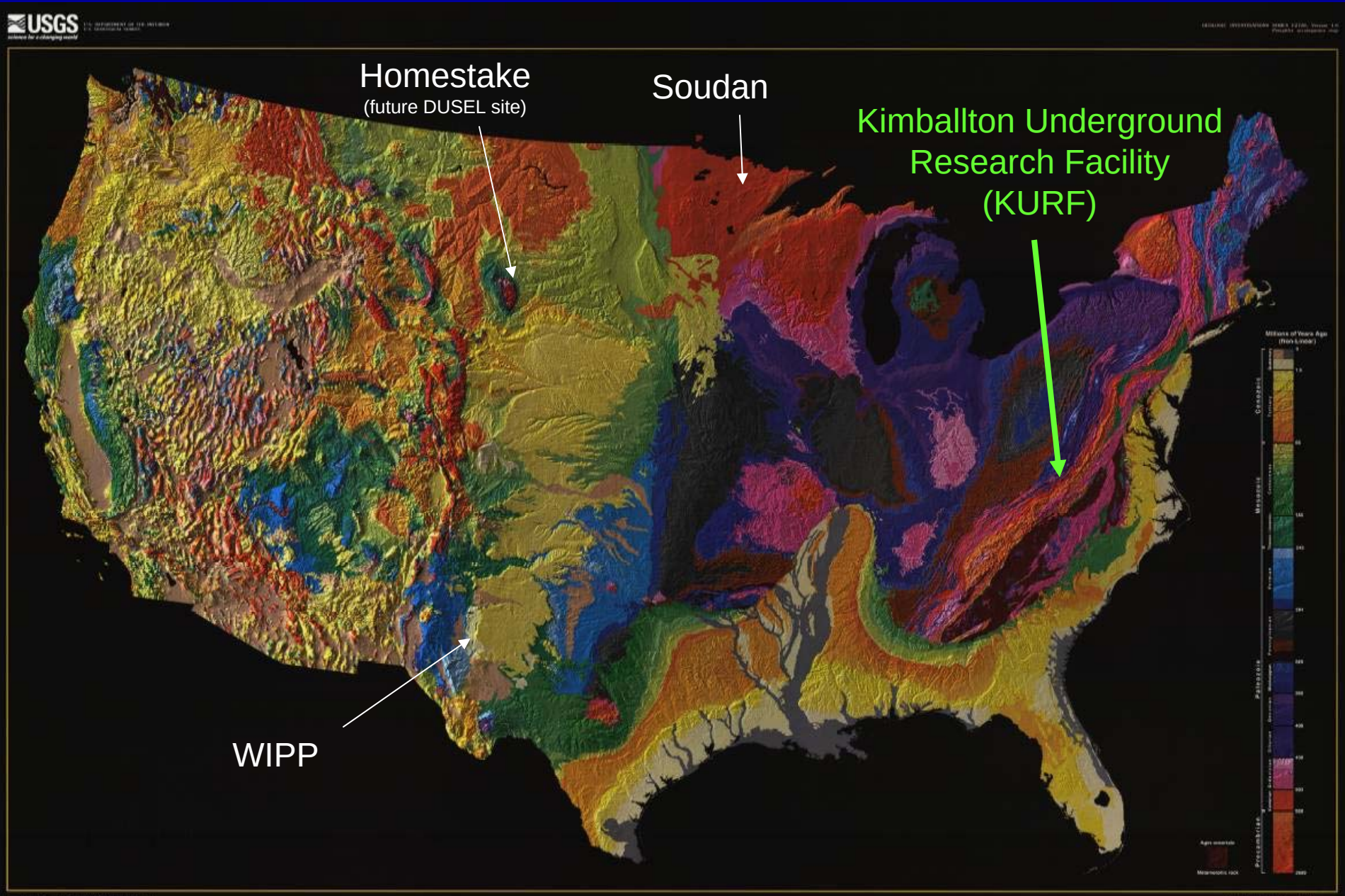
My Background

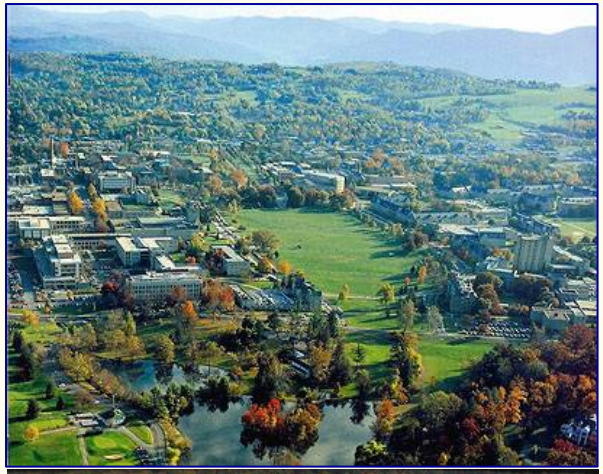
- U.S. Navy nuclear submariner, 23 years
  - Radiological Controls Officer
  - Chief Engineer
  - Naval Reactors
  - Deputy Dept Head, Engineering, Materials & Physical Sciences, Office of Naval Research
- Virginia Tech, PhD Mathematics, PDEs & abstract differential-algebraic equations (DAEs)
  - DUSEL, Unmanned Systems (JOUSTER)
  - Nuclear Engineering

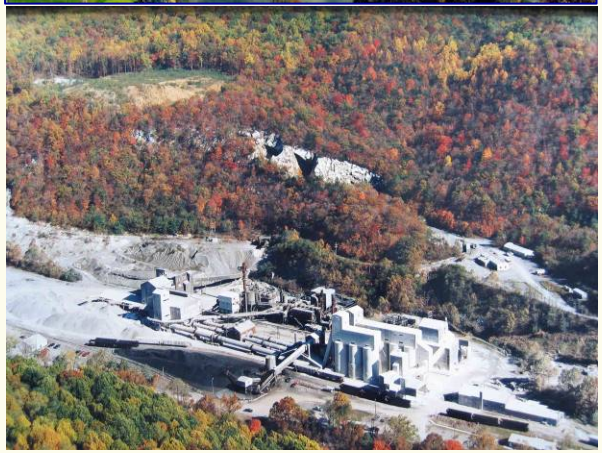
Virginia Tech Kimballton Underground Research Facility

KURF

US Deep Underground Laboratories

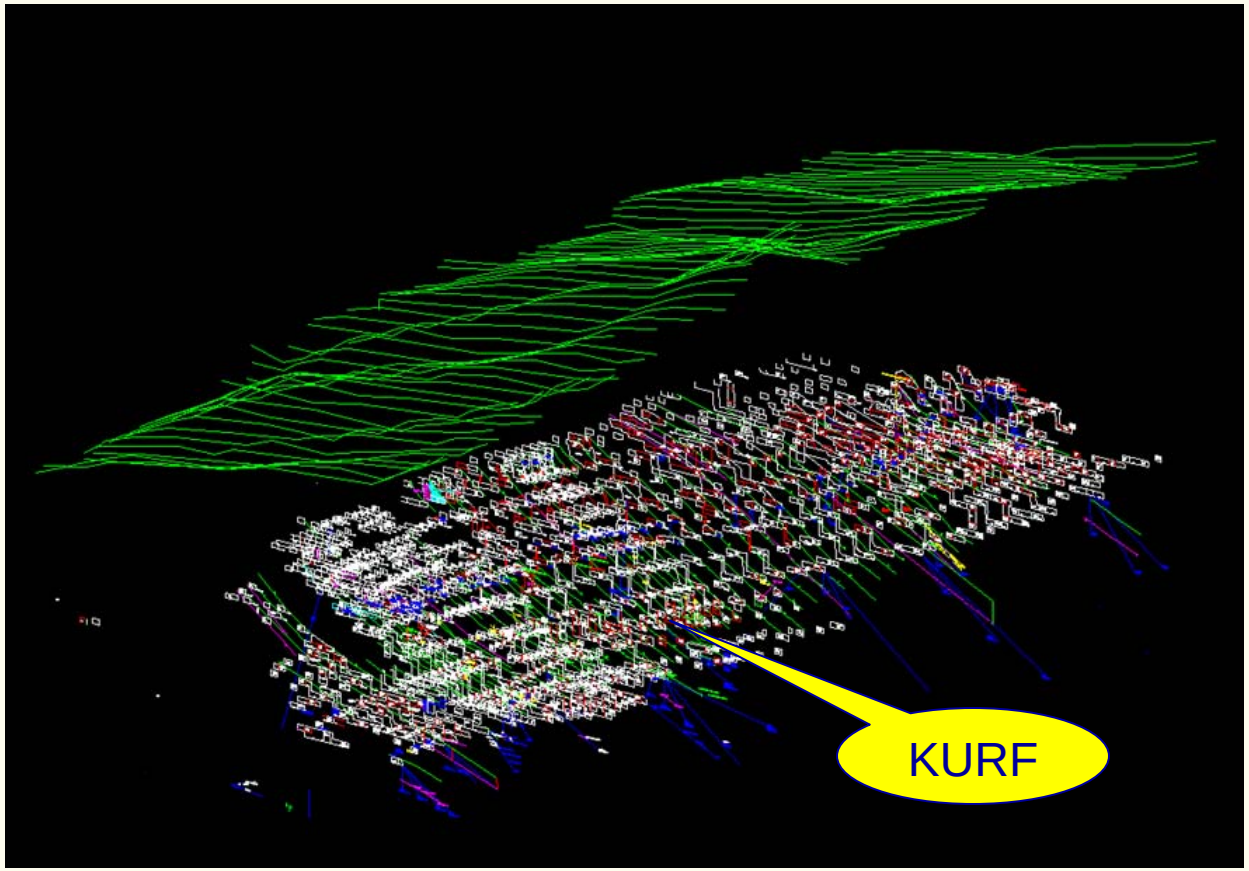






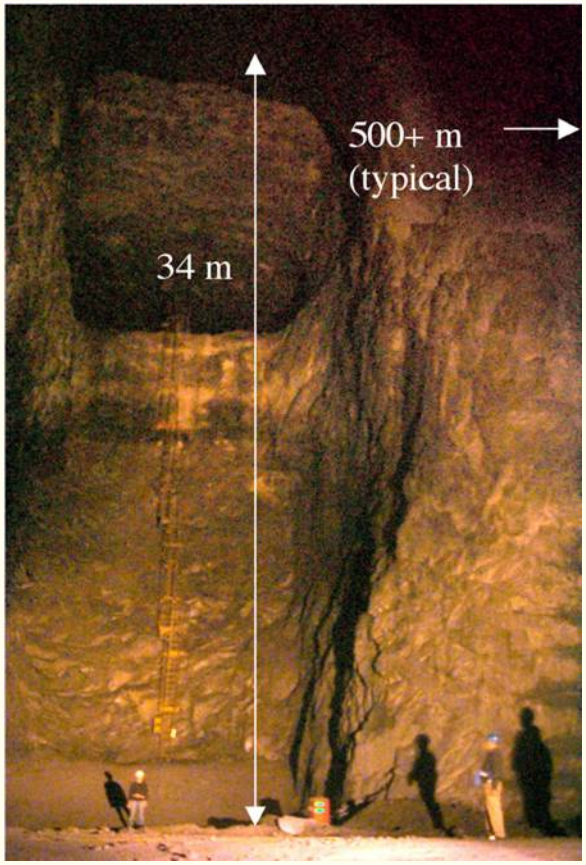
The Kimballton site:

- **30 minutes from Virginia Tech**
- **largest research university in Virginia (29,000 students)**
- **technical infrastructure and academic environment in the *immediate* vicinity of laboratory is unique**



~ 1 mile

- Current maximum depth of mine – 2300’ (~1900 mwe assuming limestone)
- over 50 miles of stopes
- 700 kton of high-grade limestone removed per year (~7 Gran Sasso Hall C’s/yr)
- Current facility at 1700’ (~1450 mwe)
- low U/Th in rock, and low Rn levels due to high air-flow
- relatively impermeable limestone results in a ‘dry location’



Drive-in Access:

Width 42’ (12.8 meters)

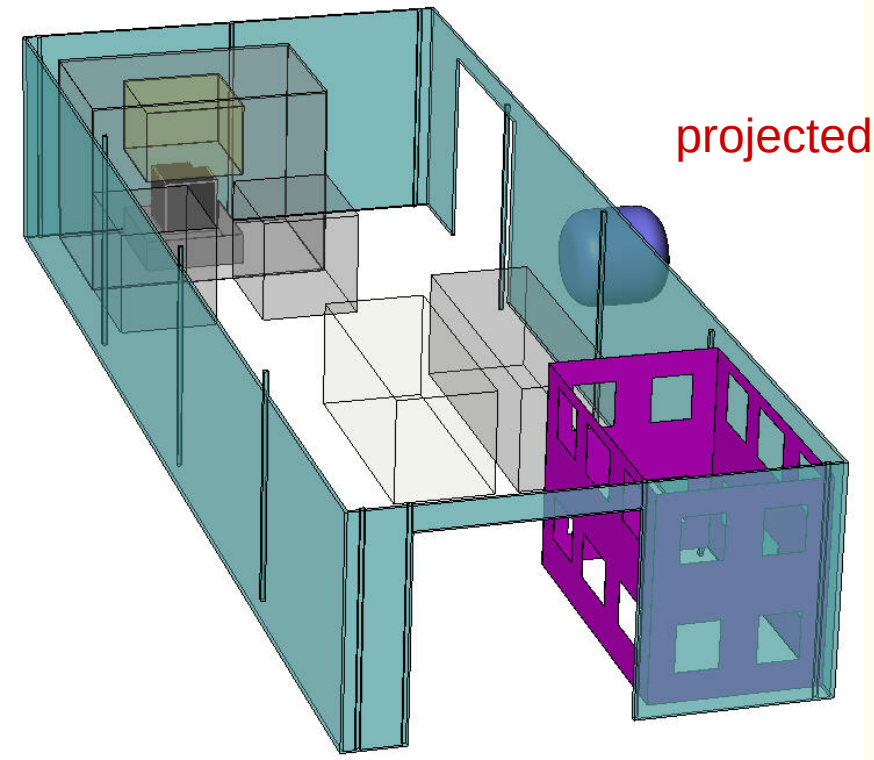
Height 26’ – 105’ (8 – 32 m)

Potential space is ***HUGE***

Kimballton Underground Research Facility

(during construction)

VirginiaTech
Invent the Future



projected layout

100’ x 36’ x 20’ (high)
HEPA filtered air
change/visitor room
local LN_2, power, internet, etc.
room for 7 + connex ‘lab modules’

possible muon coincidence detector

building now complete and initial experiments installed

Typical Laboratory Module

- internal clean-room
- Rn reduced detector housing
- local shielding from rocks

Currently

- Mo-100 double beta decay (Duke)
- NIST ‘Melissa’ HPGe detector
- VT-1 Ortec low-background detector
- partner use of NRL-1 (in Gran Sasso)

Funded DUSEL R&D

- lab-scale Rn reduction
- ICPMS –vs – radioassay
- material screening

Funded “mini-LENS”

- proto-type scale for LENS solar neutrino detector

KURF provides an excellent location for detector development and materials screening for DUSEL R&D, and is available *now*.

Nuclear Engineering @VT

Virginia Tech Nuclear Engineering Program

History

- Formerly a nuclear engineering program at VT with a research reactor in the Physics building
- Program was shut down in the mid-80's after TMI
- Restarted the program in fall 2007

Virginia Tech
Nuclear Engineering Program

Degrees/Certificates Offered/Planned

- Undergraduate nuclear engineering certificate
- Undergraduate minor in nuclear engineering (to be approved Fall 2009)
- Graduate certificate in nuclear engineering (Spring 2009)
- M.S./Ph.D. in nuclear engineering under development (to be submitted to SCHEV for approval Spring 2010)

Virginia Tech
Nuclear Engineering Program

Enrollment

	Fall 2007	Fall 2008	Spring 2009
Undergraduate Students	43	60	74
Graduate Students	18	44	51
Total	61	104	125

About 15th largest in nation by enrollment

Off-Campus Graduate Education

- Nuclear engineering graduate courses video teleconferenced to Lynchburg, Northrop Grumman Shipbuilding Newport News and Washington DC, Hampton Roads, IALR at Danville
- Next fall also to Richmond and Northern Virginia

Off-Campus	**Fall 2007**	**Fall 2008**	**Spring 2009**
Graduate Students	4	32	37

Virginia Tech
Nuclear Engineering Program

Faculty

- One Associate Professor of Nuclear Engineering
- One part-time Professor of Nuclear Engineering (ret.)
- One Professor in Nuclear Materials in Materials Science & Engineering
- Six Associate Professors and Professors in Computational Fluid Dynamics/Thermal Hydraulics in Mechanical Engineering
- One Professor in Nuclear Physics
- Various Adjunct Professors (Industry)
- Plans for hiring additional nuclear engineering faculty over next three years

Instructional and Research Areas

- Nuclear engineering
- Senior capstone engineering design and project
- Thermal hydraulics in reactor and steam generator, two-phase flow analysis, weld pool modeling
- Alternative reactor technology
- Nuclear nonproliferation and safeguards, nuclear forensics
- Robotics in nuclear applications
- Nuclear materials, microwave processing of fuel pellets
- Nuclear fuel cycle

American Nuclear Society Student Section

- Formed in March 2008
- Over 50 student members
- Faculty Advisor: Dr. Mark Pierson
  - On Executive Committee of the Virginia Section of the ANS
- Program involves guest speakers from industry and academia and field trips (ORNL?)
- Became an official ANS student section at Winter Nov 2008 ANS Meeting

Questions before I change topics?

GEM STAR

Green Energy-Multiplier

Subcritical Technology for Alternative Reactors

Roles

- GEM*STAR is proprietary information of Accelerator-Driven Neutron Applications, ADNA Corp
  - Goal is to build a pilot plant through private venture capital
- Virginia Tech is a research partner that also enhances public understanding and builds relationships
  - Goal is to pursue technology ‘stretch’ and use political influence in Virginia

Purpose of Brief

- An advance peak at what will soon be public
- For information only at this point
- May be interested in using some ORNL capabilities

New report - Nuclear Waste Disposal: Alternatives to Yucca Mountain

- Congressional Research Service
  Feb 6, 2009

OBAMA-Biden Campaign Statement

In terms of waste storage, Barack Obama and Joe Biden do not believe that Yucca Mountain is a suitable site. They will lead federal efforts to look for safe, long-term disposal solutions based on objective, scientific analysis. In the meantime, they will develop requirements to ensure that the waste stored at current reactor sites is contained using the most advanced drycask storage technology available.

The Burning Question

What do we do with the waste?

What do we do with the spent fuel?

Nuclear Issues are Unavoidable

"At least 40 developing countries have recently approached U.N. officials here to signal interest in starting nuclear power programs

… At least half a dozen countries are specifically planning to conduct enrichment or reprocessing of nuclear fuel…"

Joby Warrick, **Washington Post**, May 12, 2008

U.S. nuclear policies remain stuck in the Cold War, even as the threats the United States faces have changed dramatically… Then there is the increasing global demand for nuclear energy, which will spread the infrastructure necessary to produce fissile nuclear materials still wider. The world, in short, is on the verge of entering an age of more nuclear weapons states, more nuclear materials, and more nuclear facilities that are poorly secured…

Ivo Daalder, Jan Lodal. **Foreign Affairs**. Nov/Dec 2008

Evaluation of the Future

"We conclude that the once-through Light Water Reactor fuel cycle is likely to remain significantly cheaper than recycling in either LWRs or Fast Reactors for at least the next 50 years, even with substantial growth in nuclear power."

National Science Board Report 2005

Nuclear Energy's Fundamental Problem…

Too Few Fission Neutrons

neutron

It's the ^ economy… Stupid!

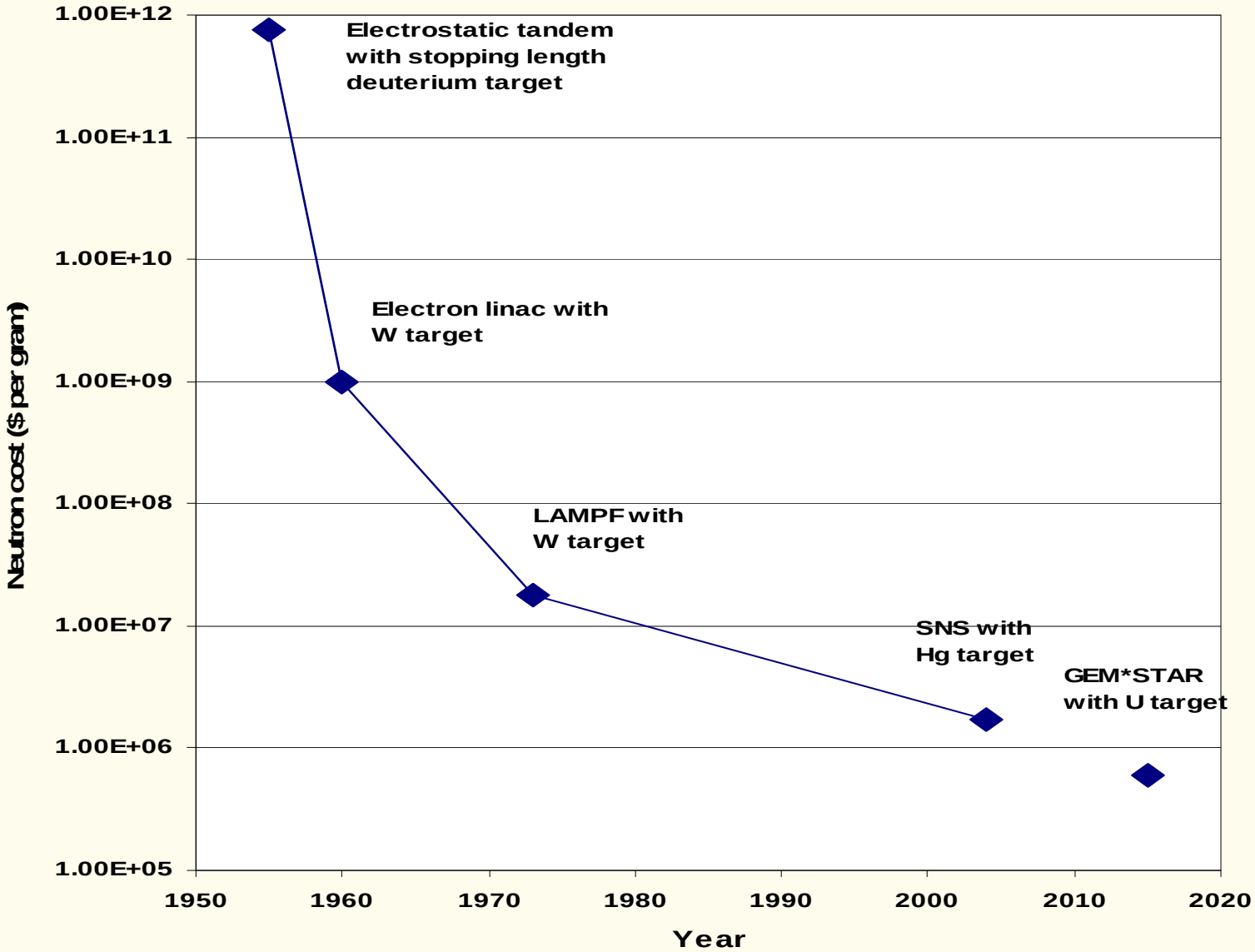
Circumvention

- Enrichment
- Reprocessing

Consequences:

- Serious proliferation burden
- Onerous international controls
- Extraordinary technological complexity
- Unnecessary high cost of nuclear energy

Cost of Neutrons



Accelerators

- Study of a 10-MW Continuous Spallation Neutron Source (BNL, 2003)

Comparison of Super-Conducting Linacs and operation power costs.

	SNS	AGS	ACNS
Kinetic Energy, GeV	1.0	1.2	1.25
Ave. Power, MW	1.0	0.045	10
Duty Factor, %	6.0	0.18	**100**
Repetition Rate, Hz	60	2.5	--
Pulse Length, ms	1.0	0.72	--
Peak Power, MW	16.7	25	10
Ion Source Current, mA	35	35	**10**
Ave. Beam Current, mA	1.0	0.035	**8**
Peak Beam Current, mA	26	21	**8**
Protons / Bunch, x 10^8	4.3	8.7	**1.43**
RF, GHz	0.805	0.805-1,61	0.7 - 1,4
Coupler RF Power, MW	170-350	260 - 400	**80 - 155**
Length, m	158	120	163
Inj. Energy, MeV	185.6	200	200
Cryo. Power (2.1°K), kW	0.5	0.15	**5.3**
Ave. AC Power, MW	3.1	0.28	**23**
Ave. Gradient, MV/m	3.1 - 6.5	5.3-10.0	3.3 - 8.7
Efficiency, %	26 -30	9 - 16	**35 - 40**
Capital Cost, M$	110	97	**85**
Operation Cost, M$ / yr	2.0	0.18	**15.2**

Addressing Neutron Economy

Neutron rate of change =

production rate - loss rate

Accelerators

Graphite

Molten salt

Graphite Experiments

Consequences for Neutron Economy

- **From Experiments at:**
  - ***Duke University, ADNA site at Callaway VA, LANSCE at Los Alamos***

- **The findings:**
  - **The diffusion coefficient is larger by 24%**
  - **Boron contamination is less than 2 parts in 10,000,000**
  - **So graphite parasitic neutron absorption reduced by 30%**

See Nuclear Science and Engineering, 161, Jan 2009

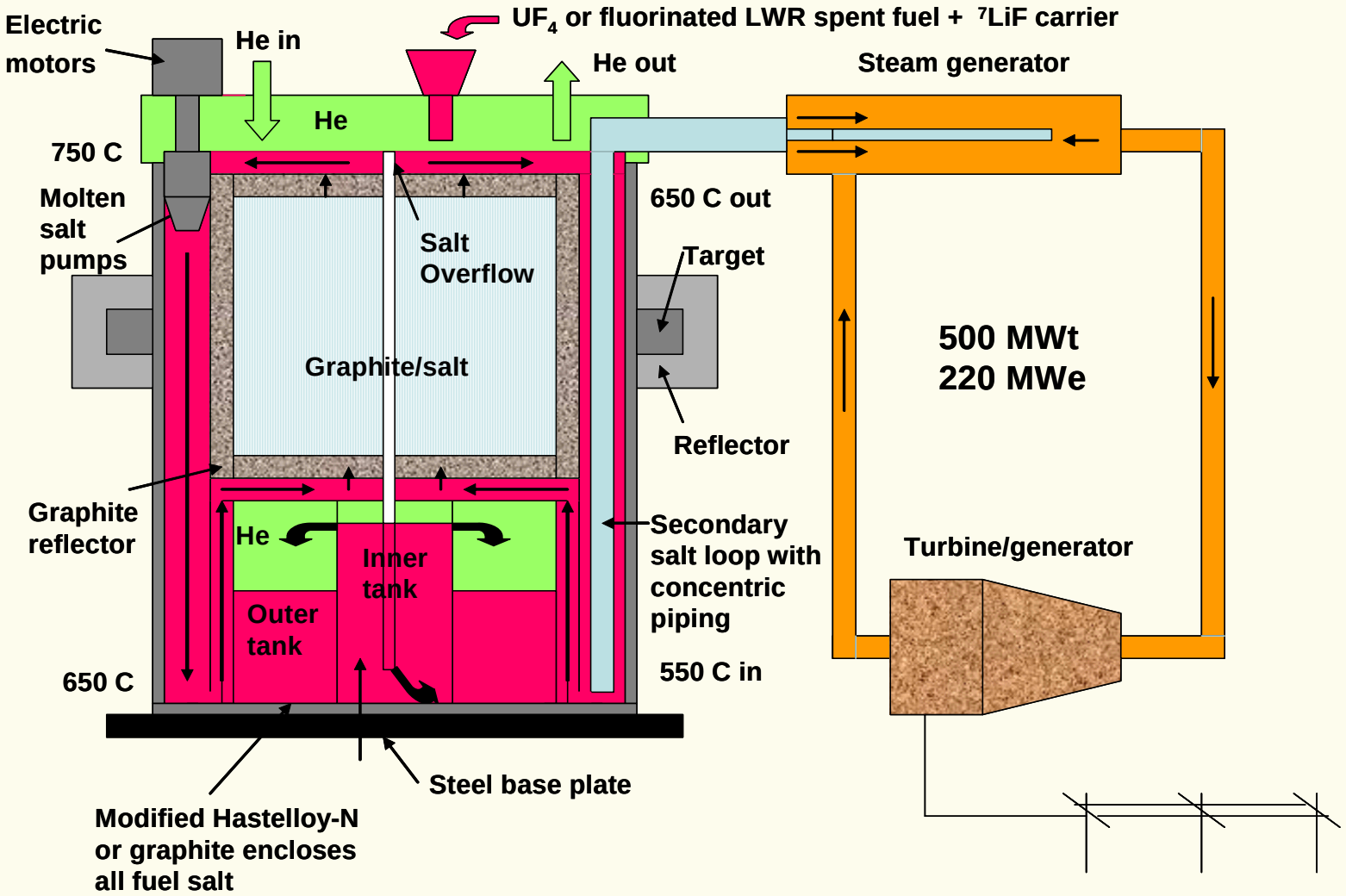
Implications

- For a natural uranium graphite reactor
  - Fermi Stagg Field reactor critical at 52 tons
  - BEPO at Harwell critical at 30 tons in 1949
  - Record minimum of 15 tons in 1953
  - ADNA estimates criticality at 8 tons with new graphite

Why Molten Salt Reactor?

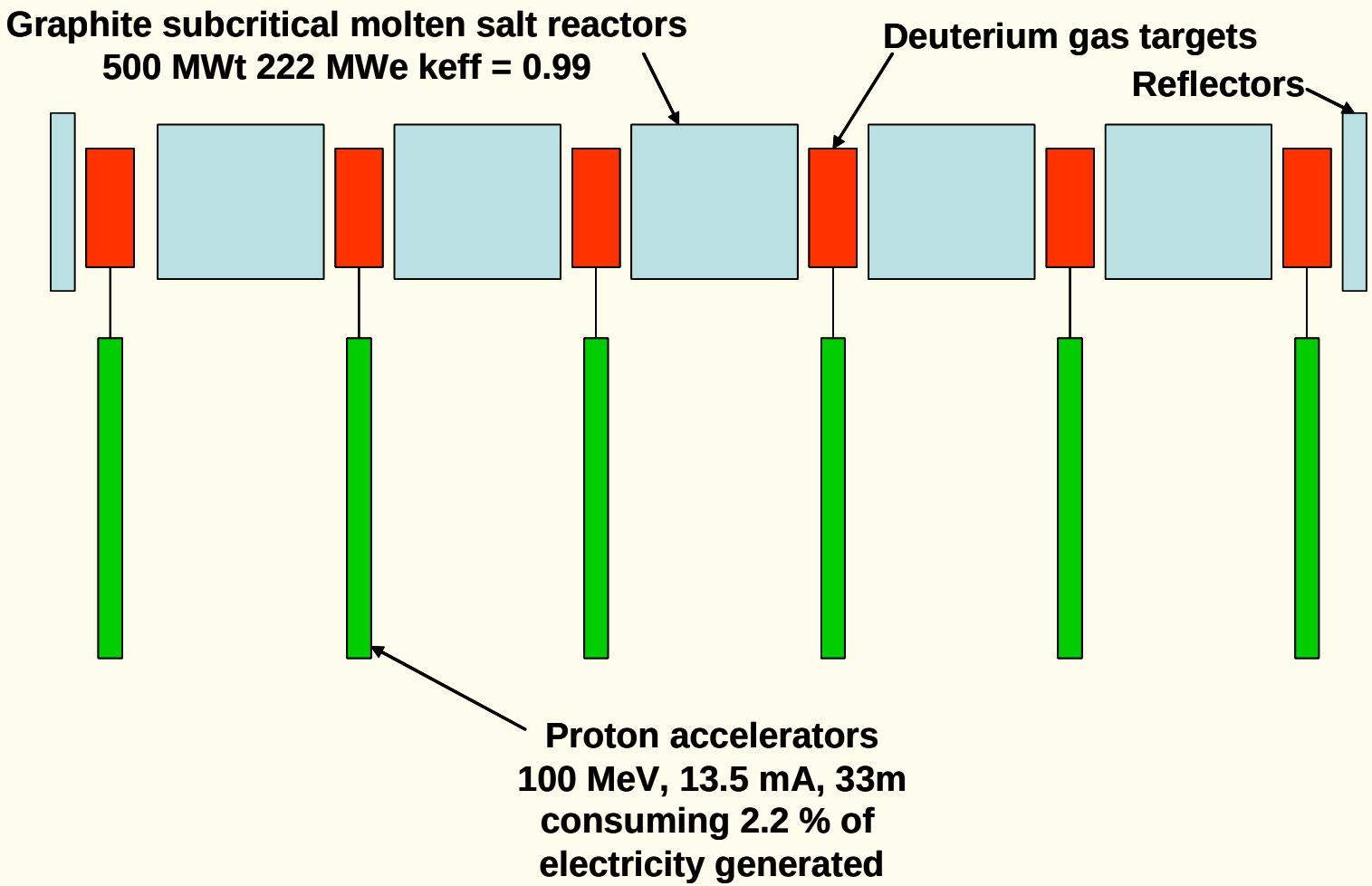
- **Molten Salt Reactor Experiment 1960's at ORNL**
  - **Very successful, well documented lessons learned**
- **Advantages**
  - **No solid fuel ⇒ lower cost, no refueling outages, better neutron economy, more compact vessel & containment**
  - **Provide uniform fuel use at constant reactivity**
  - **Large graphite volume giving high heat storage capacity and convective heat flow of salt ⇒ reliable decay heat removal system**
  - **High temperature operation (700 – 950 ºC) at very low pressure ⇒ higher plant efficiency**
  - **Liquid core ⇒ no concern for meltdowns**
  - **Continuous removal of noble fission-product gasses**

GEM*STAR


Electric motors
He in
UF_4 or fluorinated LWR spent fuel + ^7LiF carrier
He out
Steam generator
He
750 C
Molten salt pumps
650 C out
Salt Overflow
Target
Graphite/salt
500 MWt
220 MWe
Reflector
Graphite reflector
He
Inner tank
Outer tank
Secondary salt loop with concentric piping
Turbine/generator
650 C
550 C in
Steel base plate
Modified Hastelloy-N or graphite encloses all fuel salt

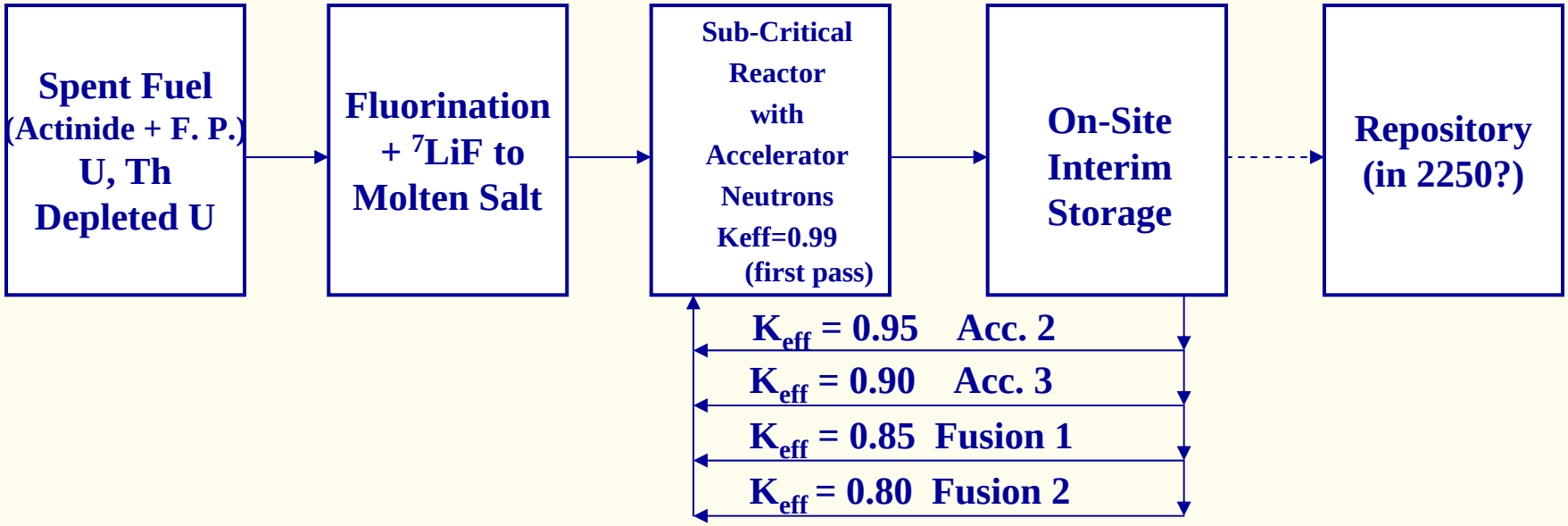
Modular

1100 MWe Power Plant
from five 222 MWe Units



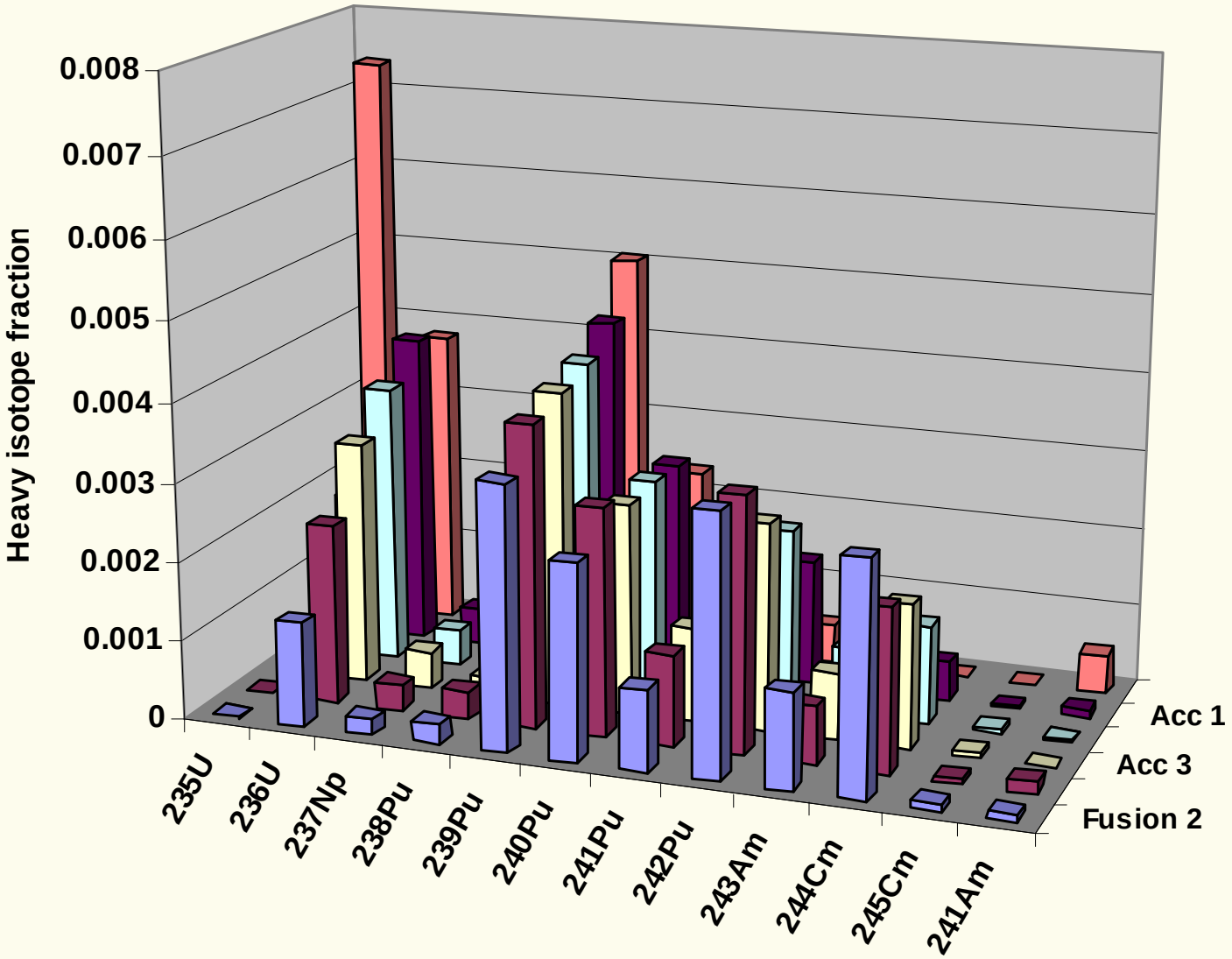
GEM*STAR Approach

Graphite-Moderated + Thermal-Spectrum + Molten-Salt and Sub-Critical Technology



* No weapons-useful material produced
* No reprocessing
* No fuel fabrication or refabrication
* No enrichment
* Three transport steps (instead of 21)
* Molten salt accommodates all actinides and fission products

Equilibrium Isotope Distributions

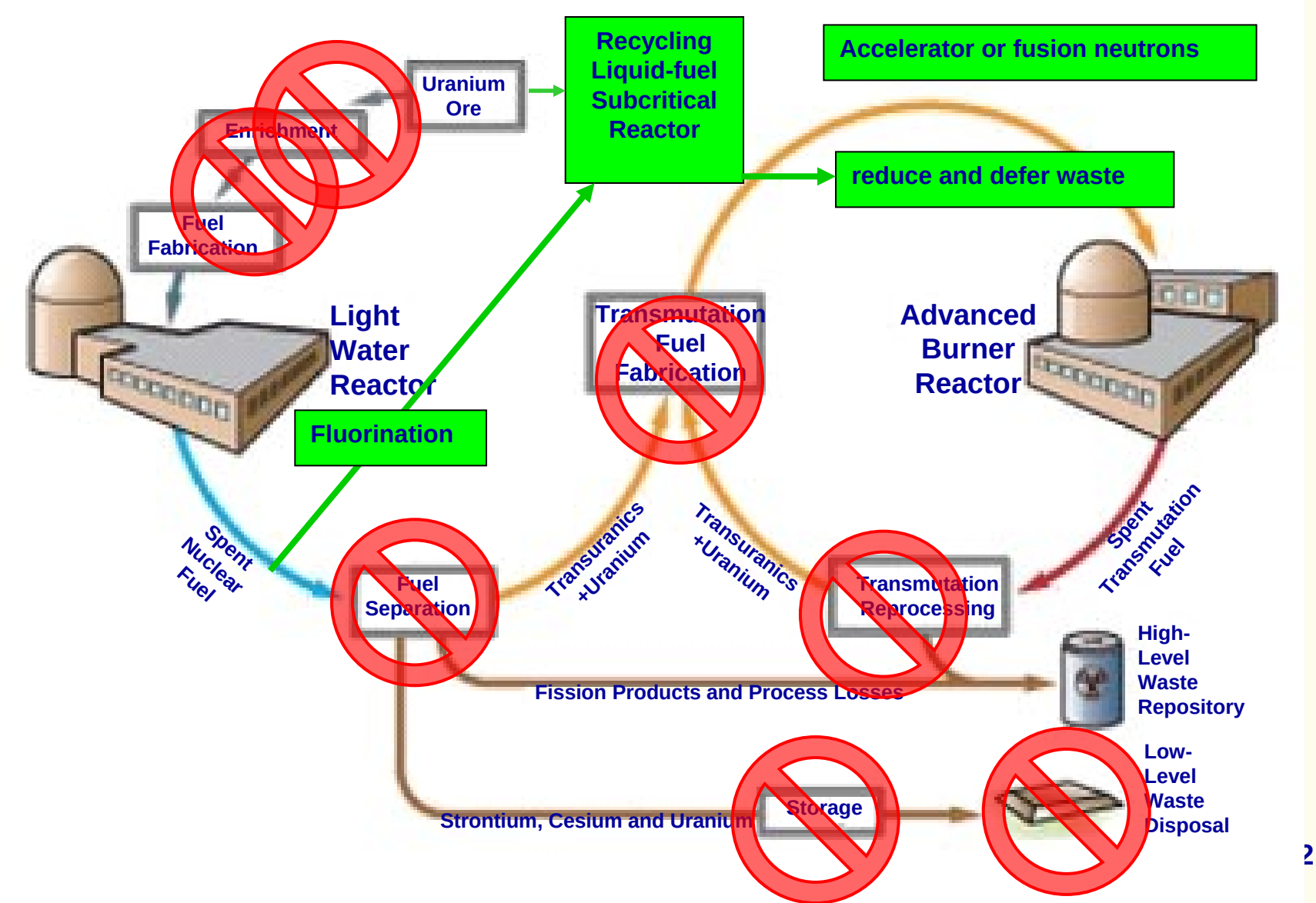


Consequences of GEM*STAR

- Can use natural uranium as fuel
- Produces twice as much energy from mined uranium as LWRs
- Can use spent fuel from LWRs and get just as much energy out
- Recycling the molten salt fuel several times with supplemental neutrons reduces long-lived waste by factor of 10
- Defers need for a geologic deposit for a century
- Divorces nuclear energy from nuclear weapons

This is HUGE!

Nuclear Fuel Cycle



GEM*STAR Launch

Stage Ic		II	III		
Technology Optimization & Implementation Report	Design & Engineer	Demonstration Facility $40MW_t$ $16MW_e$	Pilot Plant 100 MW_e	Deploy	Research 'Stretch'
$1.4M $4.6M		$75M	$400M	$4/$W_e$	
Year 1	2-4	4-8	9-13	14+	1+

- **Not a research project – this is an engineering undertaking**
- Stage I performs system integration of these existing technologies in an optimal manner through experimental and theoretical design
- Stage I tasks will provide better cost estimates for the remaining stages

Questions?