The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1953-51

International Workshop on the Frontiers of Modern Plasma Physics

14 - 25 July 2008

50 Years of Plasma Physics: Keynote Address.

R. Sagdeev
University of Maryland, College Park, U.S.A.

Why 50 years?

"Old" Plasma Physics

- Gas Discharges (incl. in Atmosphere) & Electrolytes
- Debye screening / radius
- Quasi-neutrality
- Ionization degree / Saha formula
- Langmuir frequency
- Landau damping
- MHD, Alfven waves
- Geo-, Astro- applications
- H-bomb

Controlled Fusion Declassified

Sept. 1958;

2nd Geneva Conference on Peaceful Uses of Atomic Energy

Launch of new time counting:

Major frontal advance on Controlled Fusion, previously kept classified, came to open.

Eisenhower's “Atoms for Peace initiative (UN General Assembly, December 1953):

"to.. solve the fearful atomic dilemma …. and ..finding the way by which the miraculous inventiveness of man shall not be dedicate to his death, but consecrated to his life".

The UN General Assembly in plenary session,
in December 1954, unanimously and enthusiastically
adopted a resolution which provided for the establishment
of an International Atomic Energy Agency, and
for the holding of an international technical conference
of governments under the auspices of the United Nations.

The Second Geneva Conference
(2135 papers, 46 governments,
six international organizations,
2692 participants).

1958

Very optimistic and less optimistic expectations about Fusion Energy :

Dr. Homi Bhabha predicted that it would take 20 years to generate fusion electricity

Dr. Edward Teller was much more cautious guessed that success would not come "before the end of the 20th century.“

Plasma Physicists were prideful:

- **Expectations of advent of Fusion Power and sure knowledge, that**
- **99+ % of Universe consists of Plasma**

made us feel like Masters of Universe

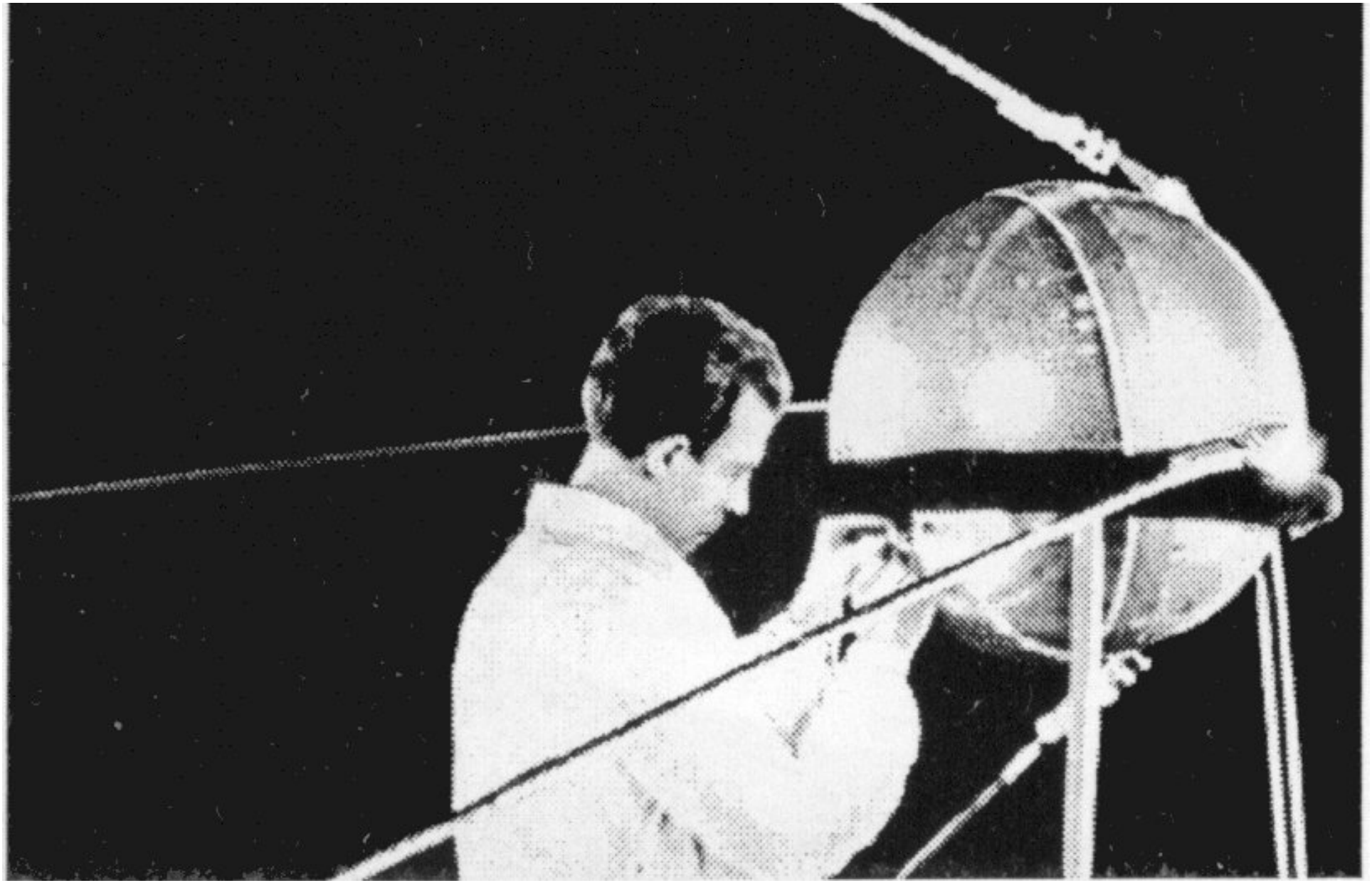
“Monster Conference”

(Time magazine, Monday, Sep. 15, 1958)

“Tourists in Geneva hotels began getting get-out notices more than three weeks ago (exception: the Emir of oil-drenched Qatar and his white-draped retinue), and a flood of nontourists saturated the town. The Second United Nations International Conference on the Peaceful Uses of Atomic Energy (full title) which started last week, is probably the biggest scientific confab ever. Besides the 5,000 scientists from 67 countries, and 900 accredited correspondents, came uncounted thousands of atomic businessmen, many with wives or camp followers. Geneva has 6,500 hotel beds, but it was so jammed that some of the delegates were forced to bunk in Evian, France, 60 miles away”.

“…was notable for unaccustomed fraternization between scientists from Communist and non-Communist countries”

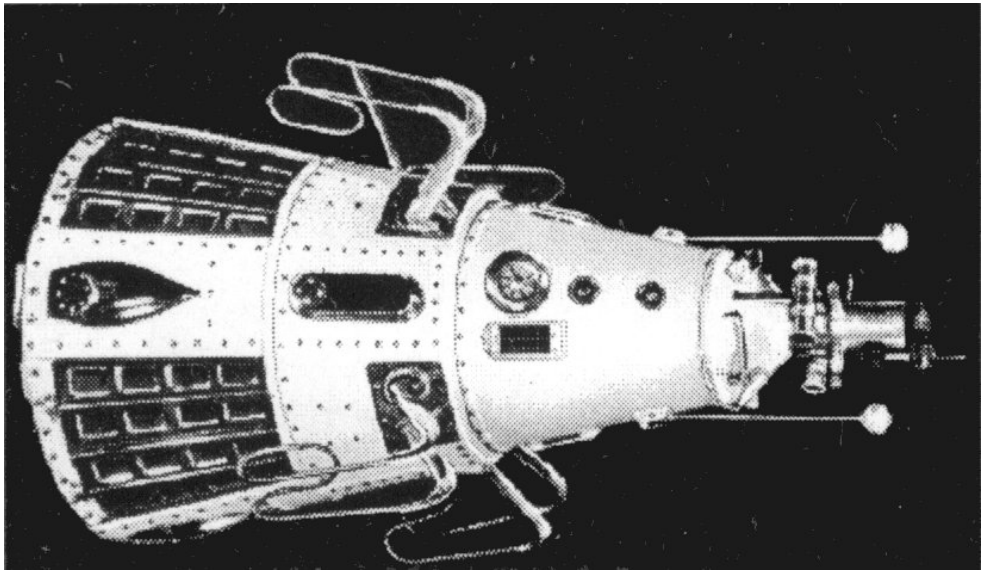
Lucky Confluence – the Birth of Space Age as another boost for Plasma Physics



Sputnik-3 (April, 1958) was promised as the first scientific satellite;

It carried a package of particle detectors to study cosmic rays in space;

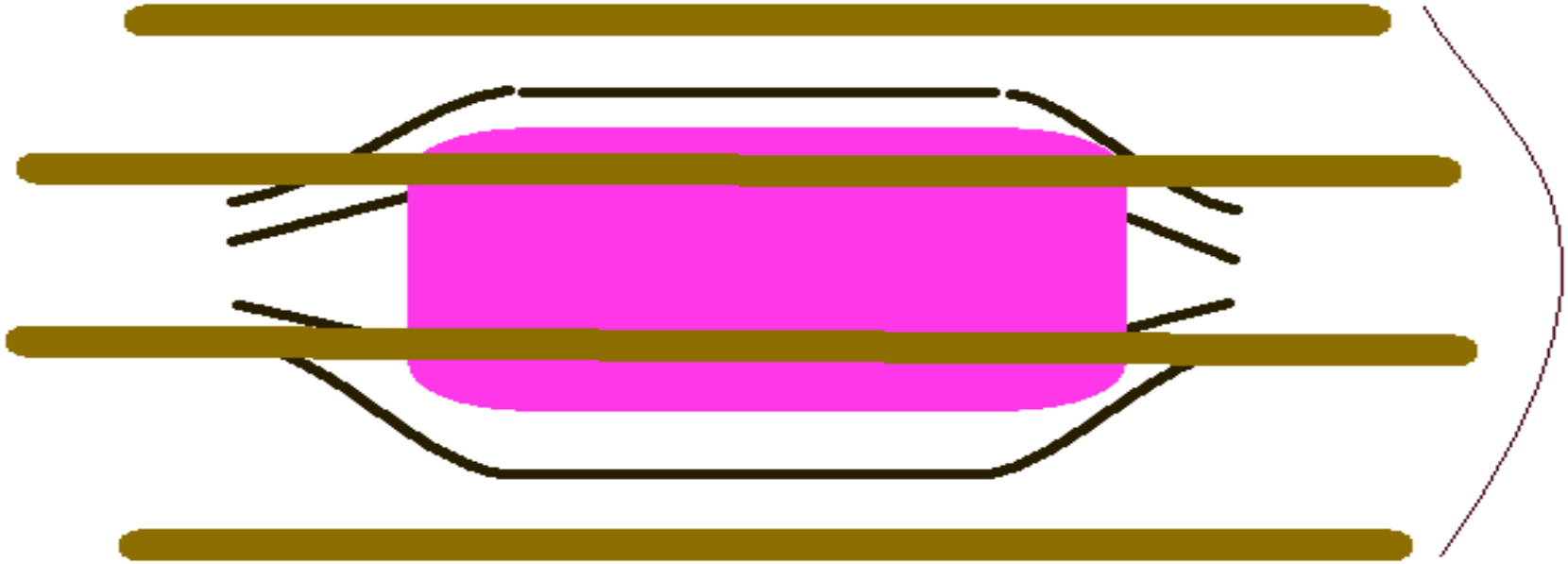
If successful it was well equipped to run on Van Allen radiation belts



Cornucopia of “new” Plasma

- Principles of Magnetic confinement;
- Closed (Tokamak vs. Stellarator) and Open Systems
- MHD Instabilities, Energy Principle
- Kruskal-Shafranov criteria
- Rosenbluth: $\min \int \frac{dl}{B}$

The First Success--Picked Fence Stabilization of Plasma Confinement in Mirror Machine



New Frameworks for Plasma description

- ***CGL Fluid***
- ***Two-fluids***
- ***Hall hydrodynamics***
- ***Hybrid models (e.g. ions-kinetic, electrons-fluid)***
- ***Drift (“Guiding Centers) Kinetics***
- ***Finite Larmor Radius / Gyrokinetics***

Menace of Bohm Diffusion ("relic" of old plasma epoch)

$$D_B \propto cT/eB$$

It served as strong driver for the search of "Universal" Instabilities (independent on specifics of configuration)

Excess of Free Energy in:

Plasma + Magnetic Field Configuration

vs.

Velocity Space Particles Distribution (non-Maxwellian)

Velocity Space related Instabilities

- **Mirror (“diamagnetic”)**
- **Firehose (“centrifugal”)**
- **“Cyclotron” Instability**
- **Weibel Inst.**

Density&Temperature gradients related Instabilities

Drift Waves

- **Collisional: “Resistive Drift inst. → Back to Bohm ?**

- **Collisionless: Ion Temperature Gradient (ITG)**
- **Trapped Particles Drift Inst.**

De-mystification of Bohm Diffusion

Drift Instability – most likely candidate

Need for growth rate of instability to be comparable to real part of frequency.
Resistive Drift mode fits if the length of system long enough.

(This is why magnetic shear would play stabilizing role)

Early Tokamak confinement Breakthrough (1968):

Energy (in Ions) confinement time consistent with then freshly discovered Neoclassical Transport ("Plateau" regime)
and much less than Bohm Diffusion.

Bootstrap Current – another gift of Neoclassical Theory (in "banana "regime)

Fading Fate of Stellarators (poor magnetic surfaces / resonances)

From Geneva Conference to Trieste, ICTP, 1966

- Indeed, it ***"…was notable for unaccustomed fraternization between scientists from Communist and non-Communist countries"***
- **6 month together (Americans, Soviets, Brits, French, Italians,..)**
- **Series of seminal papers (still quoted)**

From Piazza Oberdan to Miramare, 1968-2008

Plasma Physics of the Epoch of large Tokamaks

- **Attempt to understand anomalous electron related transport,**
- **Resistive Tearing, Ballooning and Plasma Edge modes,**
- **Scenarios for L-H transition,**
- **Origin of “Transport Barriers” etc.**

Hope for the Light at the end of tunnel - Poloidal Shear Flow generation in interaction with Drift Turbulence:

Original Drift Mode → ***New Drift Mode***

Original Drift Mode → ***Poloidal Flow (as Convective Cells)***

Attacks on Turbulence:

Quasilinear Theory

Weak Turbulence

"Averaging" technique (Non-Linear Schroedinger, Zakharov)

Computational Plasmas

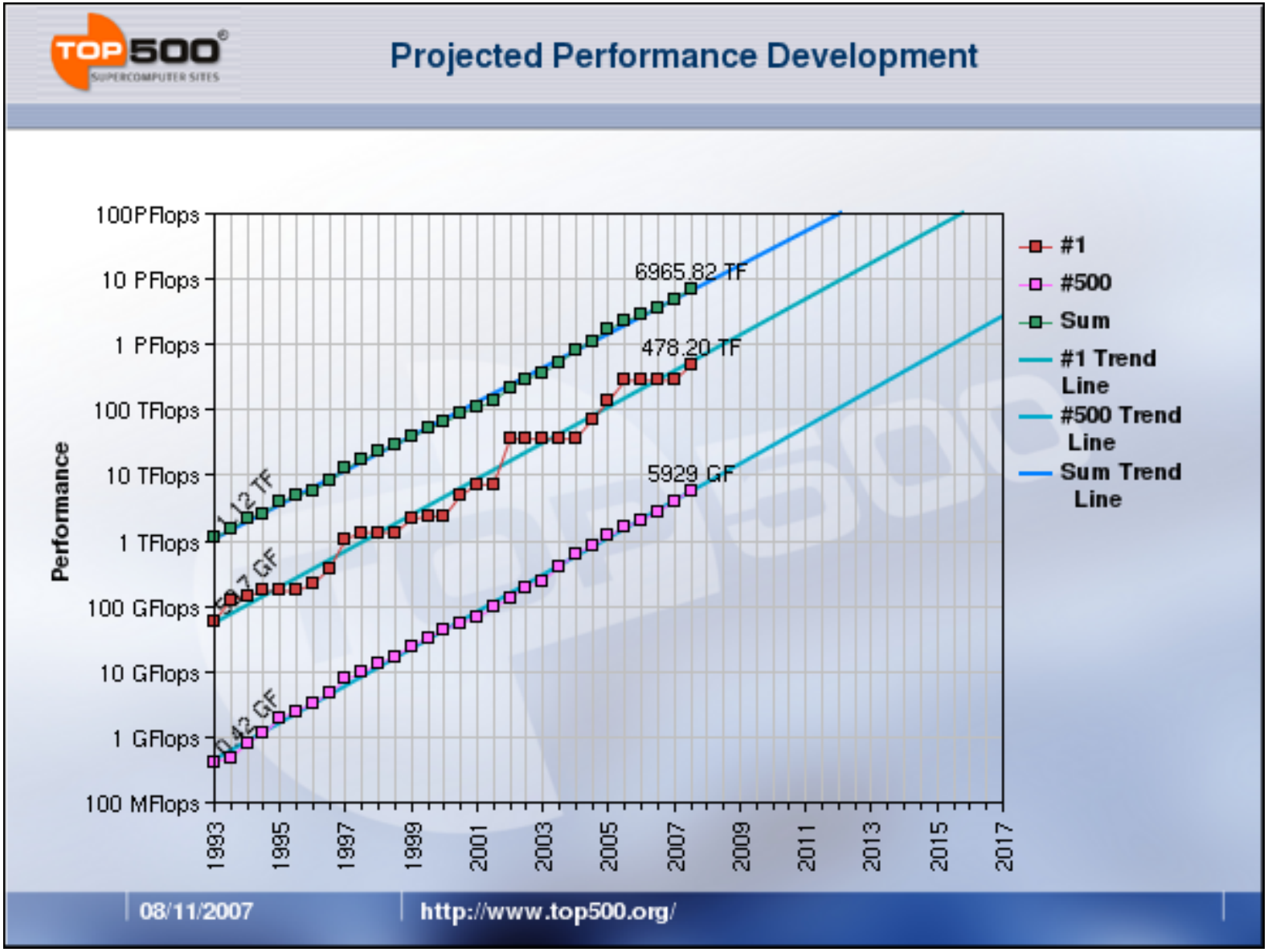
Total Fluid vs PIC
Hybrid models
Gyrokinetic

Progress of Computers (in speed, in Number of "Particles")
Need for common language with Theory!

Accomplishments in Supercomputing
November 2007 list of Top 500 Computers

SITE	COUNTRY	Vendor	SPEED (terraflops) 10^9
LLNL	U.S.	IBM	478
Julich	Germany	IBM	167
NMCAC	U.S	SGI	127
Tata Group	India	HP	118
FRA	Sweden	HP	103
SNL	U.S.	Cray	102
ORNL	U.S.	Cray	102
Watson	U.S.	IBM	91
LBNL	U.S.	Cray	85
BNL	U.S.	IBM	82

Projected Progress of Super Computing Industry



GPU based Table-Top Supercomputing

New line of CUDA powered high-performance computing (NVidia GPUs) is delivering a significant performance boost: TFps per card .

“NVidia may be best known for its gaming dedicated graphics hardware, but its latest chips are proving popular in the high performance computing space and are making a big differences to corporate customers such as the oil industry”

Interaction b. Basic Plasma Physics (as child of Fusion efforts) and other areas of application

(Spillover of early concepts from basic Plasma Research)

To Space Science:

- ***Instabilities applied to explain Van Allen belts and beyond ("cyclotron" etc.)***
- ***Quasilinear Theory***
- ***Collisionless Shocks models***
- ***Anomalous Transport***
- ***Magnetic Field Reconnection***

To Astrophysical Plasmas:

- ***Making use of earlier plasma physics concepts***
- ***Examples: galactic supernova shocks, magneto-rotational inst. of accretion disks, reconnection***

To Inertial Fusion, Laser / Plasma Interaction:

- ***Hierarchy of Non-Linear Processes of Wave/Wave and Wave/Particles coupling***
- ***Induced EM wave scattering in Plasma corona***

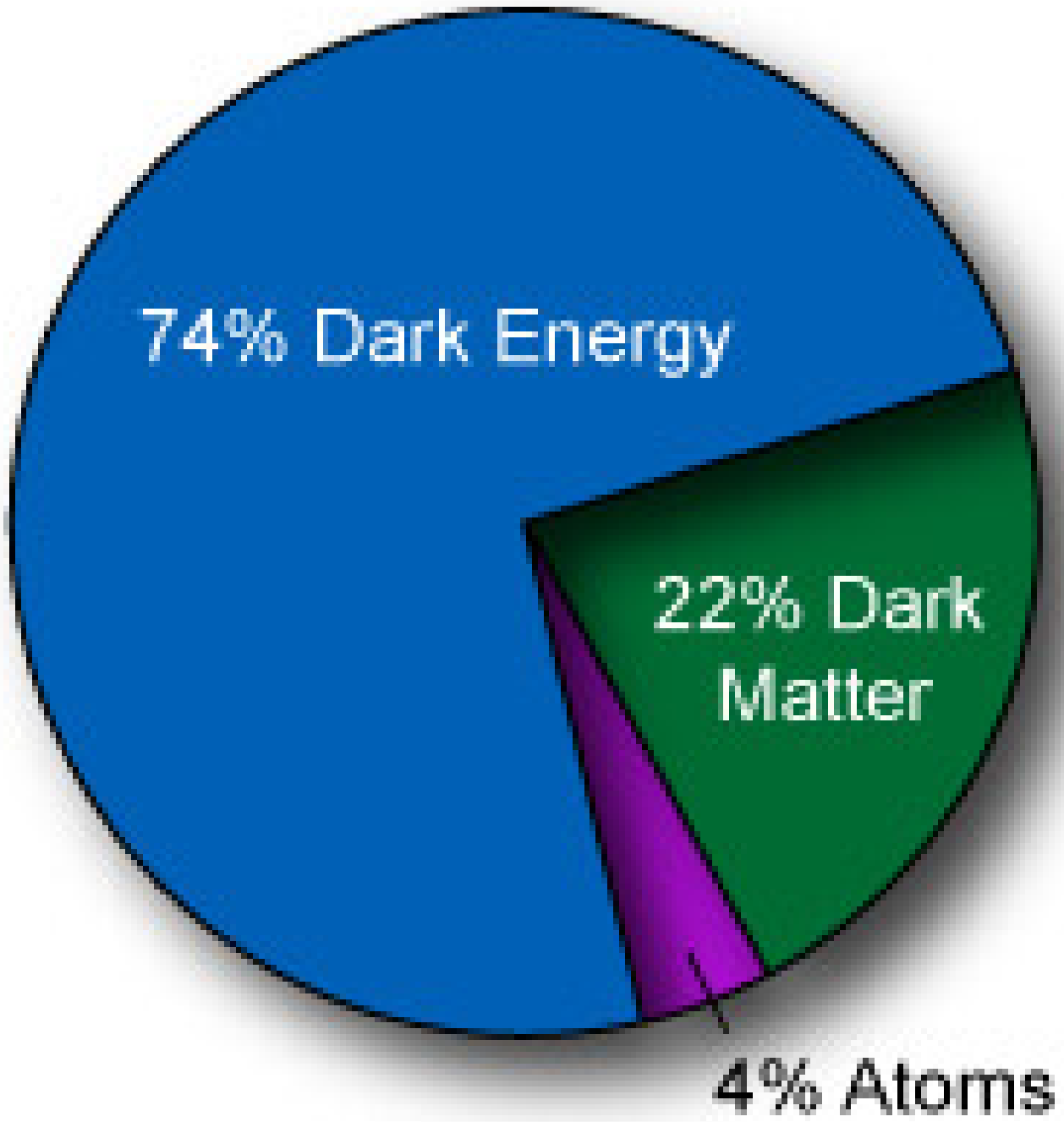
50 years after

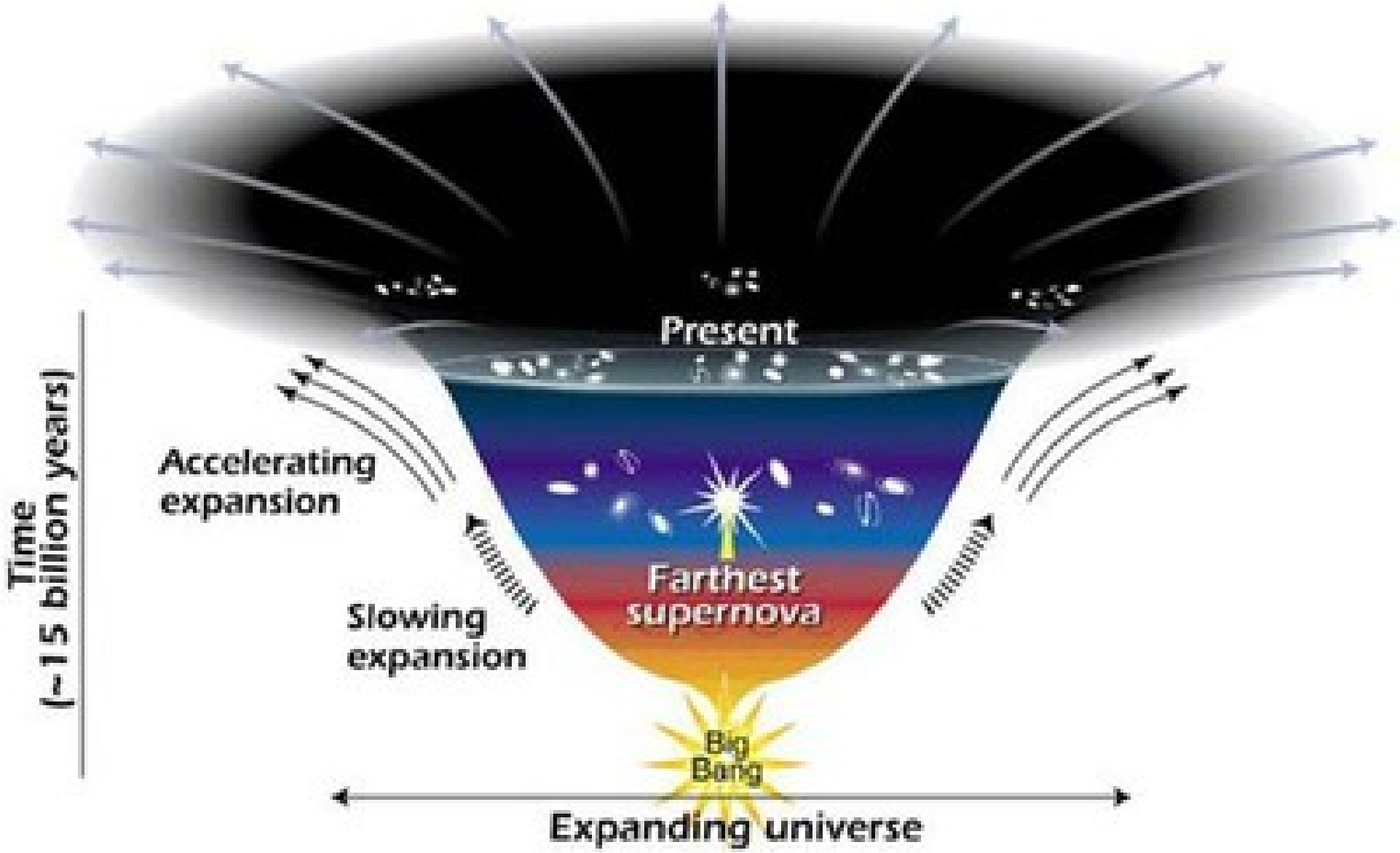
- **Is there light at the end of tunnel for Fusion ?**

Optimist (Velikhov): vs less optimistic (RS):
Industrial Prototype Not in 21st century
in 2050

- **What happened to other applications of Plasmas:**
  -MHD generators vanished
  -Plasma Processing – moderately successful
  -Plasmonics – if successful does not need much plasma
  -Space: in survival mode (losing competition to Planets)

- **Astro-: remember the Masters of Universe?**


74% Dark Energy
22% Dark Matter
4% Atoms


Present
Accelerating expansion
Slowing expansion
Farthest supernova
Big Bang
Time (~15 billion years)
Expanding universe

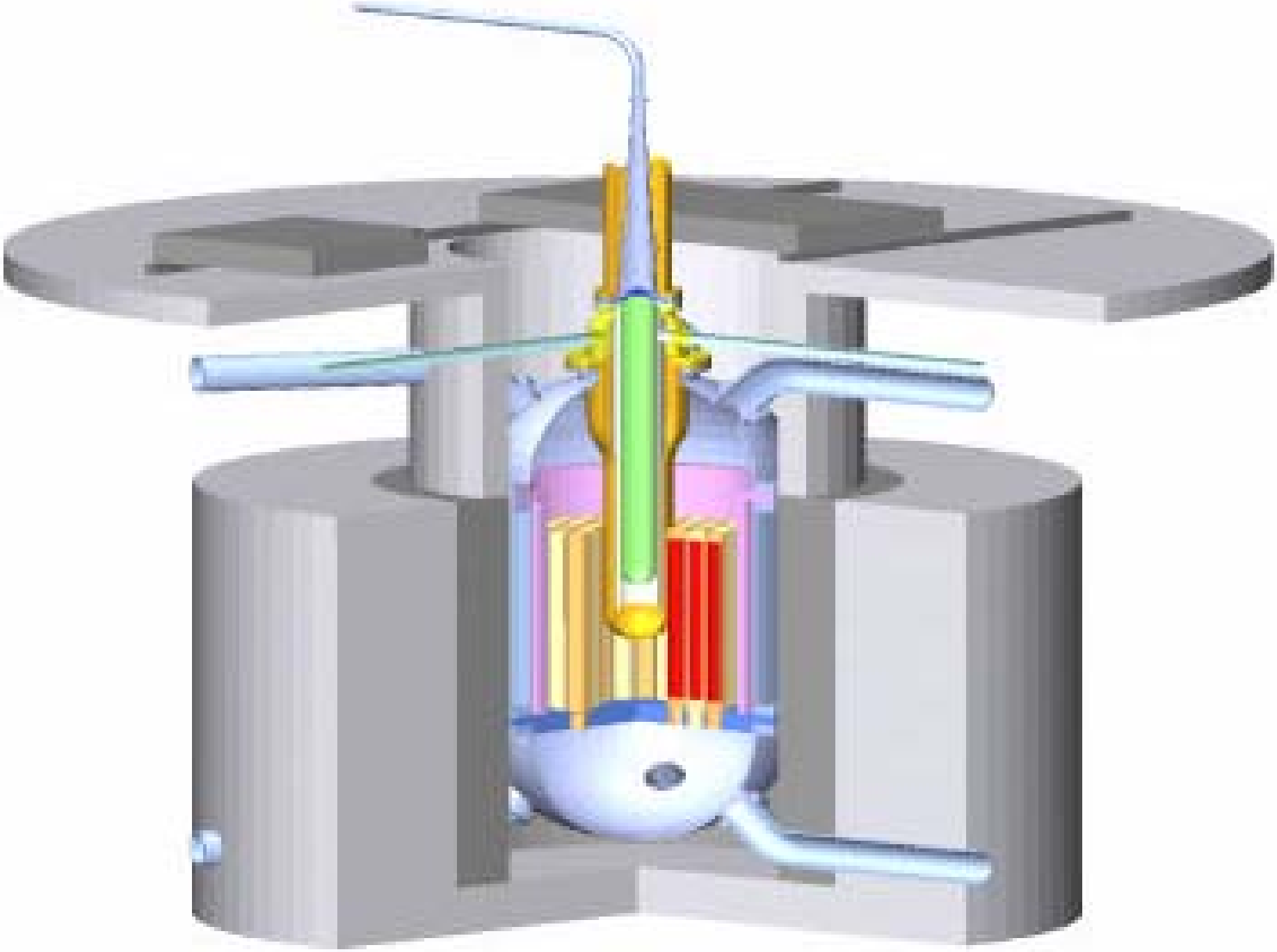
So why not to try combination “Fusion-Fission”?

- **Contribution of Fusion -14 Mev neutrons**
- **Fission in Blanket**
- **Capture of fusion neutron breaks heavy nucleus releasing 200 Mev of energy =**

  10 fold multiplication in energy release (even for U238)
- **With U235 additional multiplication (in fission cycle)**
- **Faster neutrons transmute actinides thus alleviating nuclear waste management**
- **Fusion community, watch accelerator’s people:**

  (ADS – accelerator driven system)
- **Multiplication in energy release significantly softens criteria for Q:**

  Instead of Q=30-50 like in pure fusion, Q could be brought down to the order of 1.



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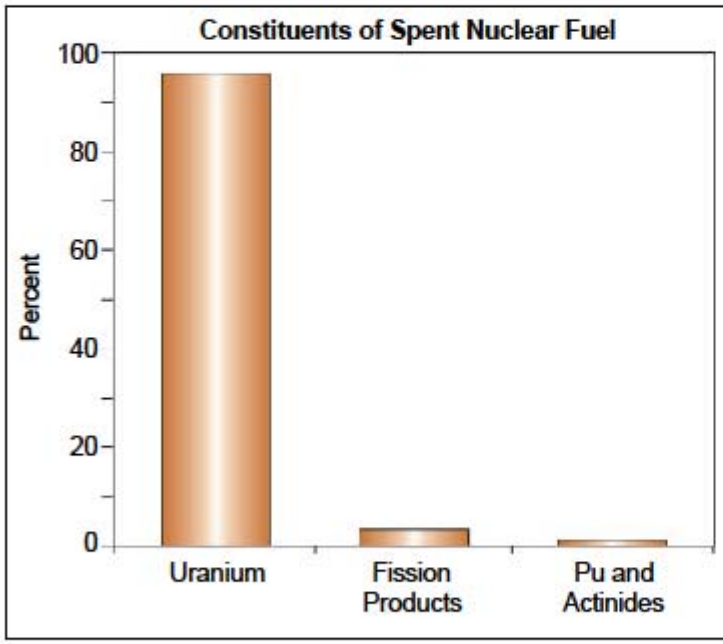
Partitioning and Transmutation Technologies will Address the Waste Issues



95.6% is uranium – can be dispositioned as Class C low-level waste or recycled

3% is stable or short-lived fission products that do not pose major disposal challenges

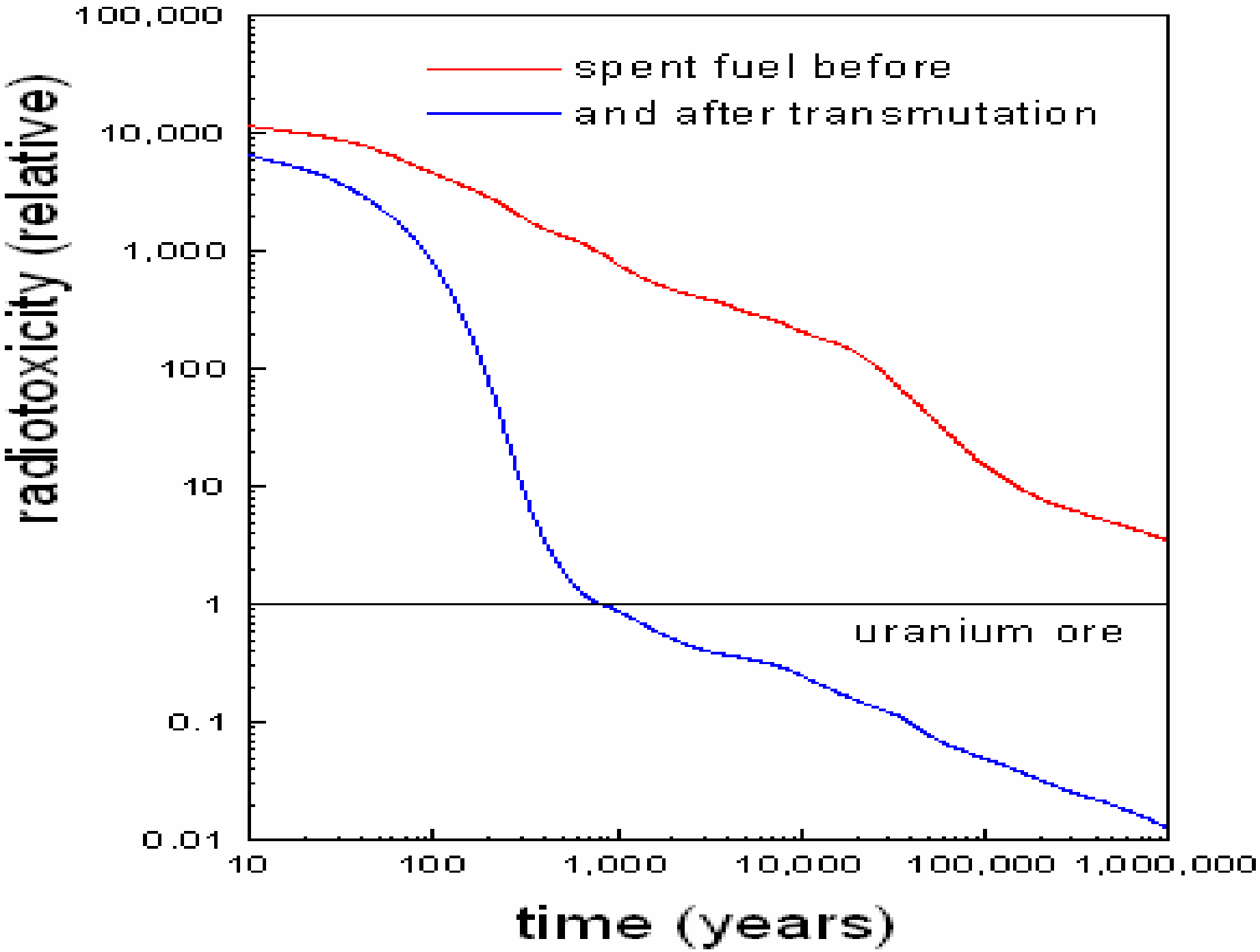
0.3% is cesium and strontium that decays in a few centuries (and are the primary near-term HLW heat source)

0.1% is long-lived iodine and technetium which can be transmuted

0.9% is plutonium which can be burned as fuel

0.1% is long-lived actinides which can be fissioned in fast spectrum reactors or accelerator-driven systems (ADS)

Los Alamos
NATIONAL LABORATORY


100,000
10,000
1,000
100
10
1
0.1
0.01
radiotoxicity (relative)
spent fuel before
and after transmutation
uranium ore
10
100
1,000
10,000
100,000
1,000,000
time (years)