Radiation Guiding in Active Nano-Structures for Shielding and Nuclear Reaction Control Systems

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Courtesy to Anand Pathak

Abstract.

In outer space the radiation is complex having many origins, as galactic, solar and local from the spaceship own power system, that for the moment is dominant and is pounding the nuclear power systems for space.

The **actual** nuclear reactors for space are using booms, and partial shielding, in order to reduce the radiation inside the crew chambers, and to be as light as possible.

This solution has the disadvantage that it reduces the outside maneuverability space for docking and space-walk that has to take in consideration the radiation zones around the spaceship.

The main radiation **attenuation method** is called mass, because no matter (with some approximation) what material we are using, in order to get a radiation attenuation ratio, about same mass is required, no matter if it is hydrogen, water or tungsten for electromagnetic radiations with energies above 300 keV, inside gamma ray domain.

For neutron attenuation, light, neutron absorbent materials are used for shielding surrounded by gamma absorbent shielding, which all together makes the **nuclear power source heavier** by a factor of 2 to 10 times.

The novel material relies on trapping the gamma radiation and neutrons inside specially engineered nano-structures, which **guides** it along the structure, changing its direction without changing its energy.

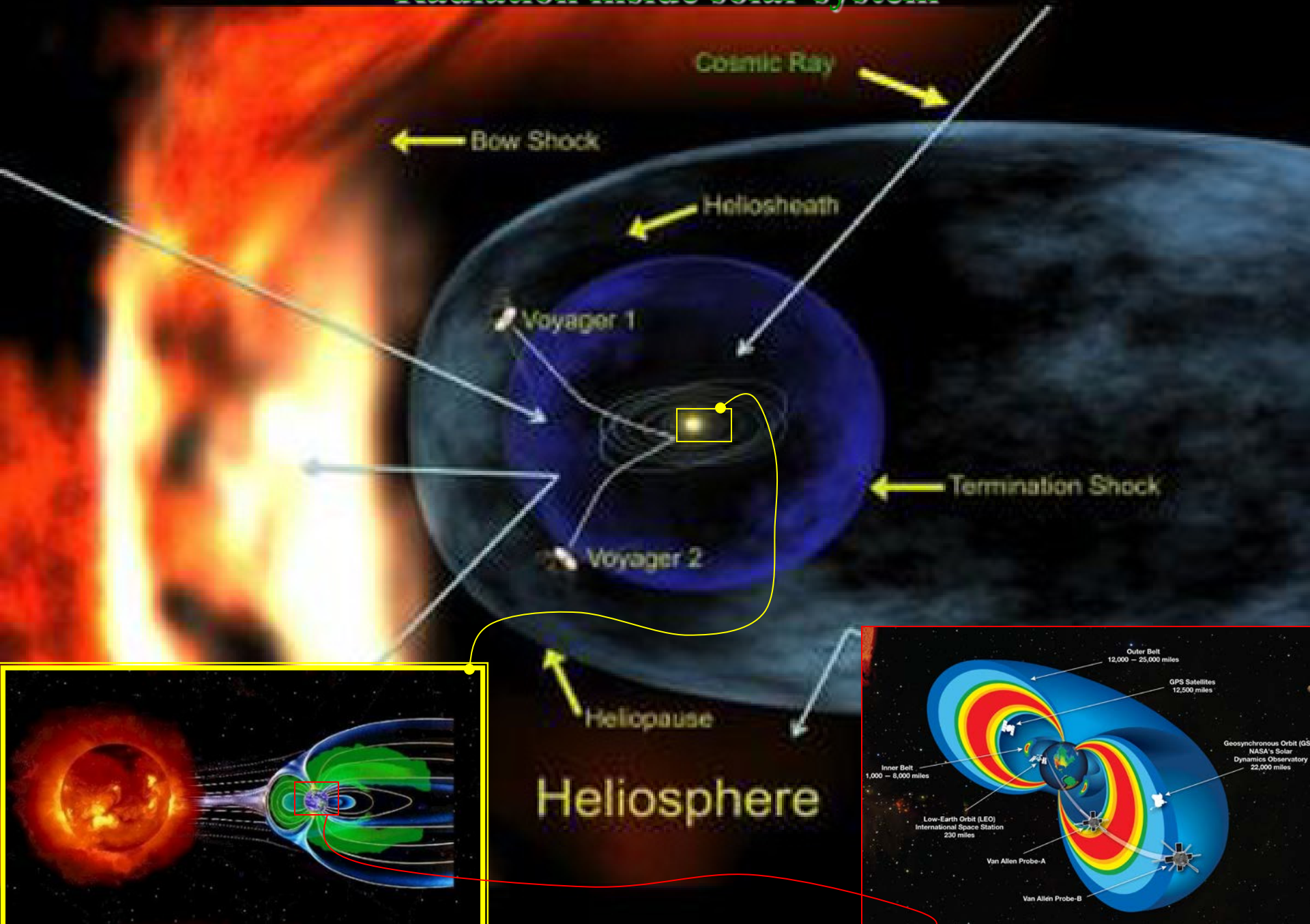
This type of material may take the emergent radiation, and redirect it on a preferred escape direction or towards an absorbent element.

It may also turn around the neutrons, normally being lost outside through external surfaces and redirect them inwards to the reactor's core, and increasing its reactivity. Adding electrically controlled structures on along the radiation guide, that acts as electrically controlled **path switches**, for radiation, it is possible to control the radiation final direction.

Using the radiation switches we may drive the escaped neutrons towards the reactor core, increasing its reactivity and power, or towards an absorbent where it can do fuel breeding or special isotope production, and decrease the core, power and reactivity. This is what is called active nuclear reaction shielding, because it acts like the actual reflector drums and shielding. This material is also good for other applications very useful in space as radiation concentrators for imaging or non-imaging purposes, and radiation modulators.

The shield made of the new material is lighter that the actual shielding, and it may be used as reactivity control device, having a response time in micro-seconds being by at least 1000 times faster than the actual reflective drums, allowing the nuclear reactor power (amplitude) modulation up to MHz frequencies, good for neutrino communication systems.

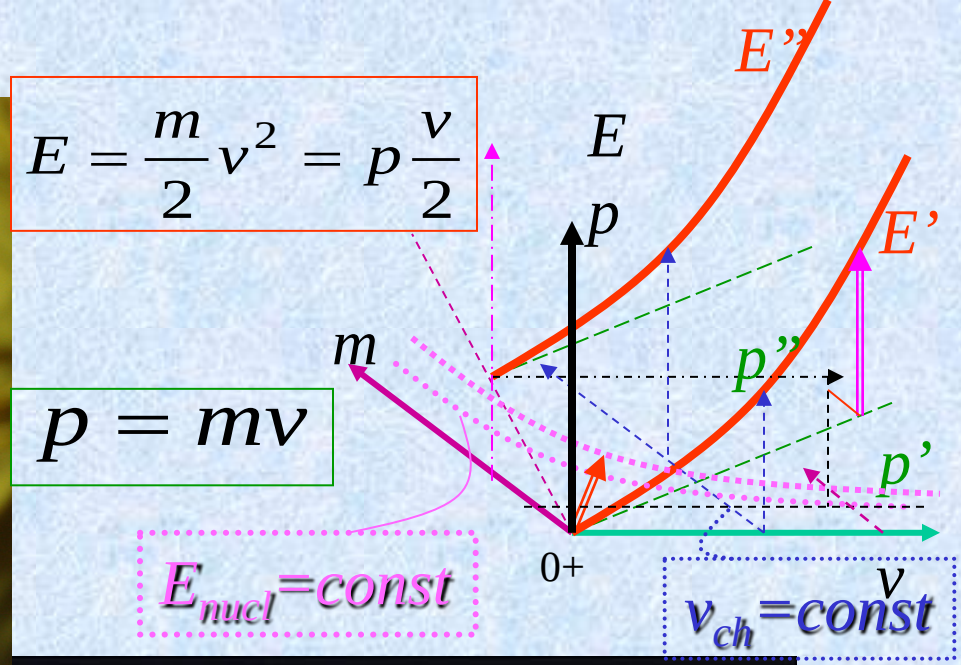
Radiation inside solar system



A finite amount of energy

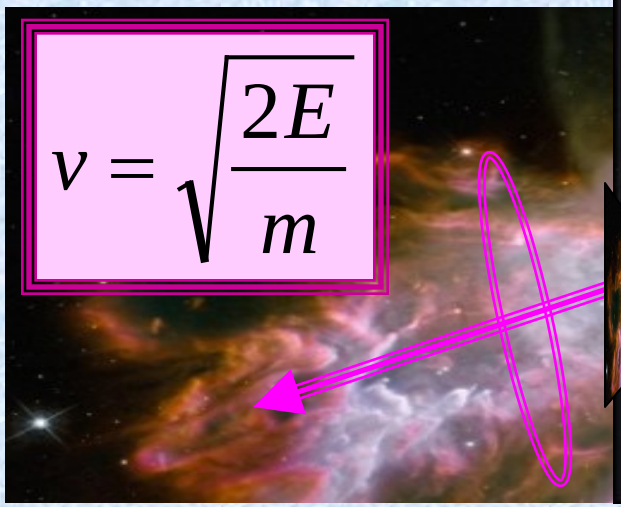
$$E = \frac{m}{2}v^2 = p\frac{v}{2}$$

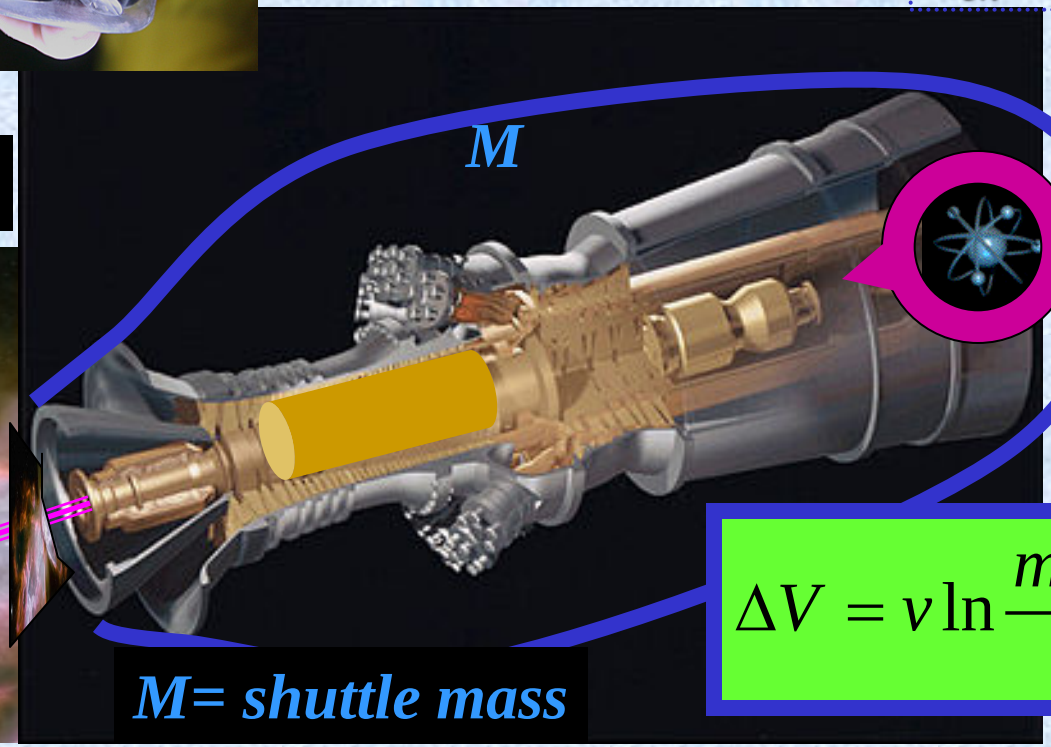
$$p = mv$$



m=propellant mass

$$v = \sqrt{\frac{2E}{m}}$$

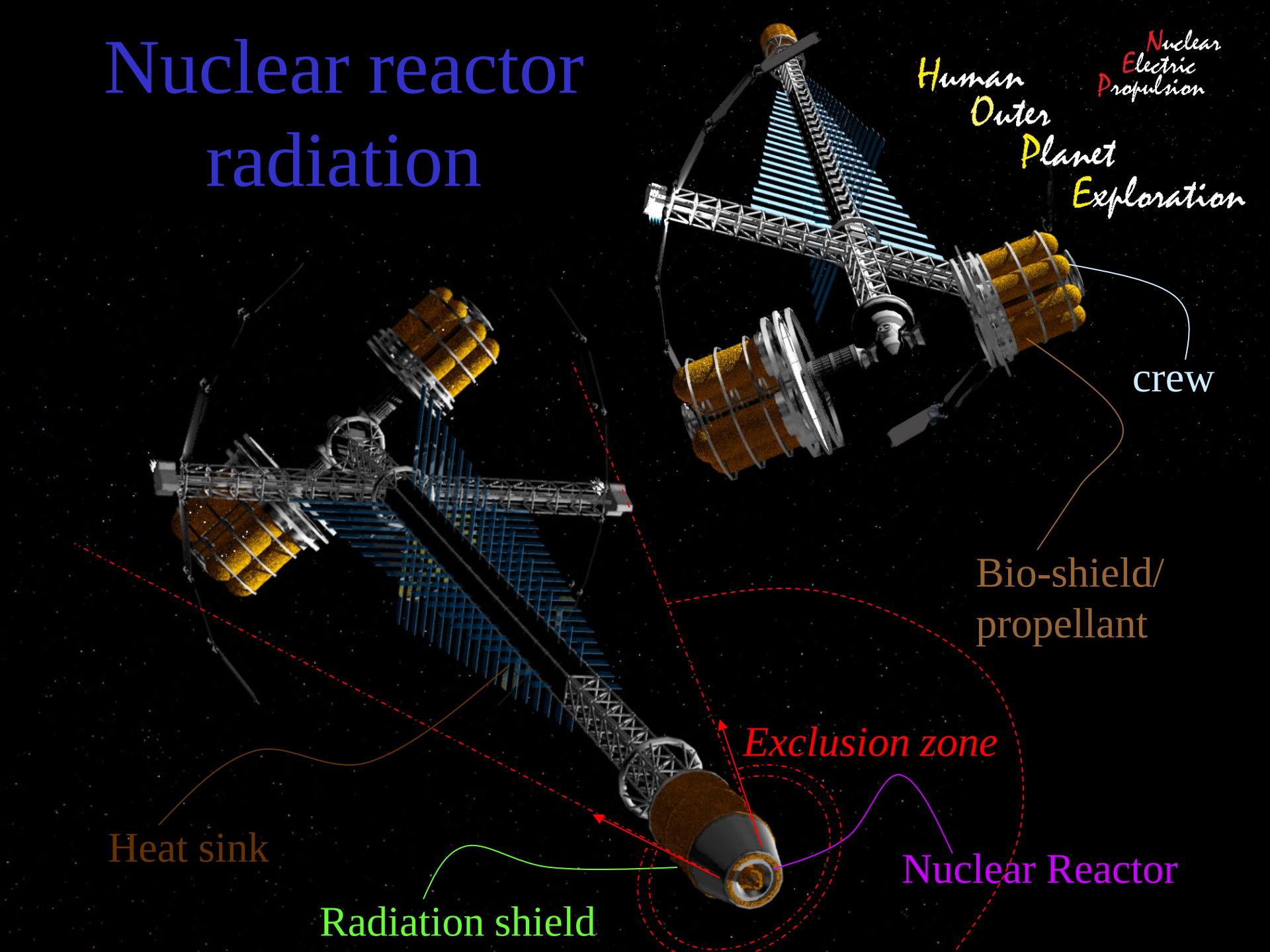


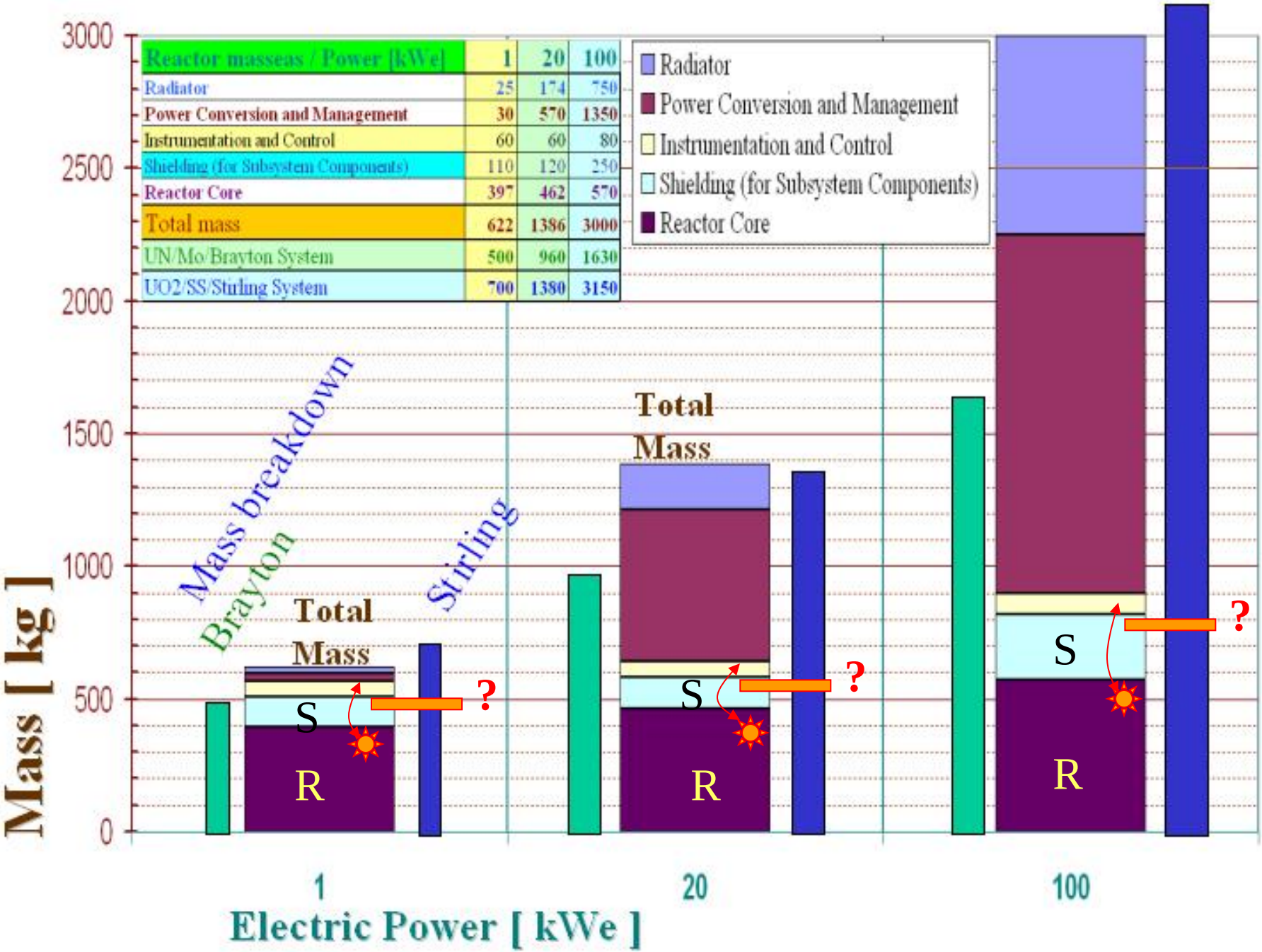


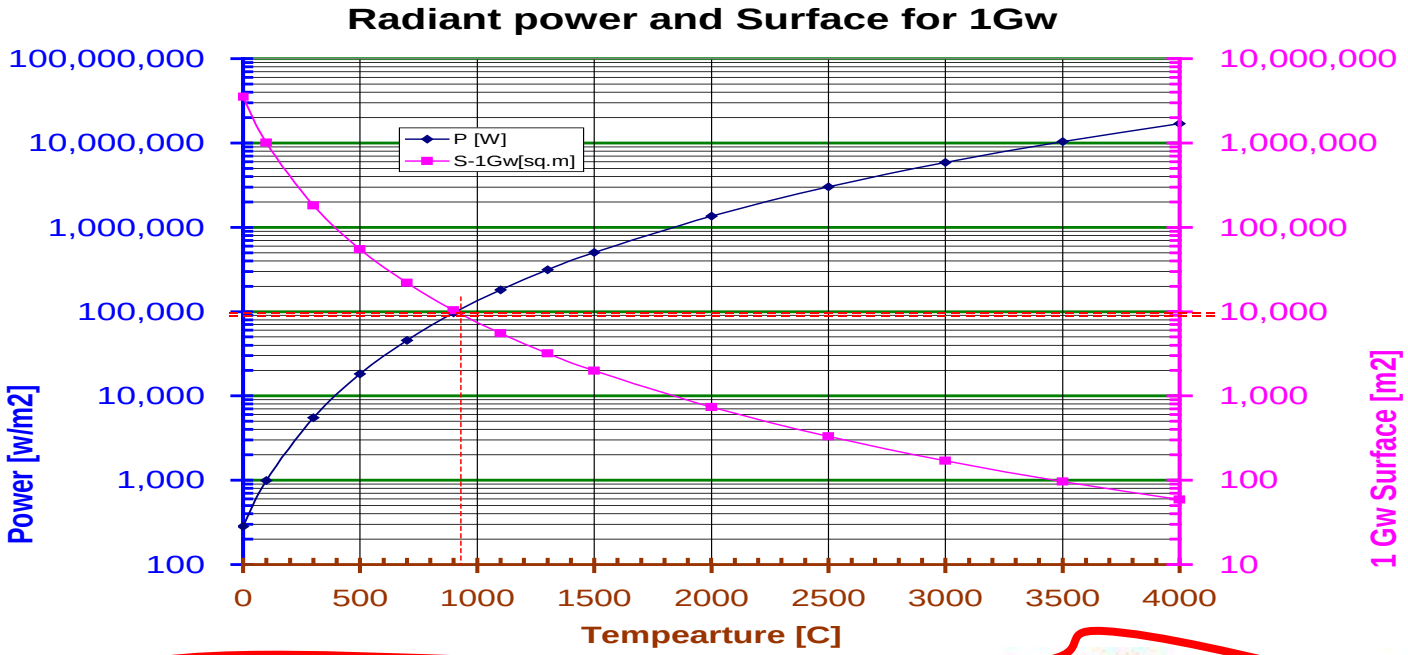
M= shuttle mass

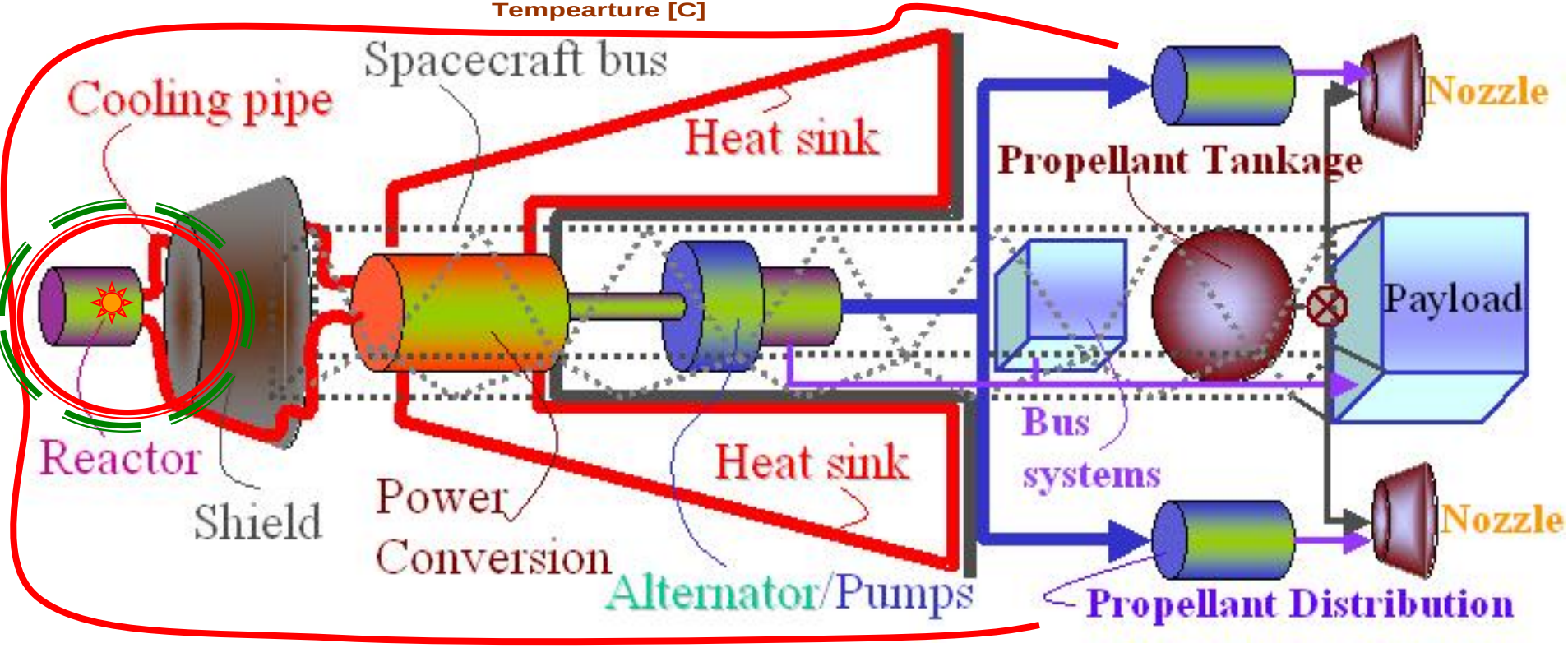
$$\Delta V = v \ln \frac{m+M}{M}$$

Nuclear reactor radiation



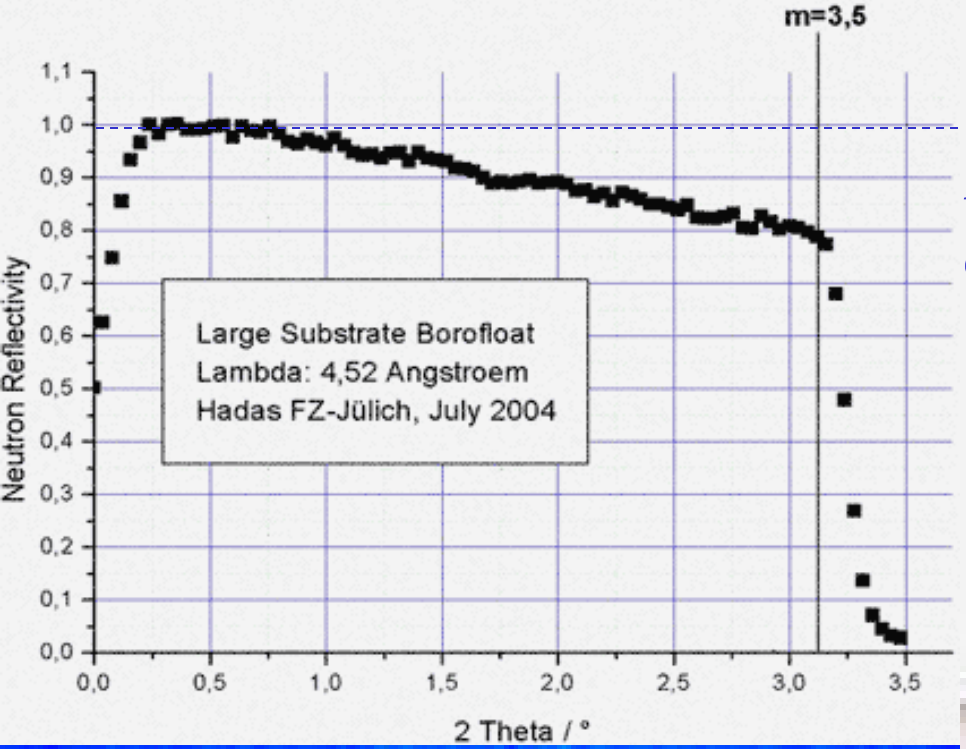

Reactor masseas / Power [kWe] 1 20 100
Radiator 25 174 750
Power Conversion and Management 30 570 1350
Instrumentation and Control 60 60 80
Shielding (for Subsystem Components) 110 120 250
Reactor Core 397 462 570
Total mass 622 1386 3000
UN/Mo/Brayton System 500 960 1630
UO2/SS/Stirling System 700 1380 3150
Radiator
Power Conversion and Management
Instrumentation and Control
Shielding (for Subsystem Components)
Reactor Core
Mass breakdown
Brayton
Stirling
Total Mass
Total Mass
S
R
S
R
S
R
?
?
?
Mass [kg]
3000
2500
2000
1500
1000
500
0
1
20
100
Electric Power [kWe]

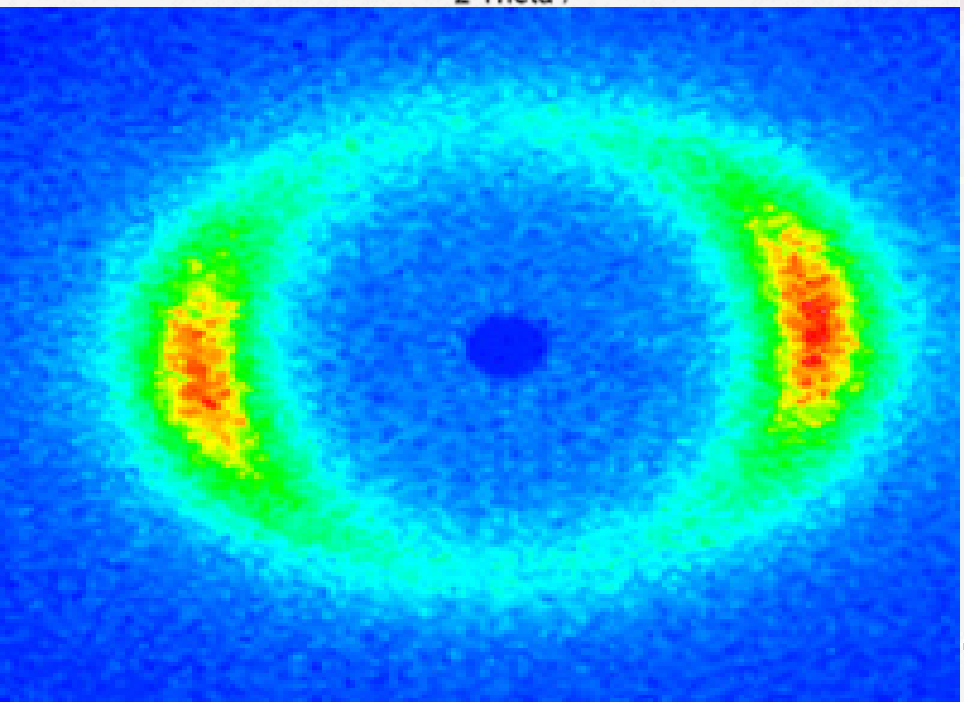

Radiant power and Surface for 1Gw
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
Power [w/m2]
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1 Gw Surface [m2]
P [W]
S-1Gw[sq.m]
0
500
1000
1500
2000
2500
3000
3500
4000
Tempearture [C]


Spacecraft bus
Cooling pipe
Heat sink
Propellant Tankage
Nozzle
Payload
Reactor
Shield
Power
Conversion
Heat sink
Bus
systems
Alternator/Pumps
Nozzle
Propellant Distribution

Radiation guiding

Previous work

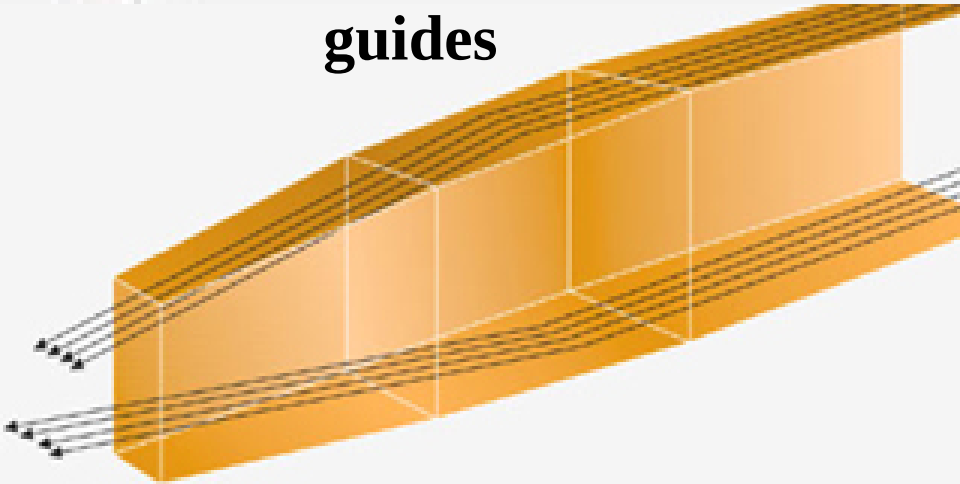


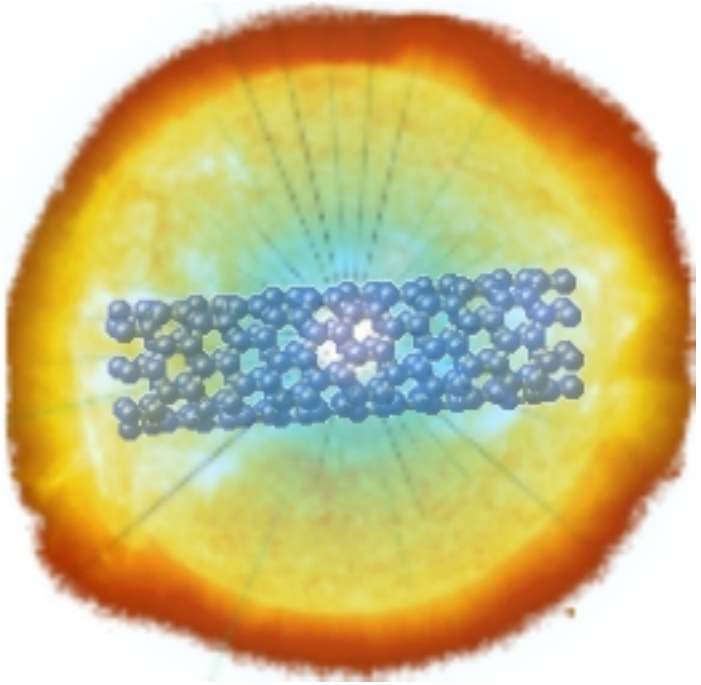


Neutron transport guides

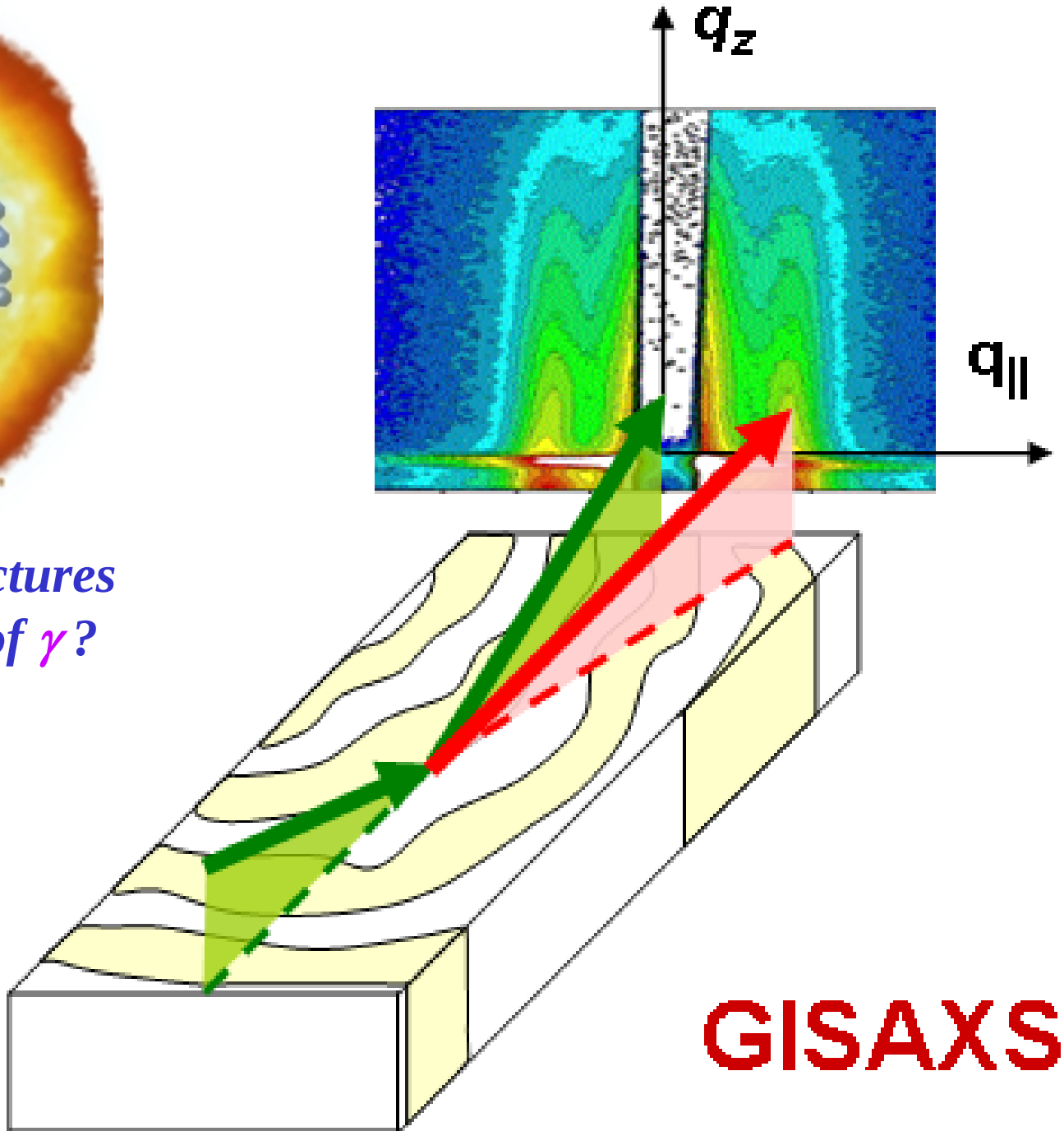
Based on ***total reflection*** *at grazing angles*

Focusing Neutron guides





Does a nano-structures reflect neutrons of γ ?



Neutron reflection on super-mirror

GISAXS

JOURNAL OF X-RAY SCIENCE AND TECHNOLOGY 7, 139–158 (1997)
ARTICLE NO. XR970257

GCC= Glass Capillary Converters

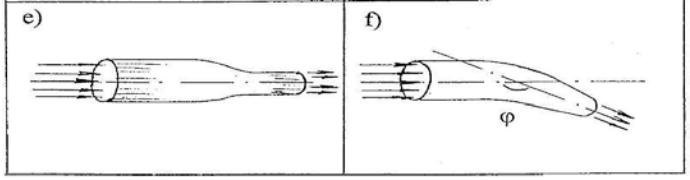


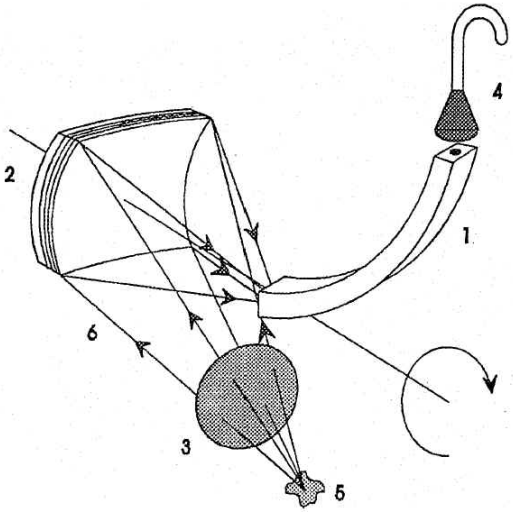
FIG. 1. Comparison of the different types of GCCs.

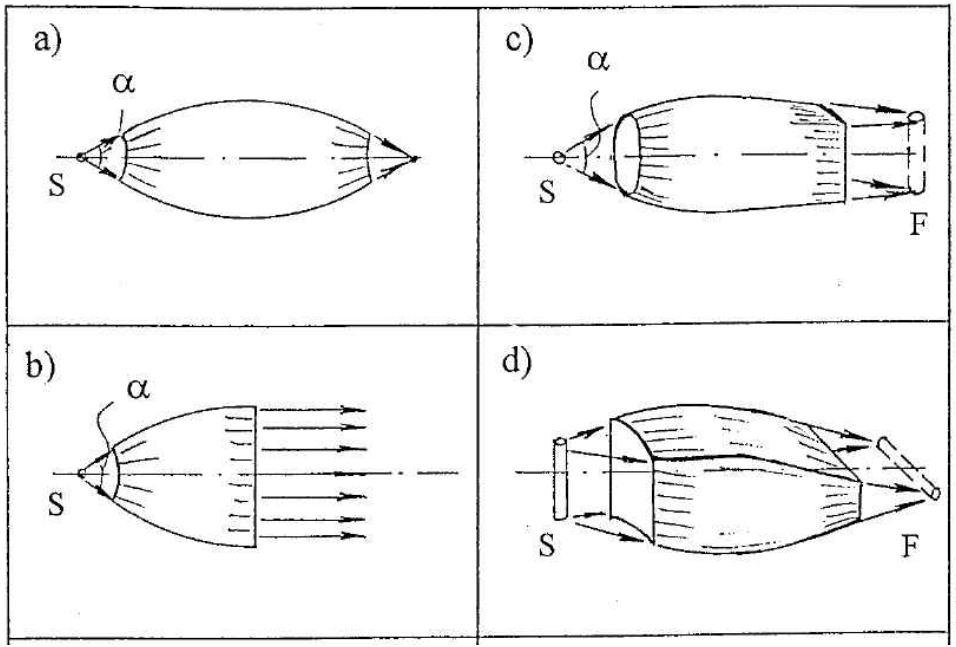
New Concepts for X-Ray, Soft X-Ray, and EUV Optical Instrumentation Including Applications in Spectroscopy Plasma Diagnostics, and Biomedical Microscopy: A Status Report[1]

V. L. Kantsyrev, R. Bruch, R. Phaneuf, and N. G. Publicover

University of Nevada Reno, Reno, Nevada 89557

NEW CONCEPTS FOR X-RAY INSTRUMENTATION





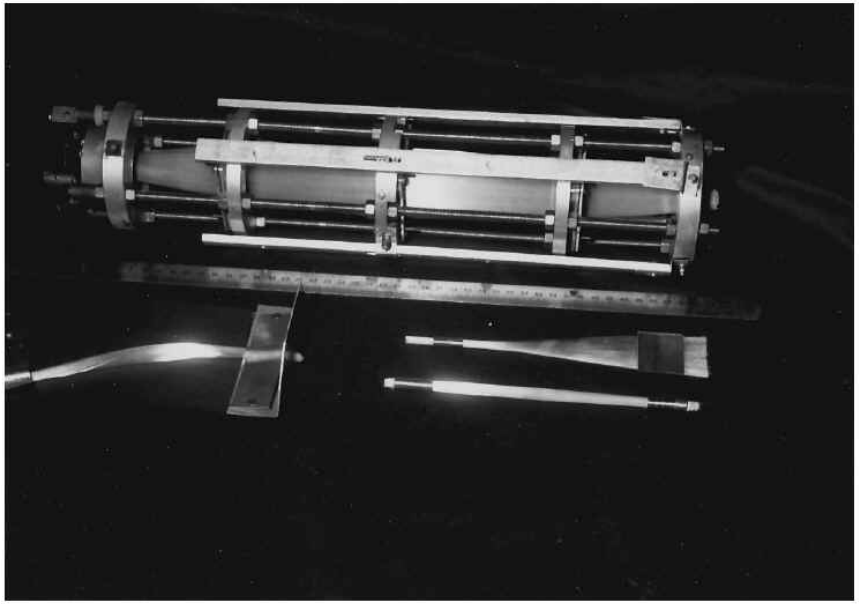


FIG. 2. One of the first GCCs, developed in the late 1980s and early 1990s: (Top) focusing GCC ("point" source–"point" focus type) for solid state physics and plasma diagnostics studies (*4, 5, 16, 17, 21*). (Bottom) Simple GCC type e and f (see Fig. 1) for plasma diagnostics (*8*).

S - International Centre for Diffraction Data 2004, Advances in X-ray Analysis, Volume 47.

Grazing-Incidence X-Ray Diffraction

Sergey Stepanov

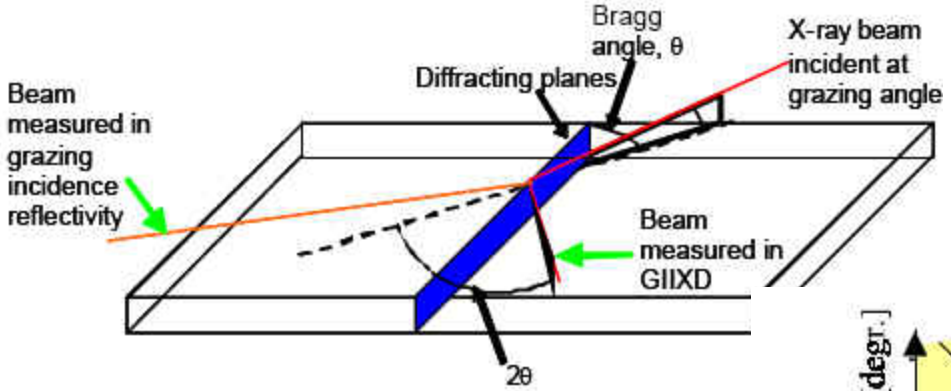
Illinios Institute of Technology, BioCAT at the Advanced Photon Source,

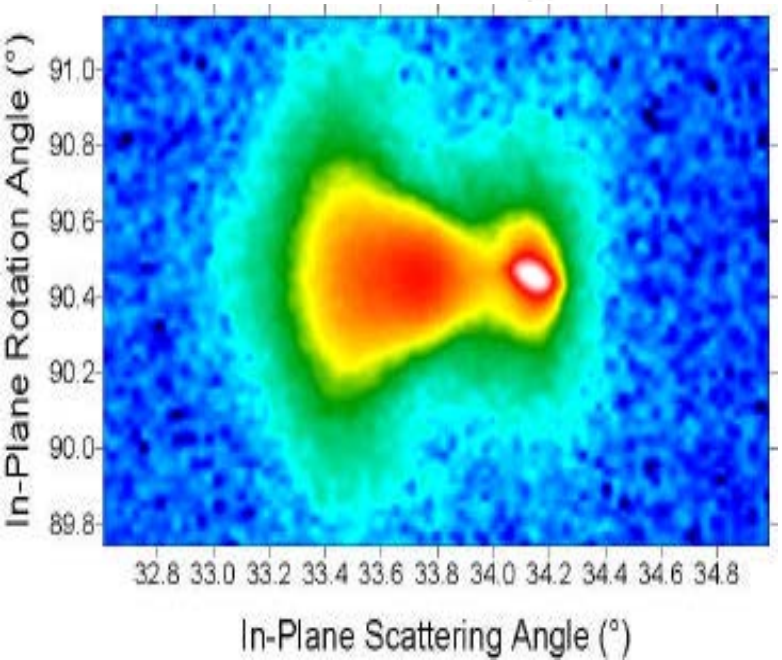
Argonne National Lab, 9700 S. Cass Ave., Bldg.435, Argonne, IL 60439

GRAZING INCIDENCE IN-PLANE X-RAY DIFFRACTION IN THE LABORATORY

B. K. Tanner, T. P. A. Hase, T. A. Lafford[+] and M. S. Goorsky*

Department of Physics, University of Durham, Durham, DH1 3LE, UK





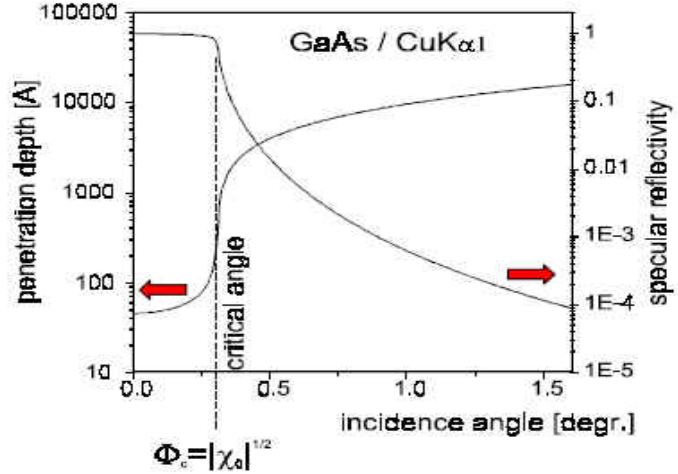


Fig.1 Penetration depth and reflectivity of x-rays at grazing angles

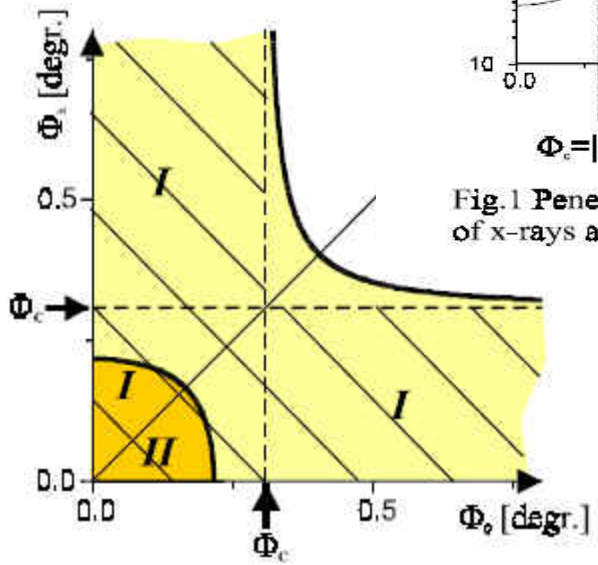


Fig.3. Angular area of total reflection for anti-Borrmann (*I*) and Borrmann (*II*) x-ray fields. The total reflection area for kinematical GID is hatched.

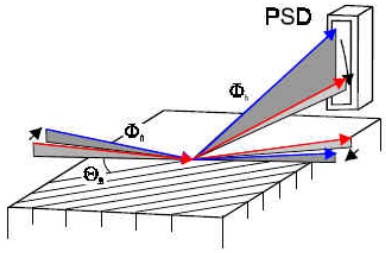
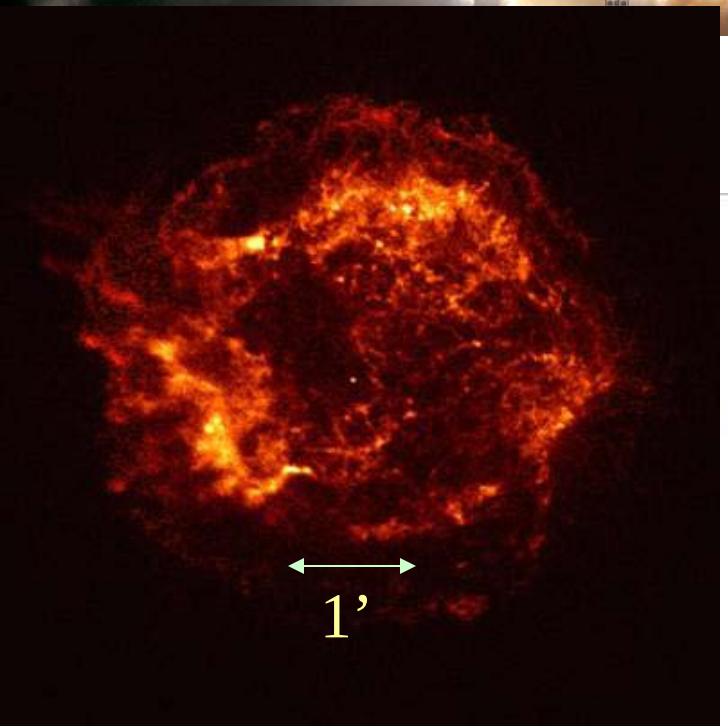


Fig.4. Dependence of diffracted wave takeoff on the deviation from Bragg condition in GID.

The role of project science in the Chandra X-ray Observatory

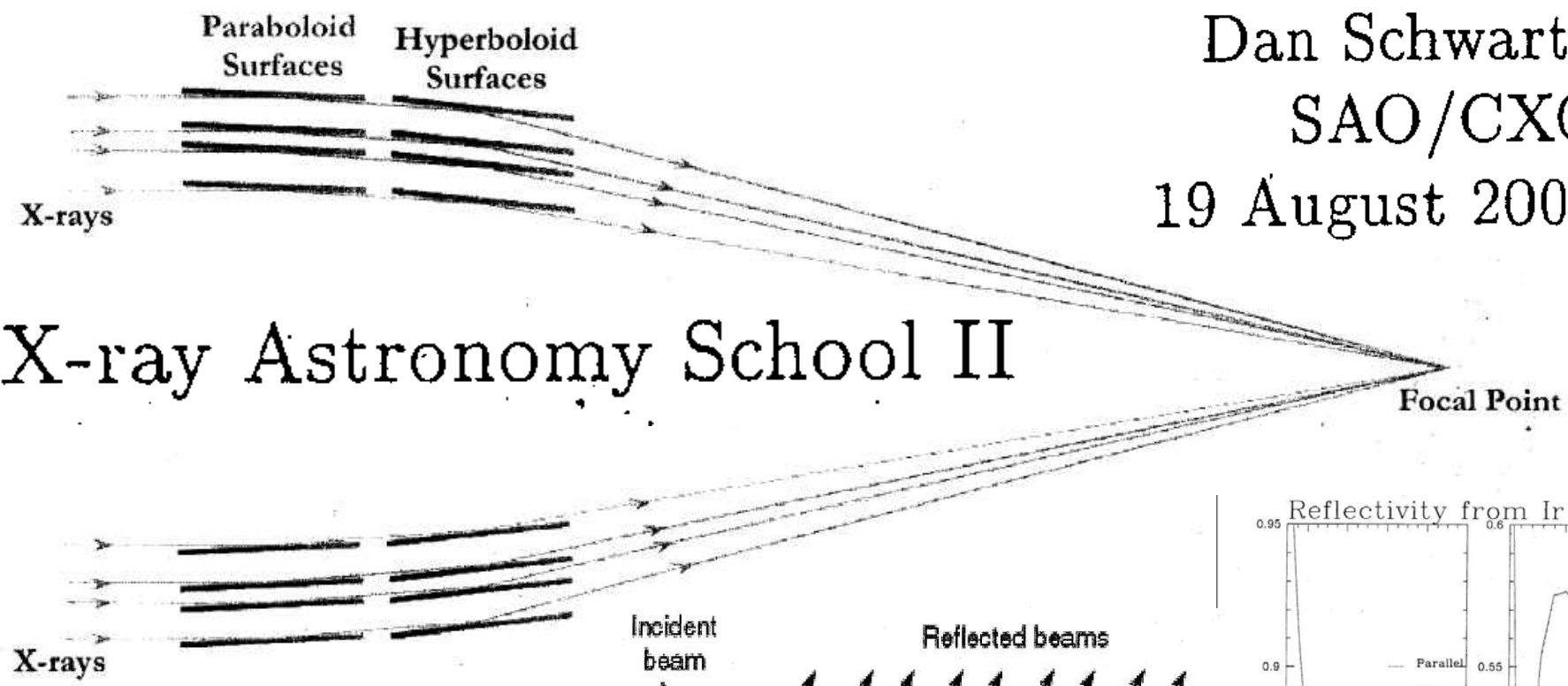
Stephen L. O'Dell & Martin C. Weisskopf

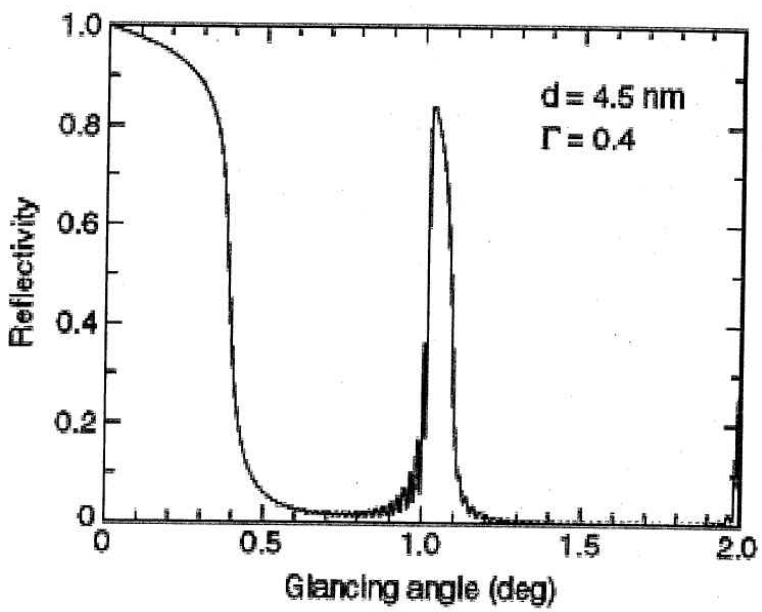
NASA Marshall Space Flight Center,

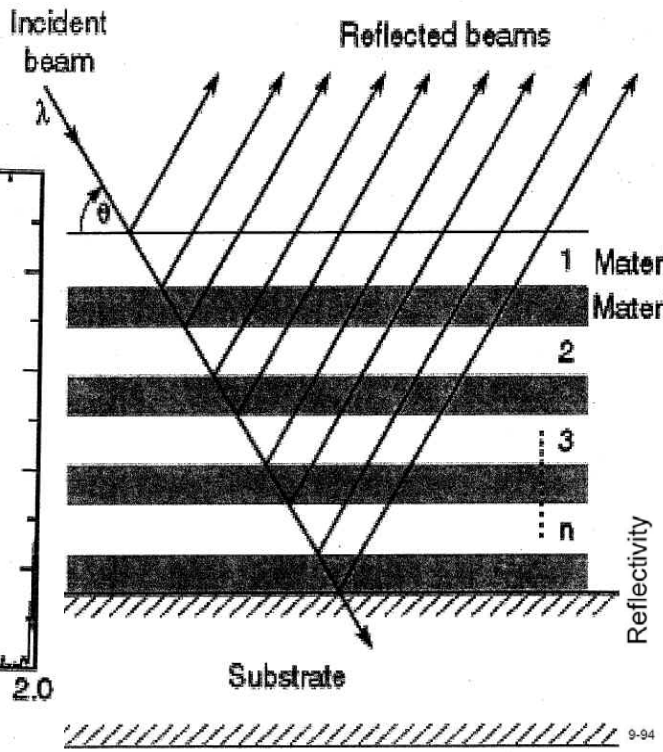


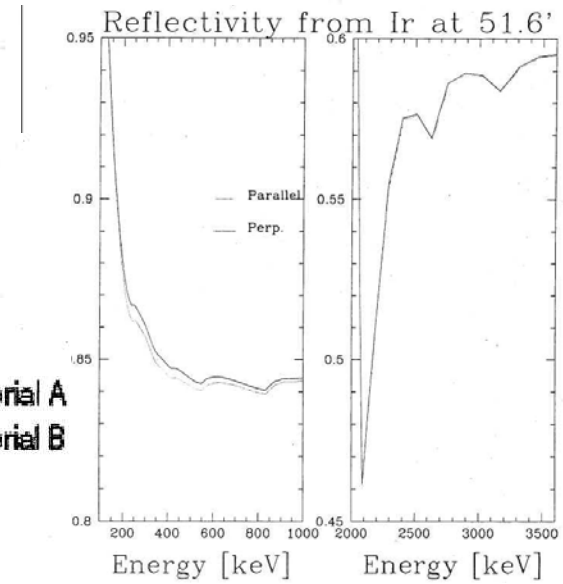
X-ray Astronomy School II

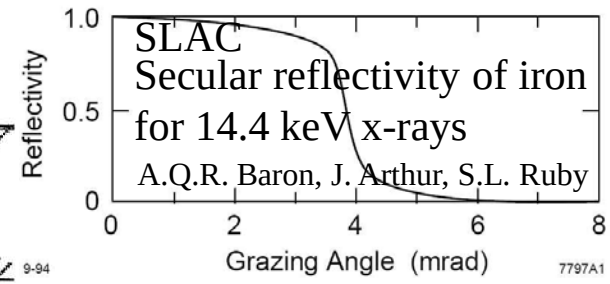
Dan Schwartz
SAO/CXC
19 August 2002





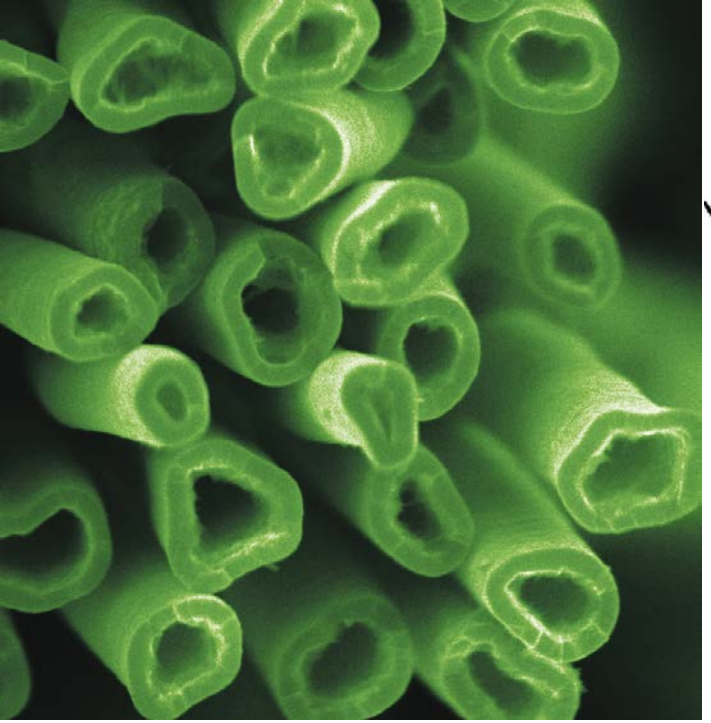


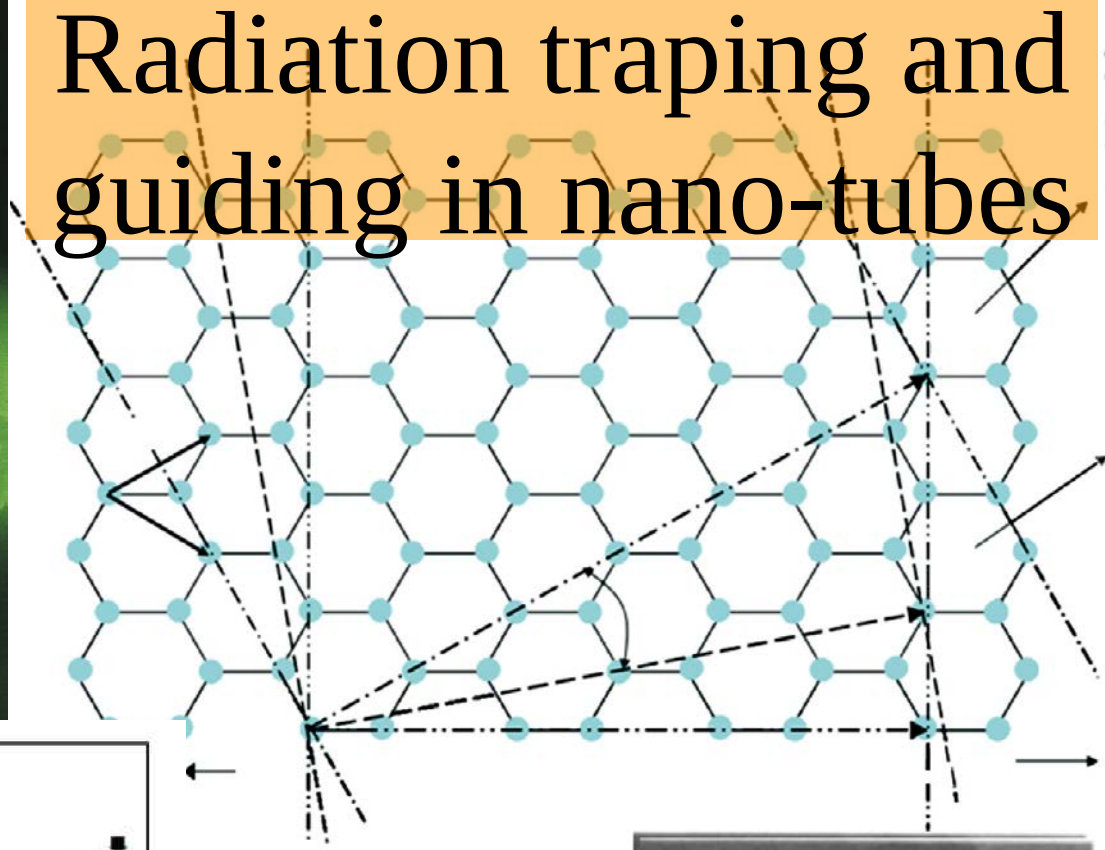


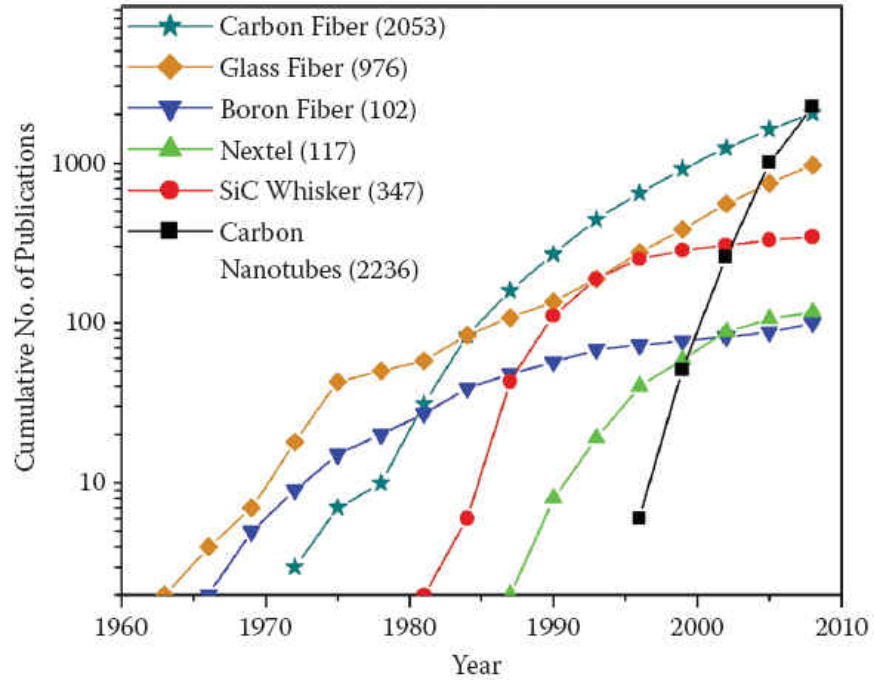


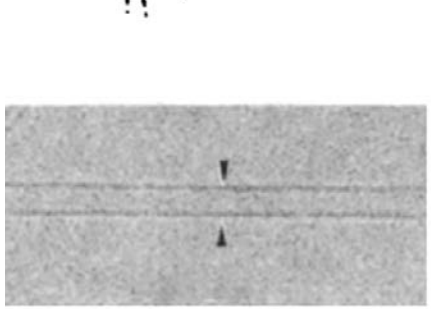
SLAC
Secular reflectivity of iron for 14.4 keV x-rays
A.Q.R. Baron, J. Arthur, S.L. Ruby

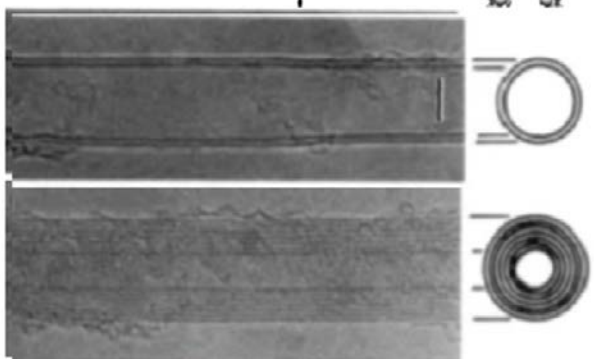
Radiation traping and guiding in nano-tubes











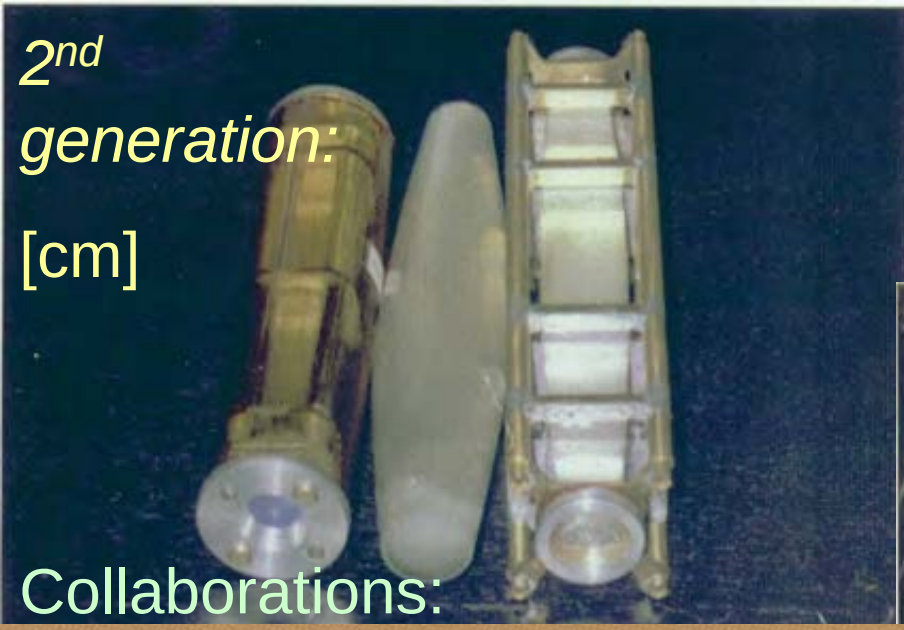
CRC Press – Carbon nano-tubes CNT

X-ray and neutron capillary optic

1st generation:[m]

2nd generation:

[cm]



Collaborations:

Italy, Russia, USA, France, Germany, Switzerland,

Ukraine, Belarus, Armenia

5th generation:

[μm – nm]

n-capillaries

CHANNELING projects at LNF:

From Crystal Undulators to Capillary Waveguides

Sultan Dabagov, Massimo Ferrario, Luigi Palumbo and Luca Serafini

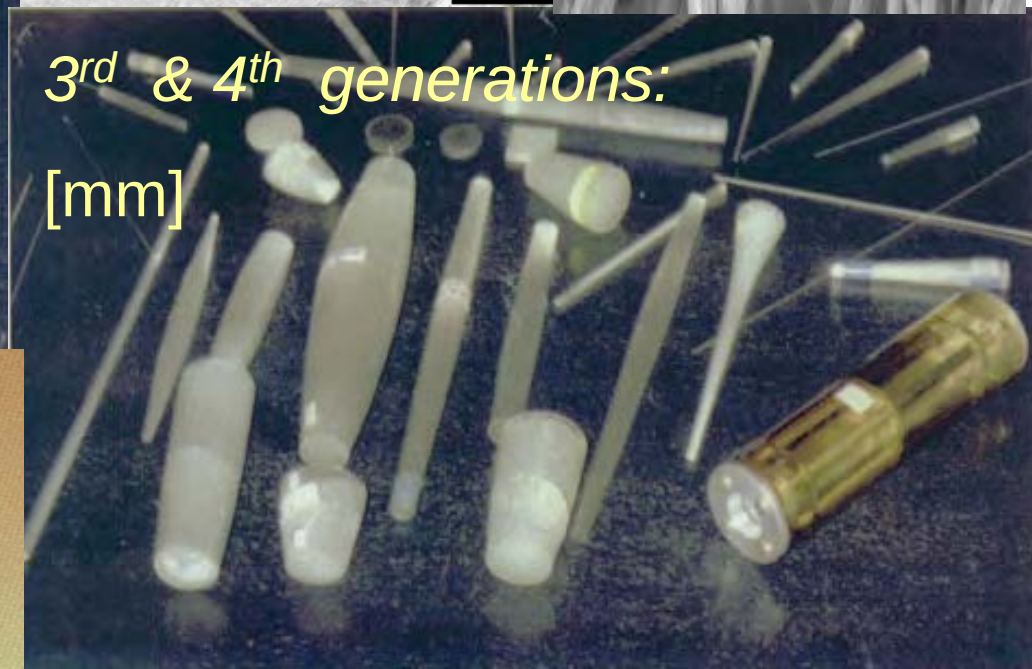
PAHBEB -2005, Erice,13 October 2005

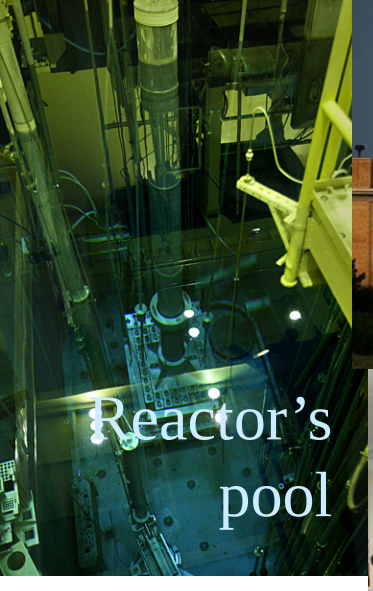
http://www.unisantis.com

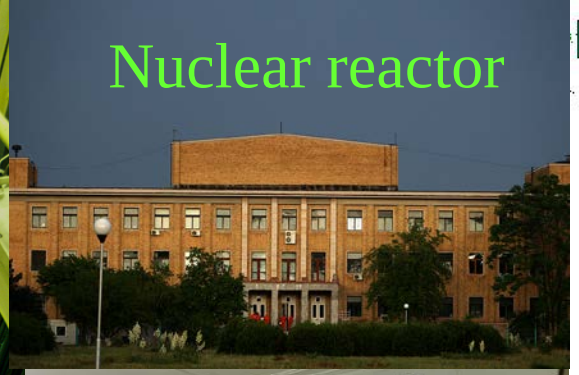
http://www.iroptic.com

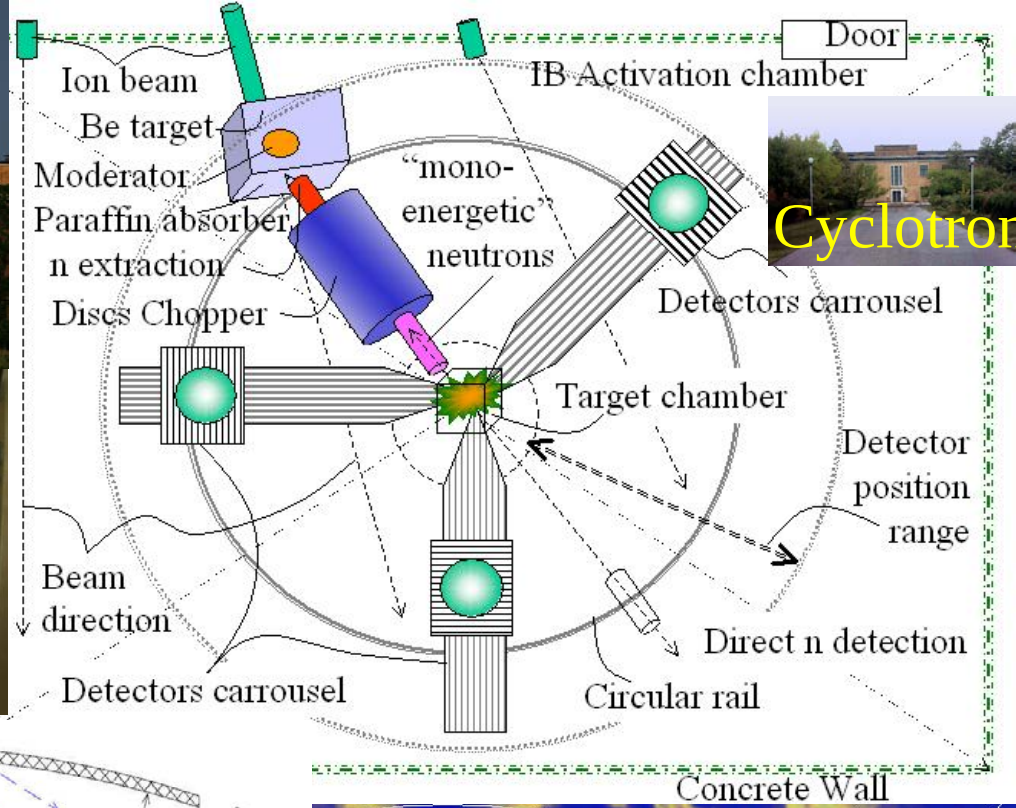
3rd & 4th generations:

[mm]

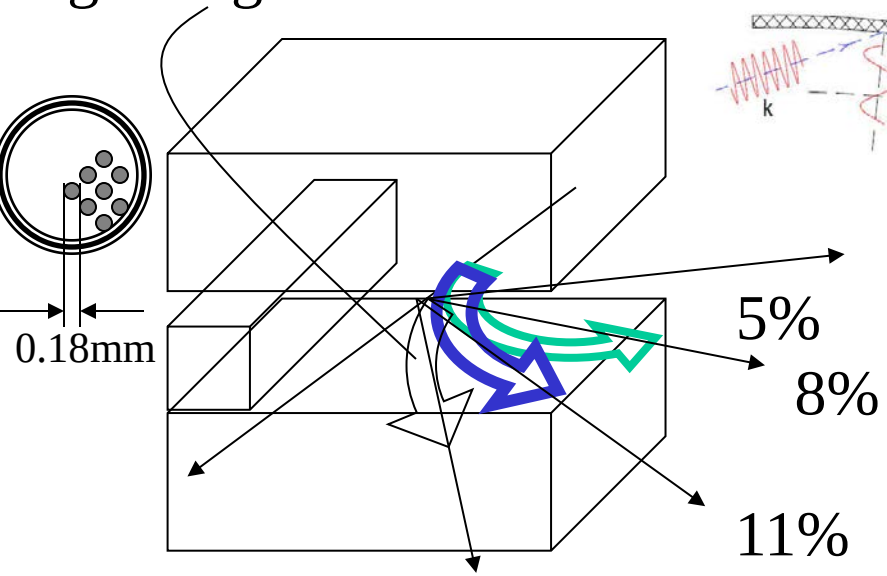


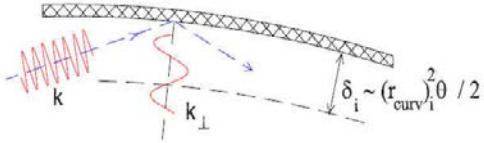


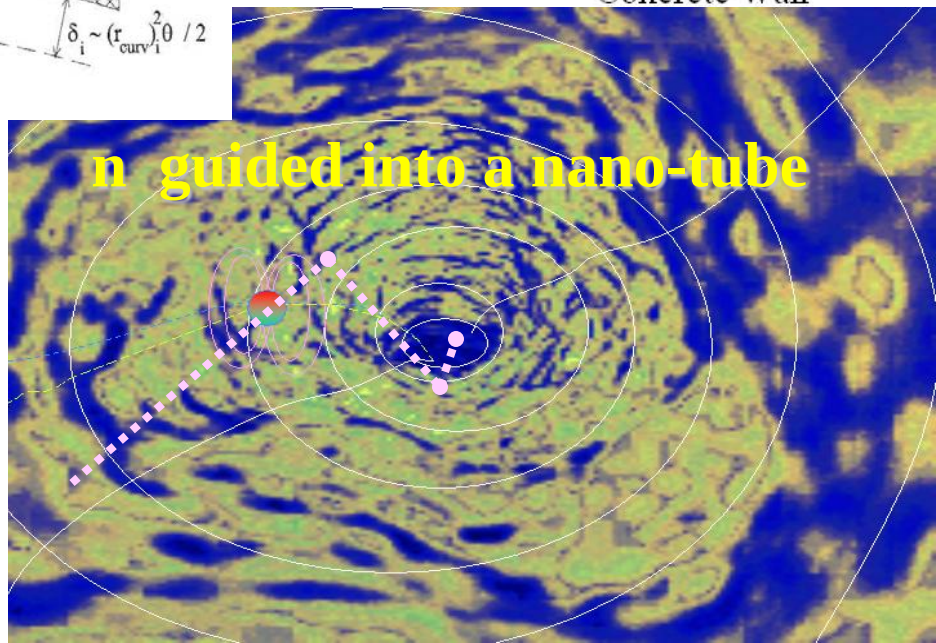




Optical Fiber
n guiding

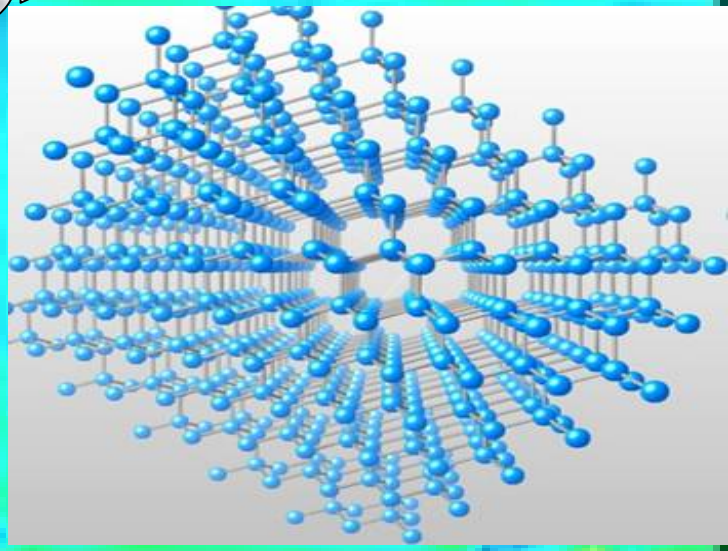




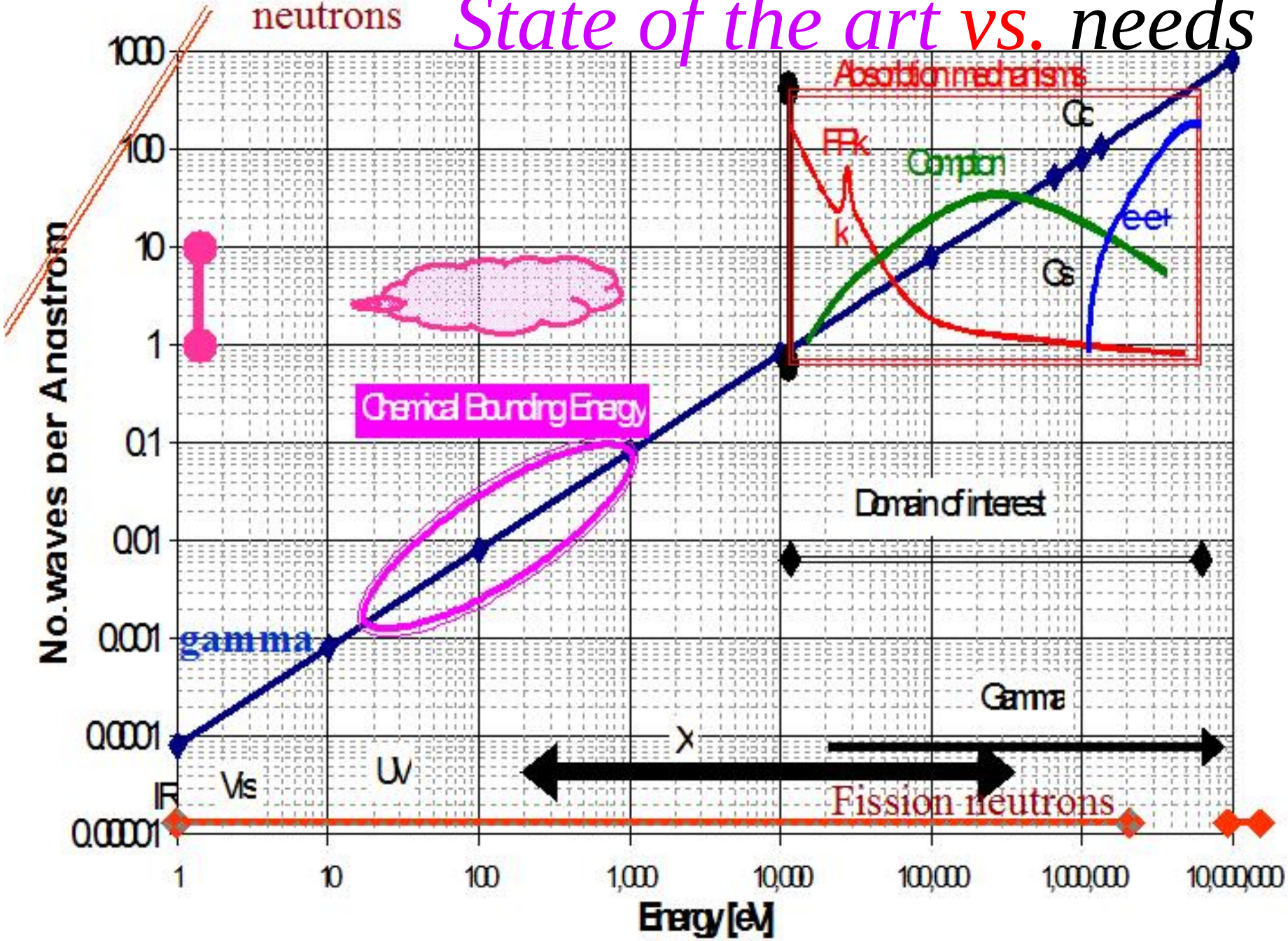


(Juki card puncher, light guide)

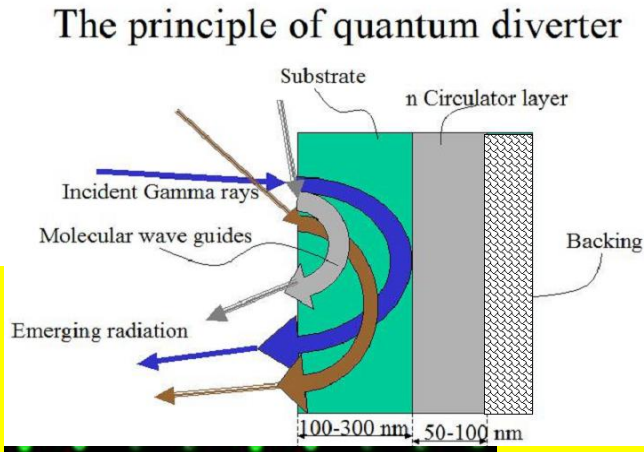
Nano-guides for nuclear radiation



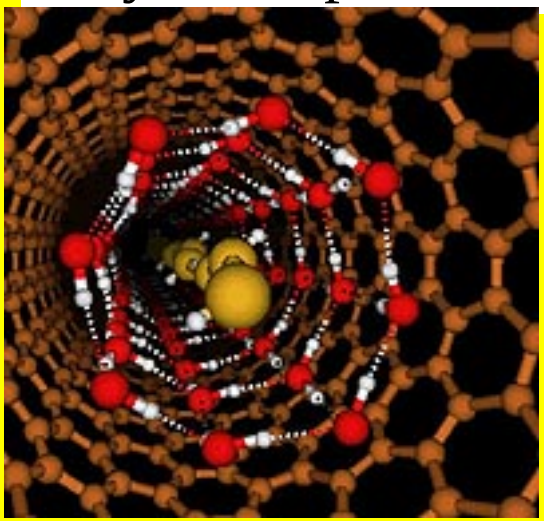
State of the art vs. needs



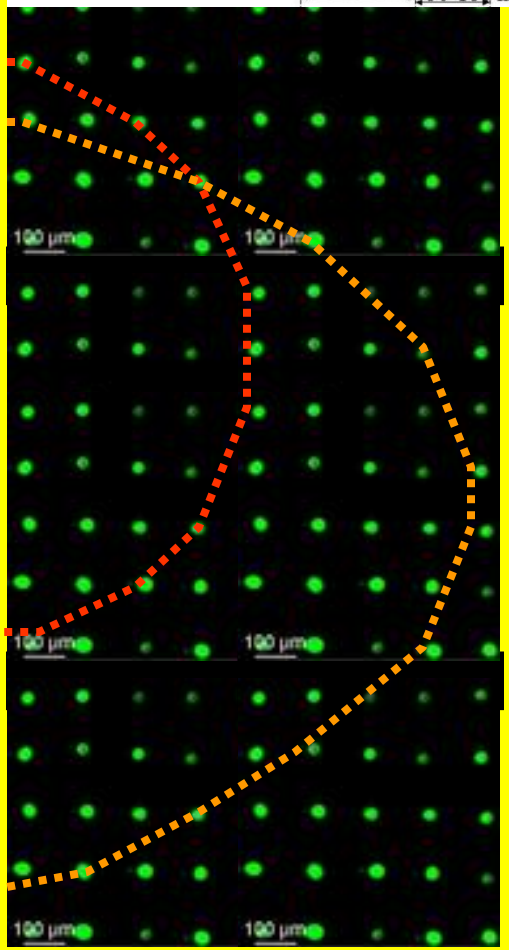
Nano-structure collective interaction in guiding radiation



Multiple sequential scattering equivalent to particle backscattering, but with smaller energy loss have a very small probability in crystals.

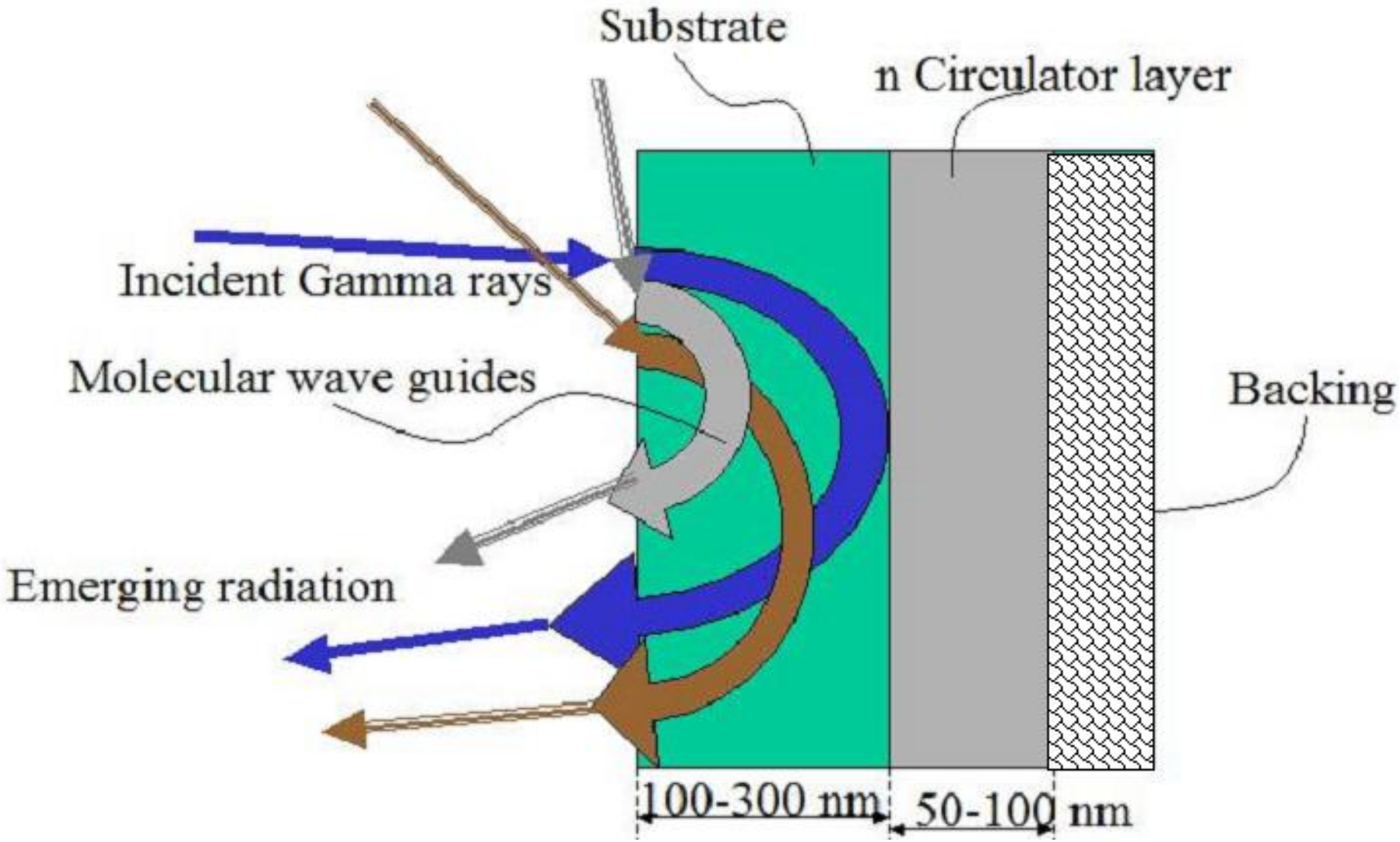


Is there possible to use a nano structure at grazing reflection to use like a optical fiber?

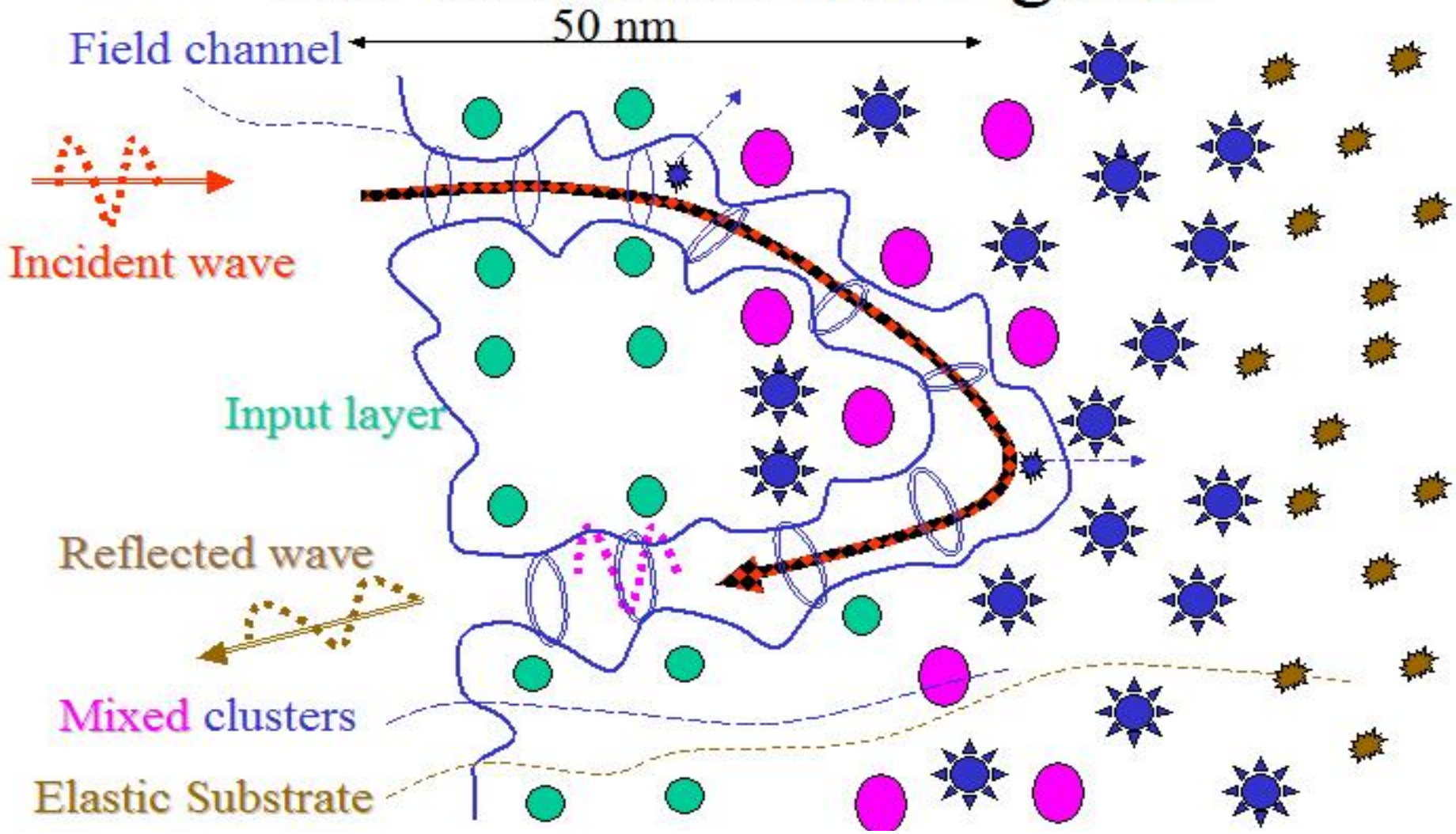


Theory and simulations gave answer: YES !

The principle of quantum diverter



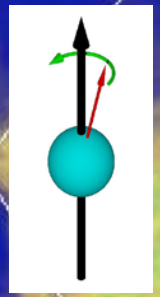
The quantum reflection model
– The chemical wave guide –

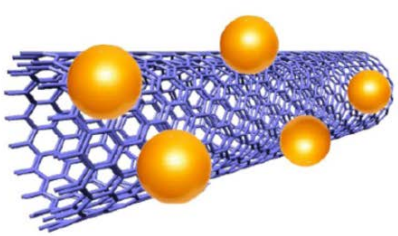


$\mu_n = -1.91304272(45)\ \mu_N$

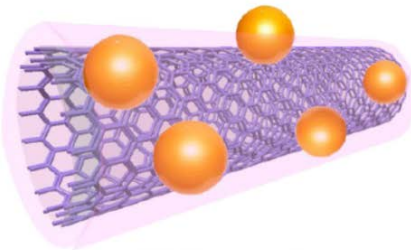
$$\mu_N = \frac{e\hbar}{2m_p}$$

$$\boldsymbol{\mu} = \frac{g\mu_N}{\hbar}\boldsymbol{I}$$

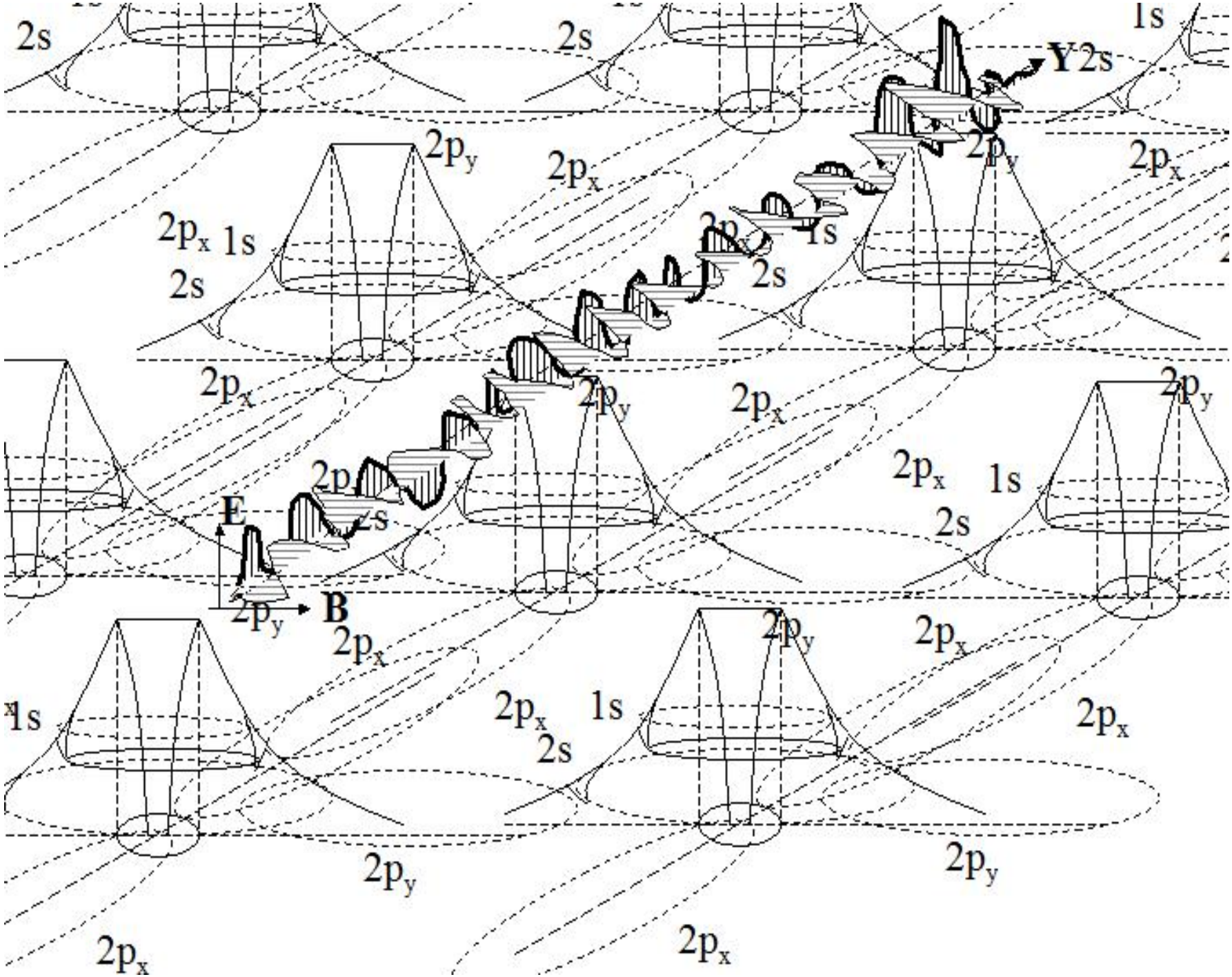




Fe3O4-coated CNTs

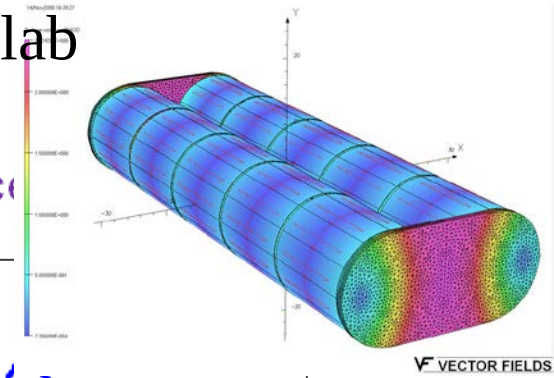


PANI-coated Mag-CNTs

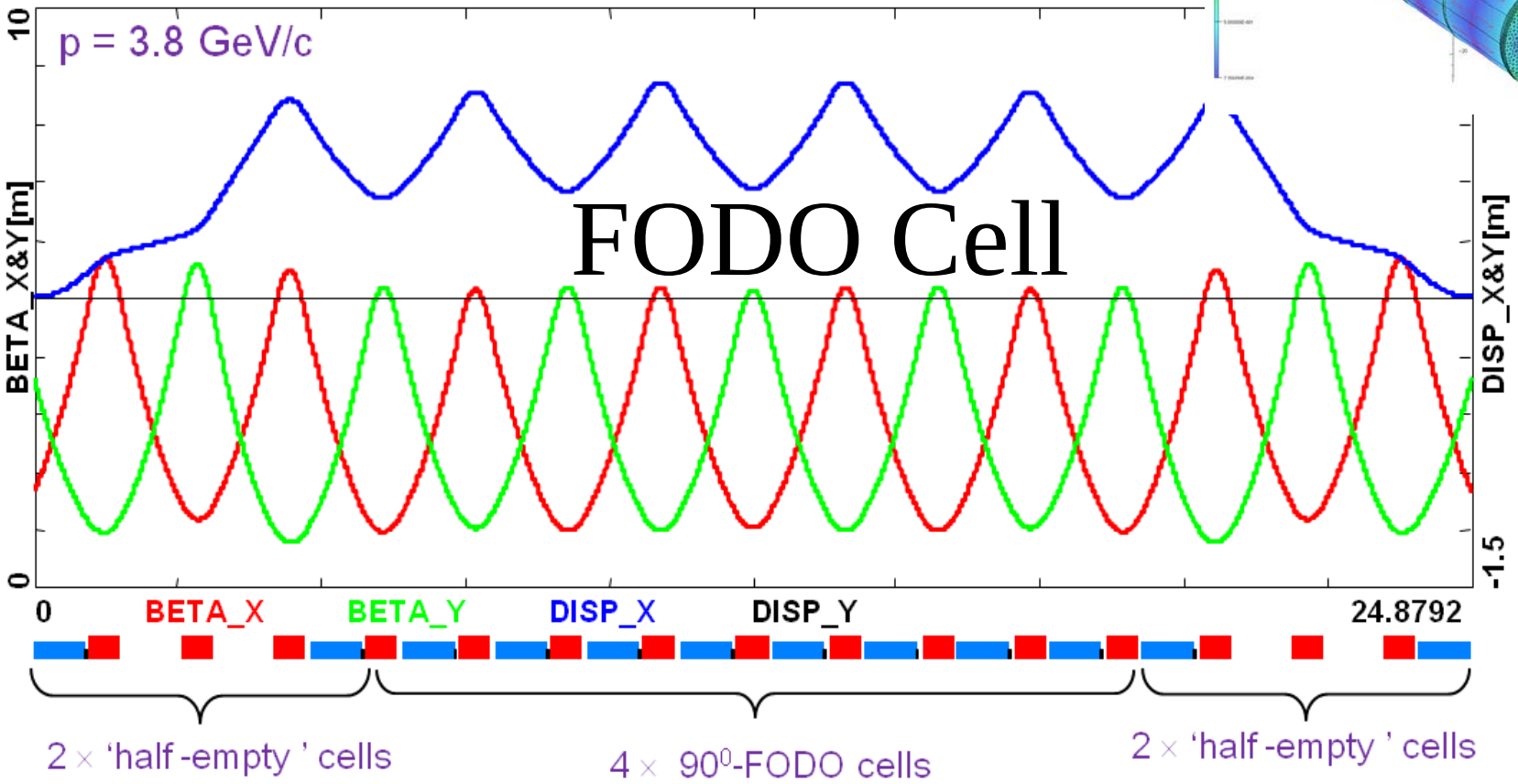

2s
2s
1s
Y
2s
2p$_y$
2p$_x$
2p$_y$
2p$_x$
2p$_x$
1s
2s
2p$_x$
1s
2s
2p$_x$
2p$_y$
2p$_x$
2p$_y$
2p$_x$
1s
2s
E
2p$_y$
B
2p$_x$
2p$_y$
2p$_x$
1s
2p$_x$
1s
2s
2p$_x$
2p$_y$
2p$_y$
2p$_x$
2p$_x$

nuSTORM - Neutrinos from STORed Muons Fermilab

http://inspirehep.net/record/1117009?ln=en



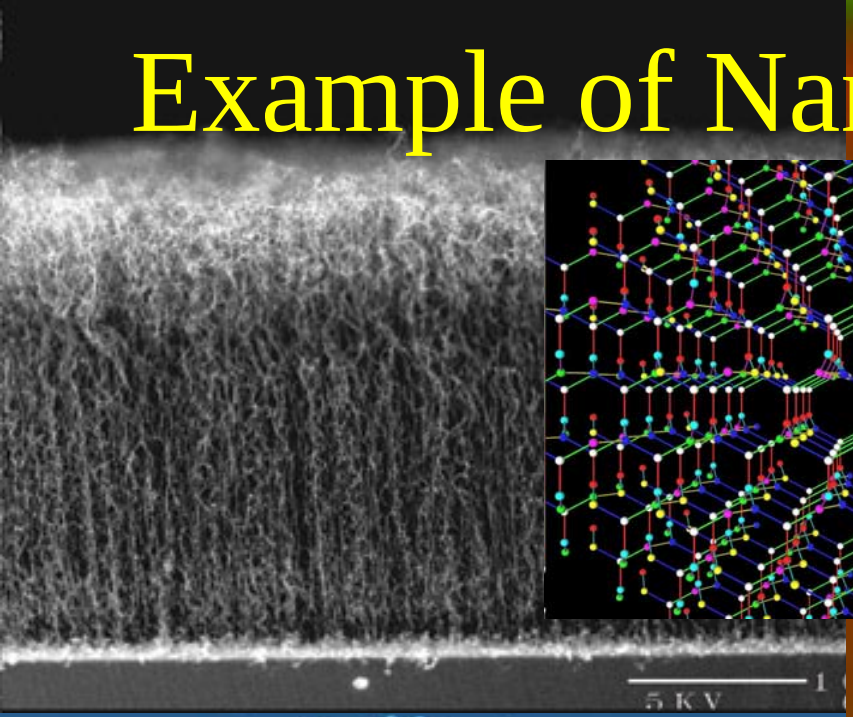
25 meter 180^0 Arc based on 90^0-FODO lattice

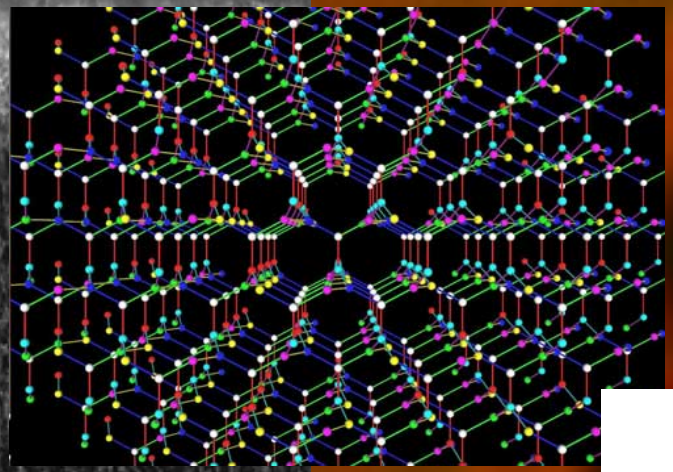


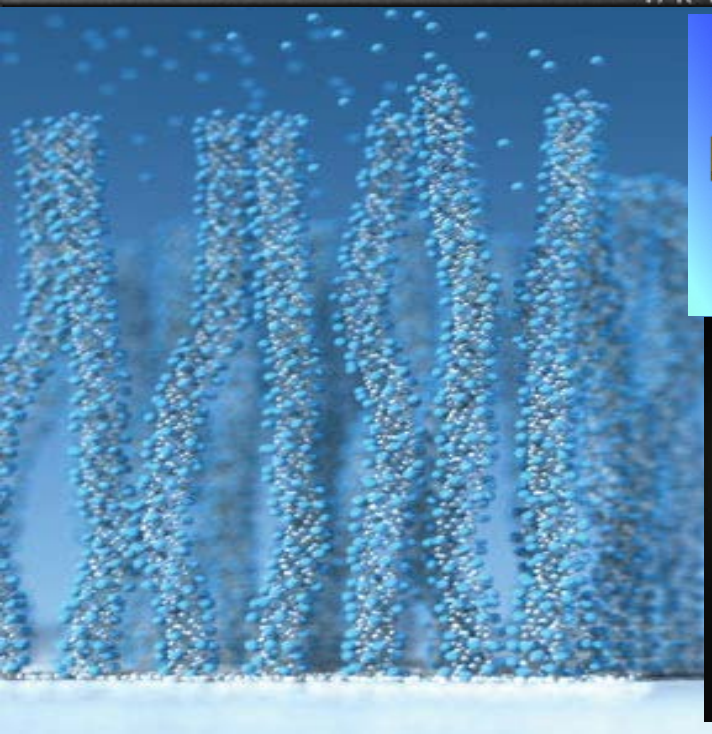
Aperture radius: r = 15 cm

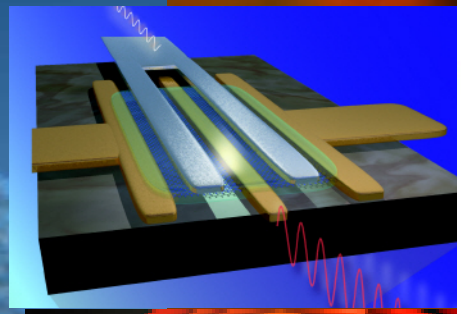
12 × Dipoles:	field: 3.9 Tesla	length: 85 cm
15 × Quads:	gradient : 25 Tesla/m (3.8 Tesla at the pole)	length: 50 cm

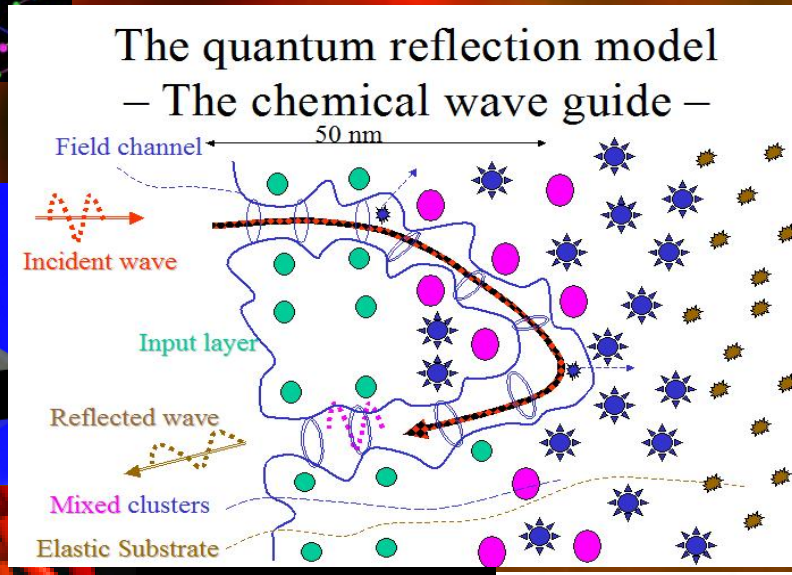
Example of Nano-Hetero Structures

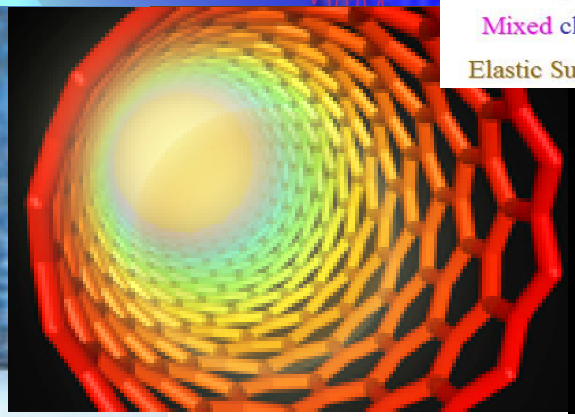


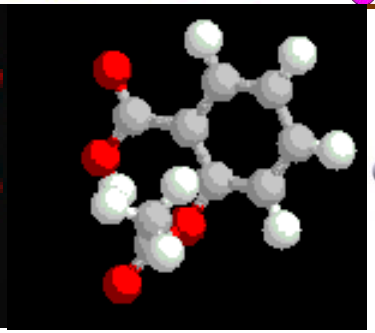


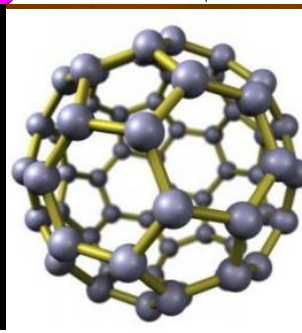




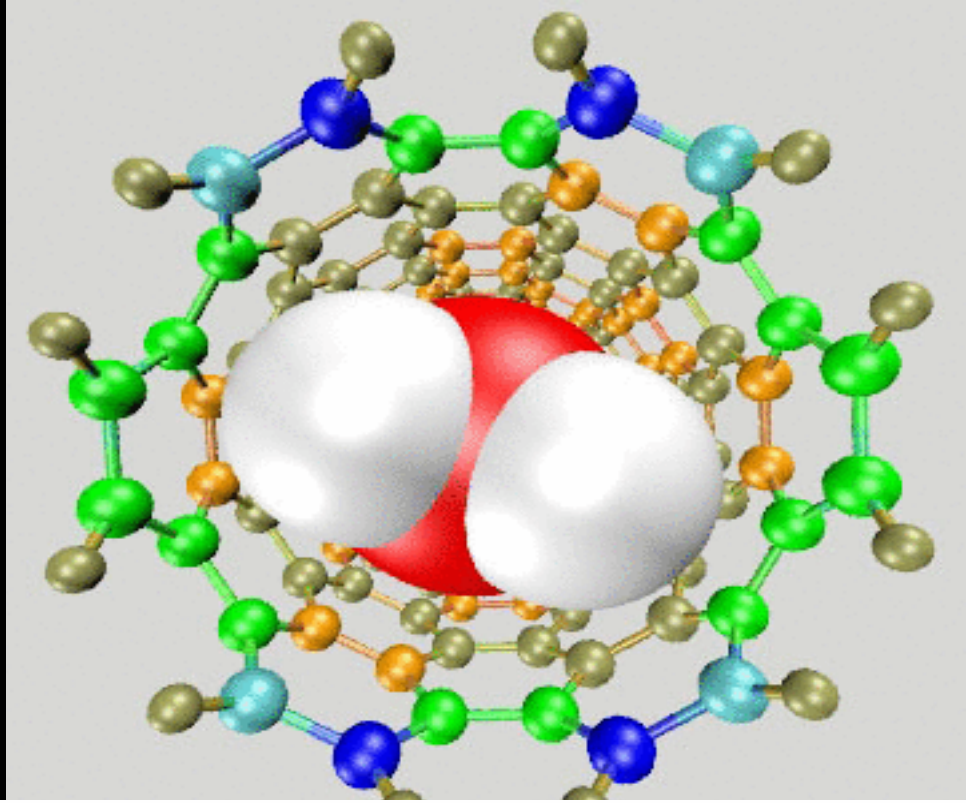


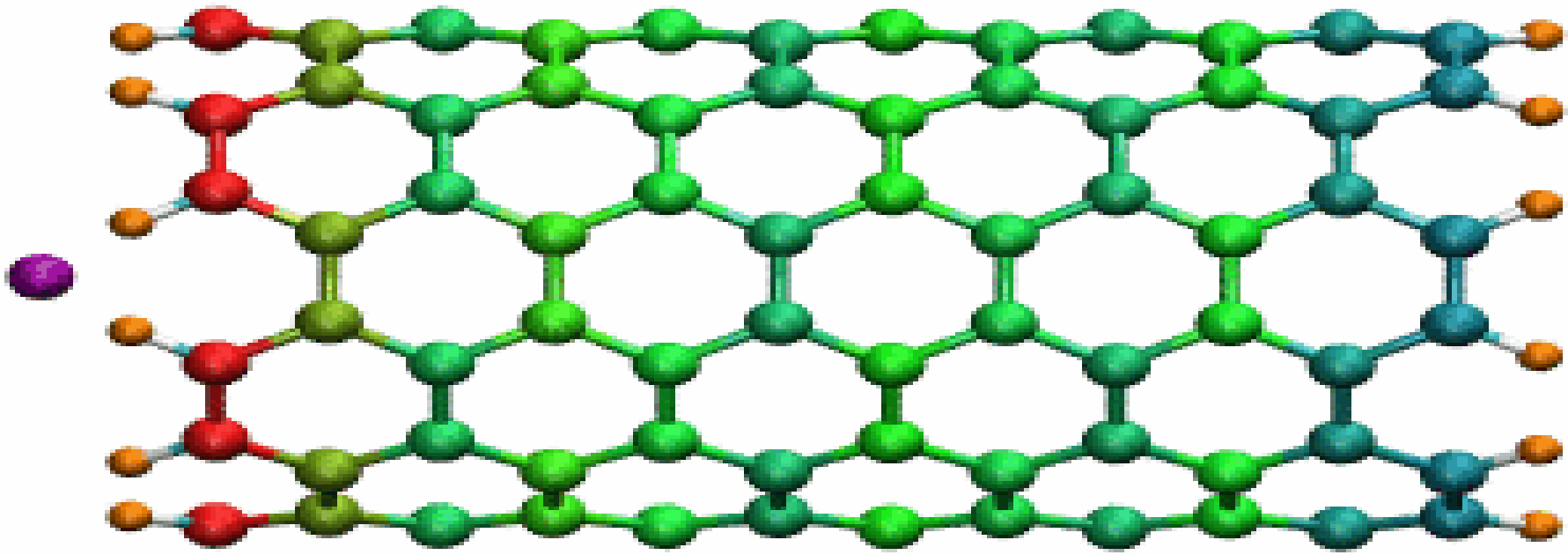






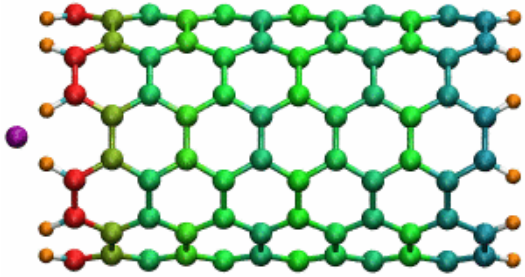
Particle guiding in nano- tube structures

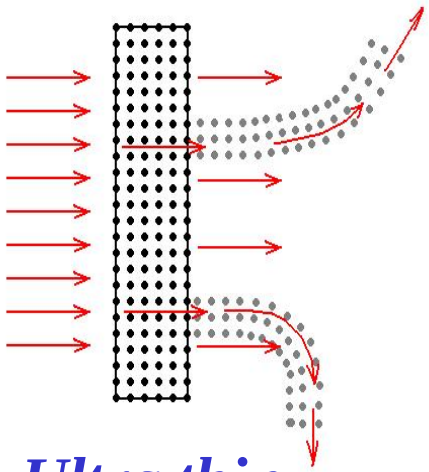


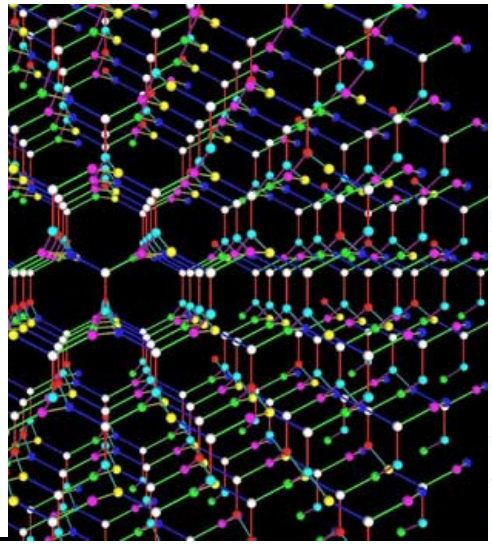


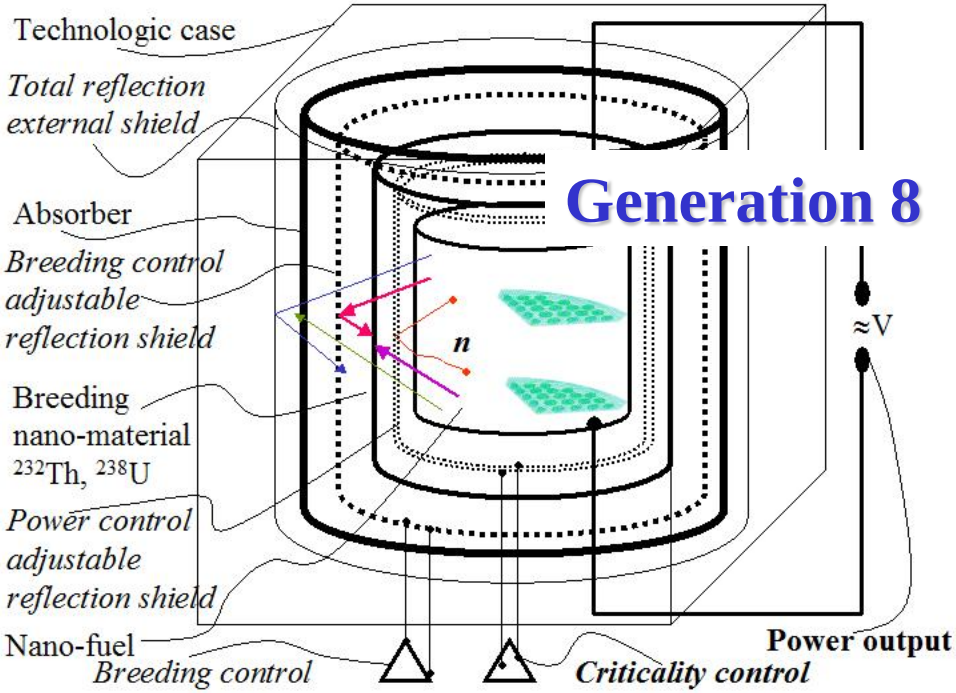
Nano-waveguides for nuclear radiation advanced shielding

Generation 8

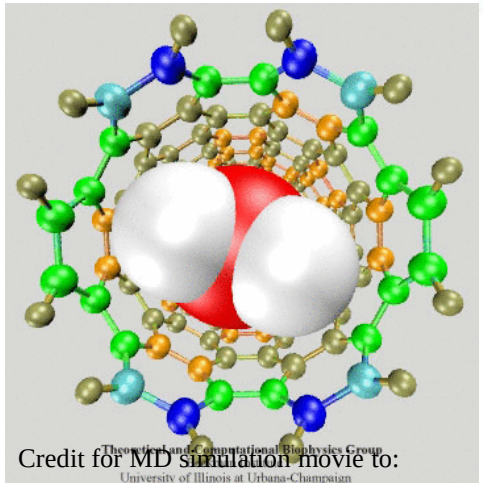




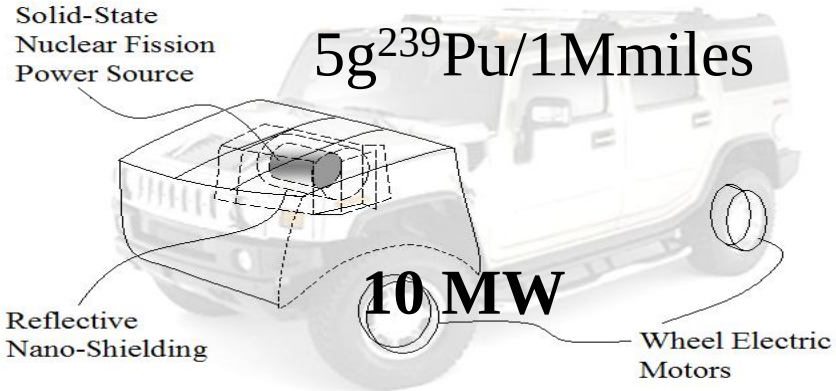




Ultra thin, ultra light active shielding for mobile ultra-small reactors



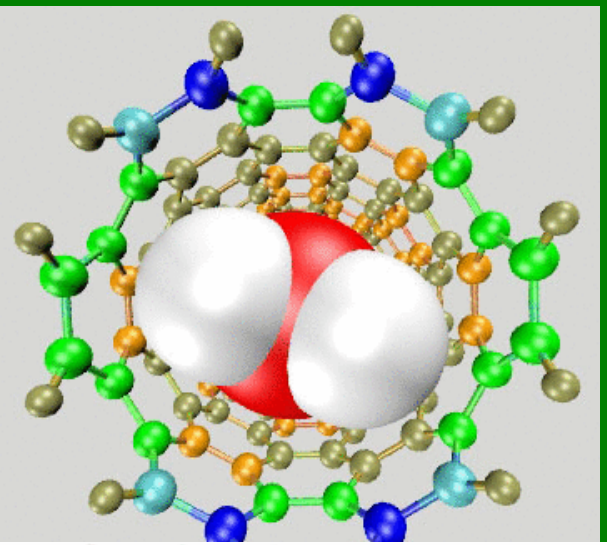
Credit for MD simulation movie to:

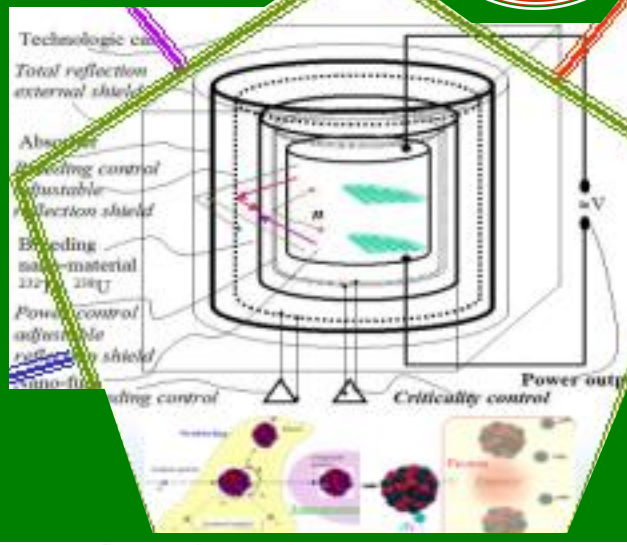


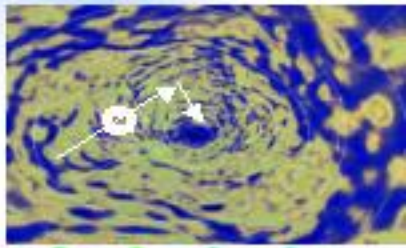
Five fundamental developments based on nano-technologies to improve the fission reactors

Micro-nano-patterned structures →radiation guiding

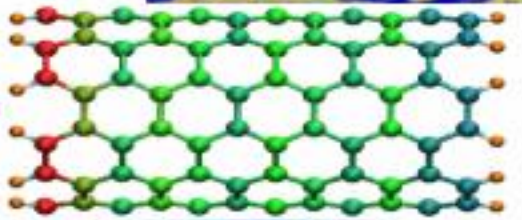
µnps/RG



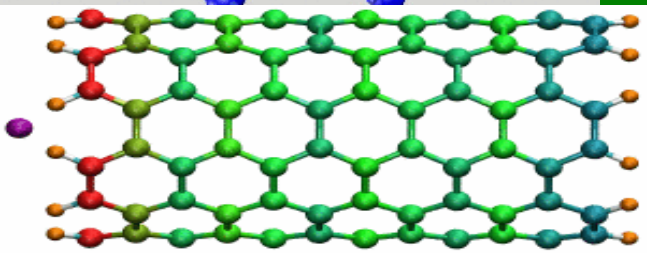


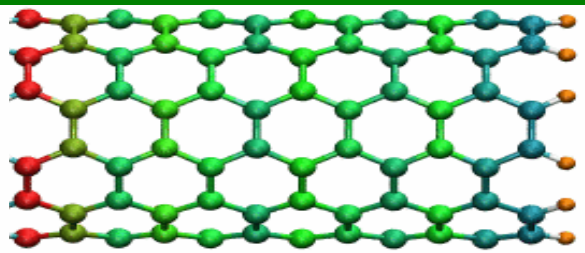


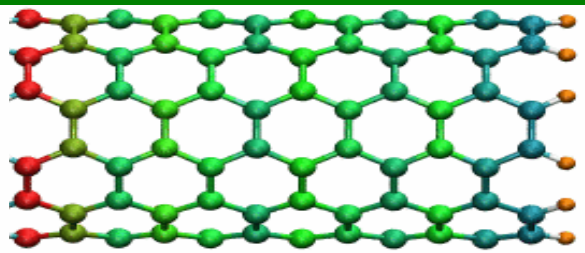
Radiation nano-guiding structures



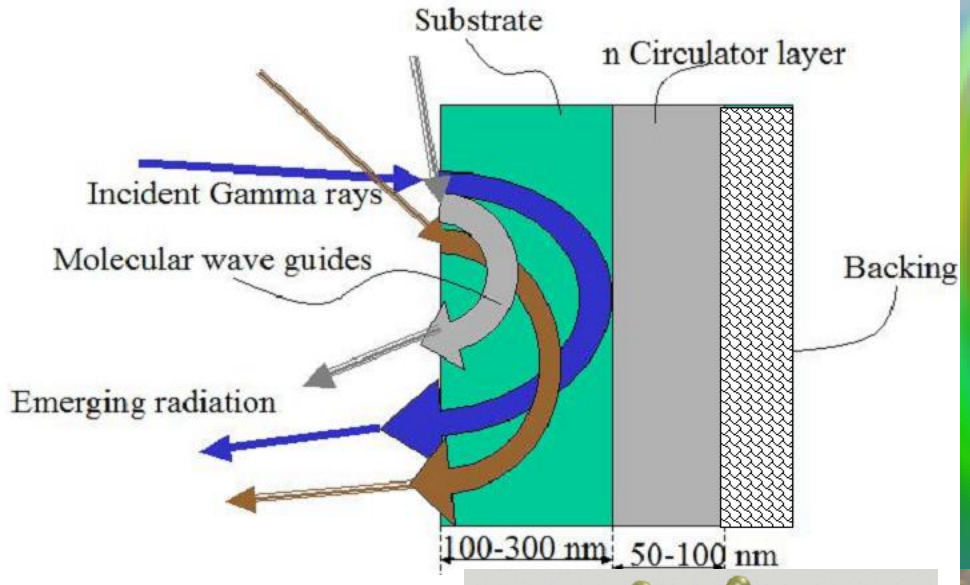
Shielding and Criticality Control

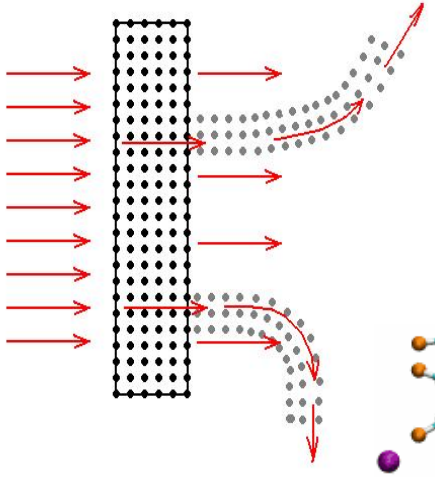


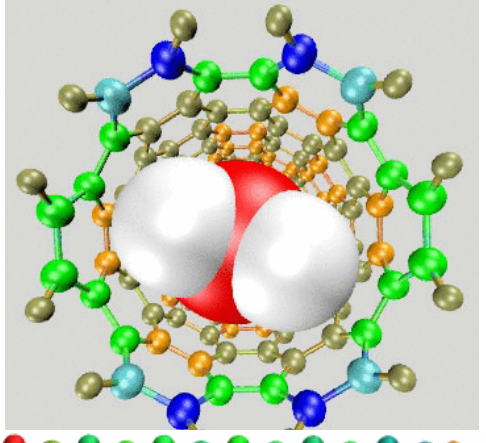


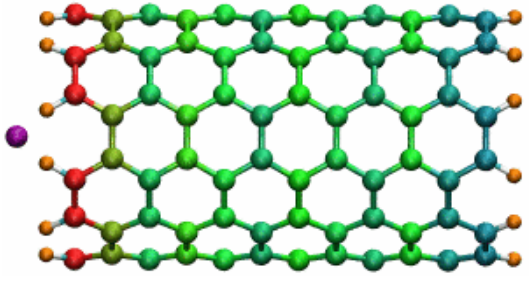


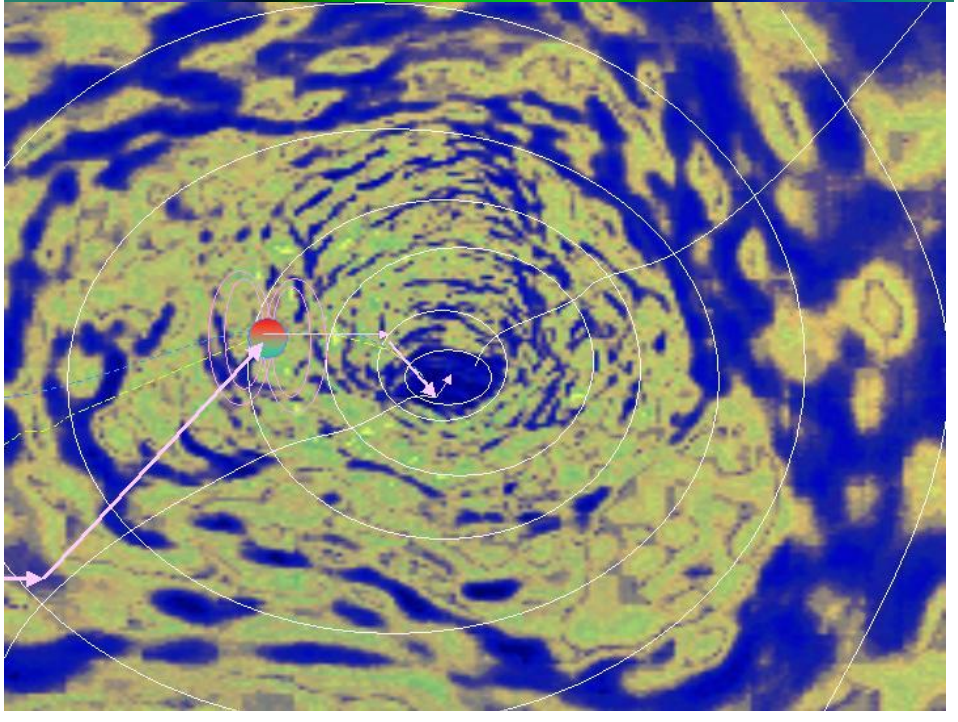
The principle of quantum diverter



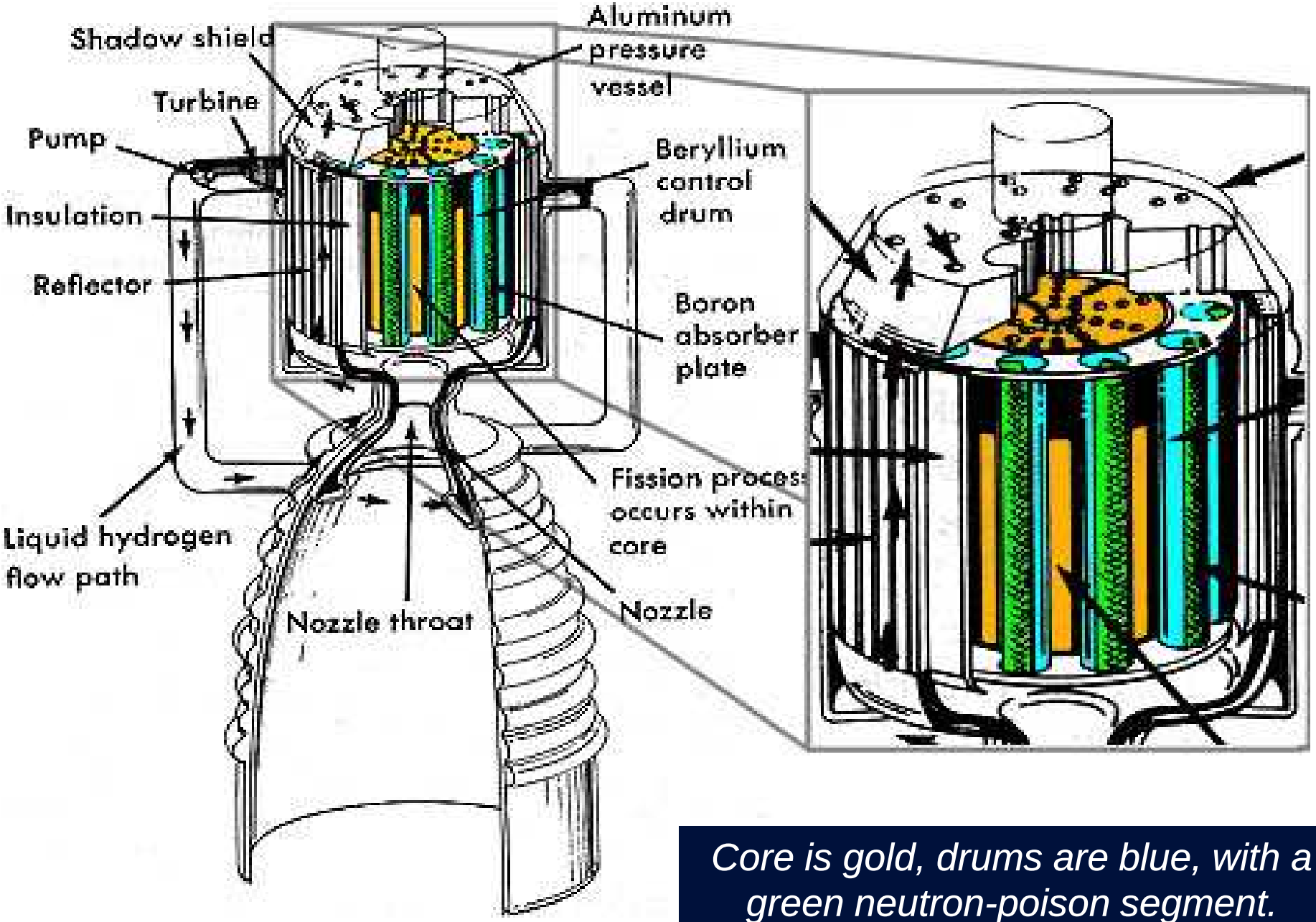








Actual rocket's nuclear reactor control

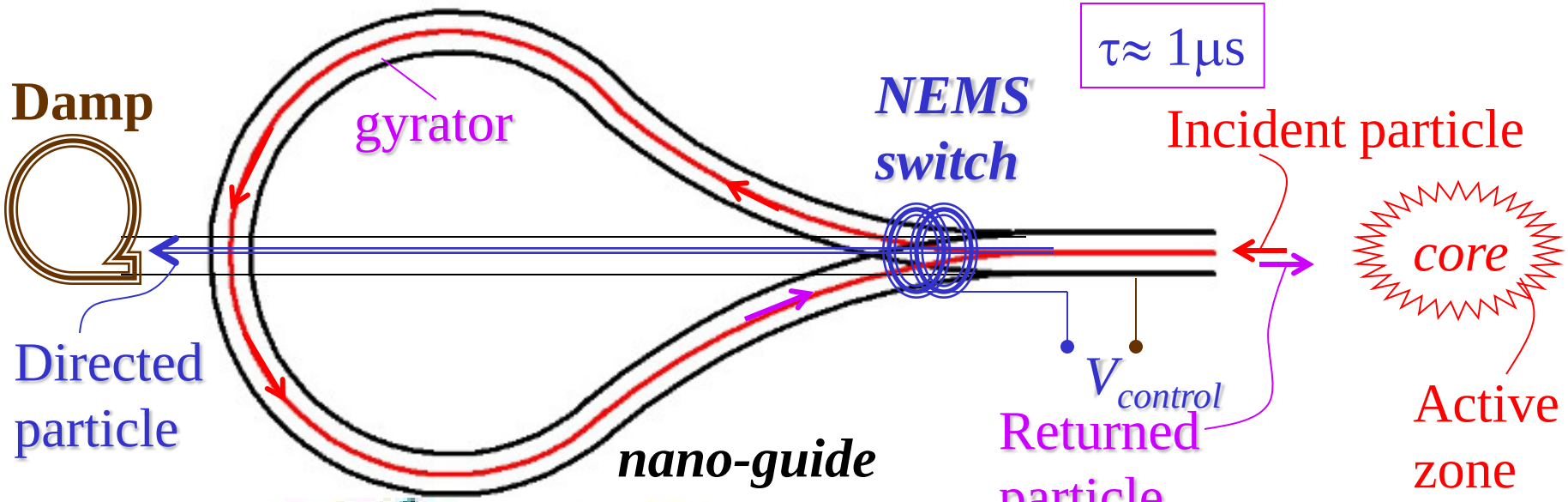


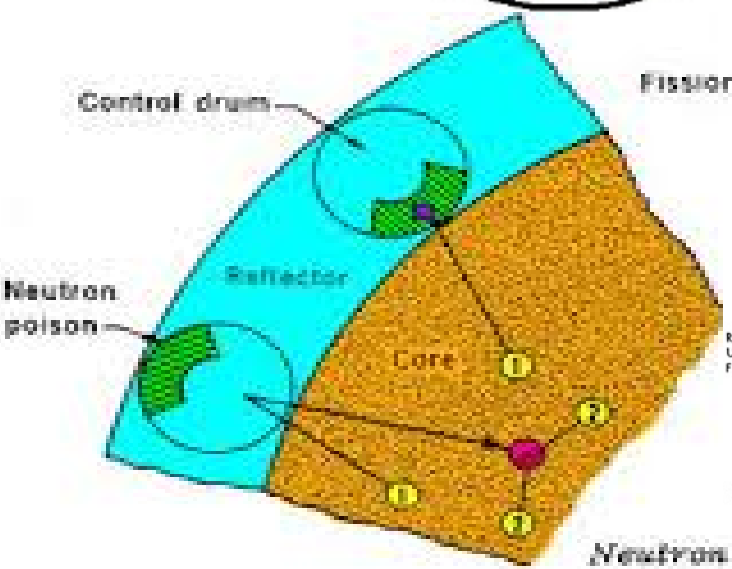
Core is gold, drums are blue, with a green neutron-poison segment.

Replaces control drum

Particle channel switch

$\tau \approx 1\mu s$





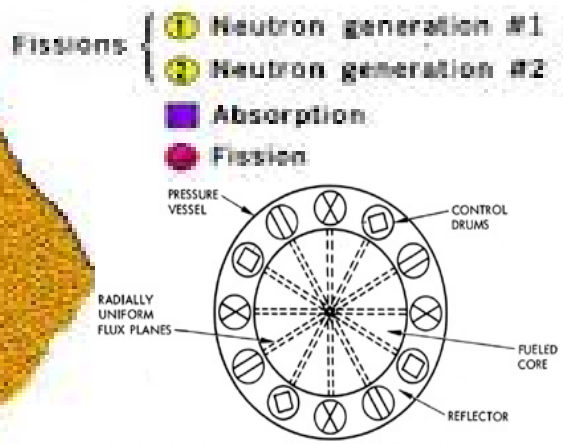
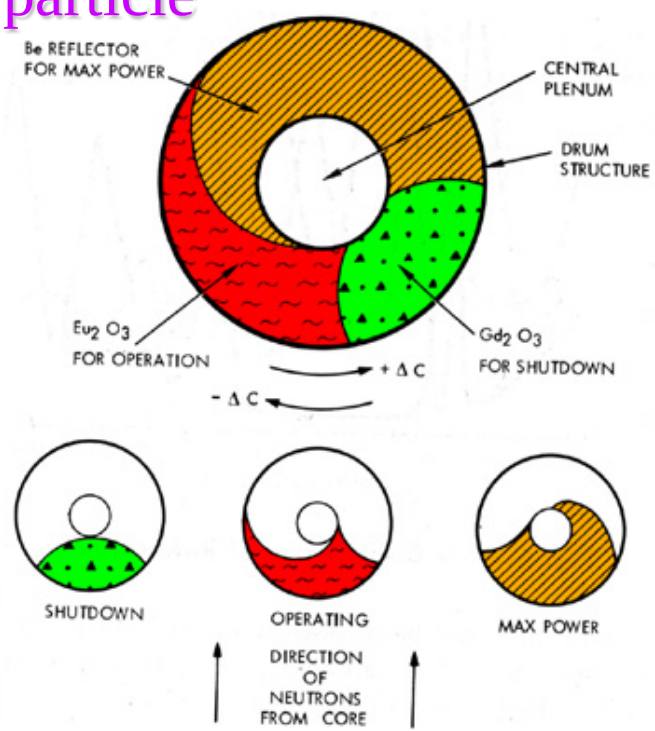


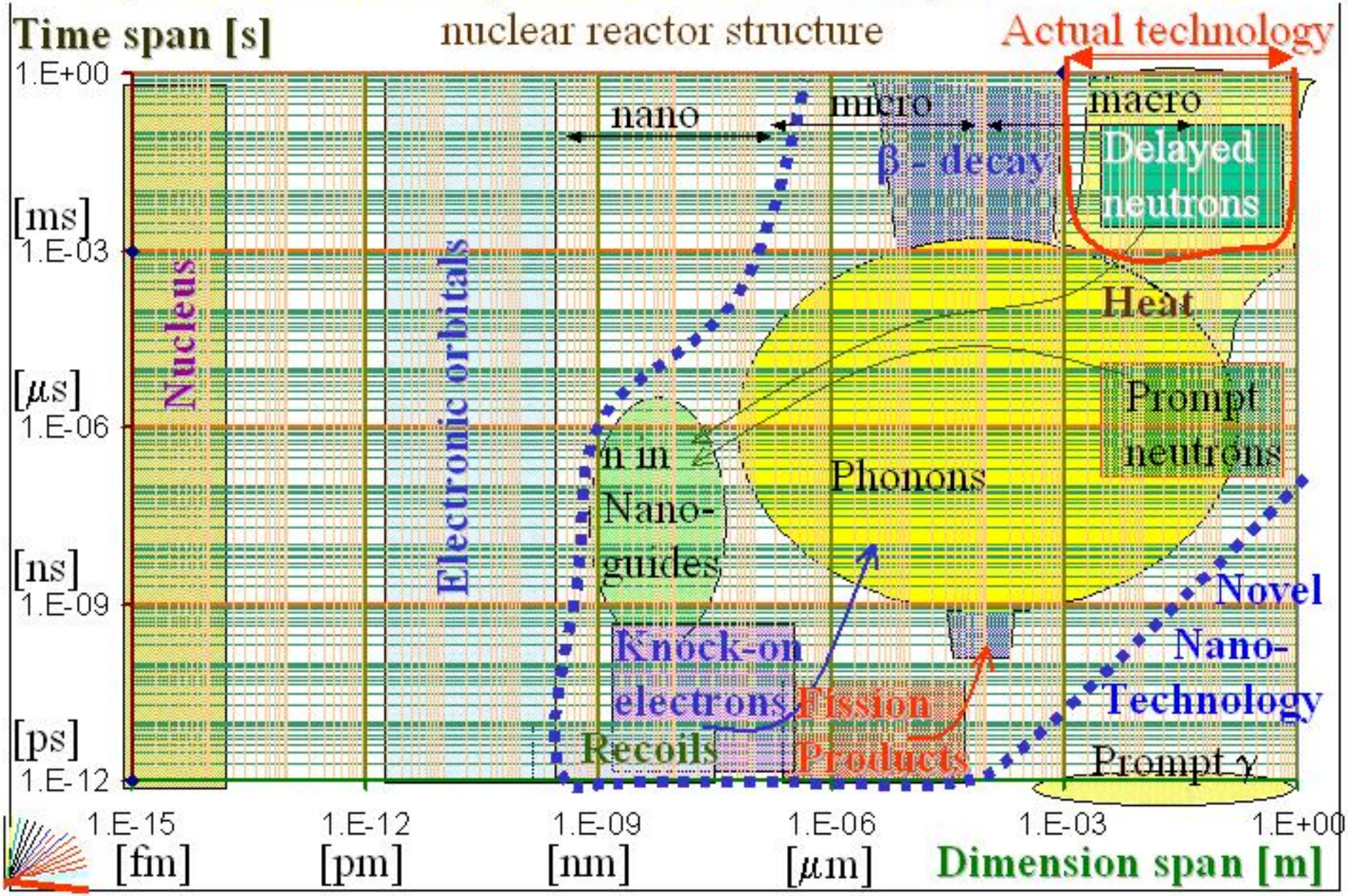
Fig. 5–3 Quadrapairing of Reactor Control Drums

Neutron absorption occurs when the neutron "poison" sides of the control drums are turned toward the reactor core. In an actual control system all drums turn together.

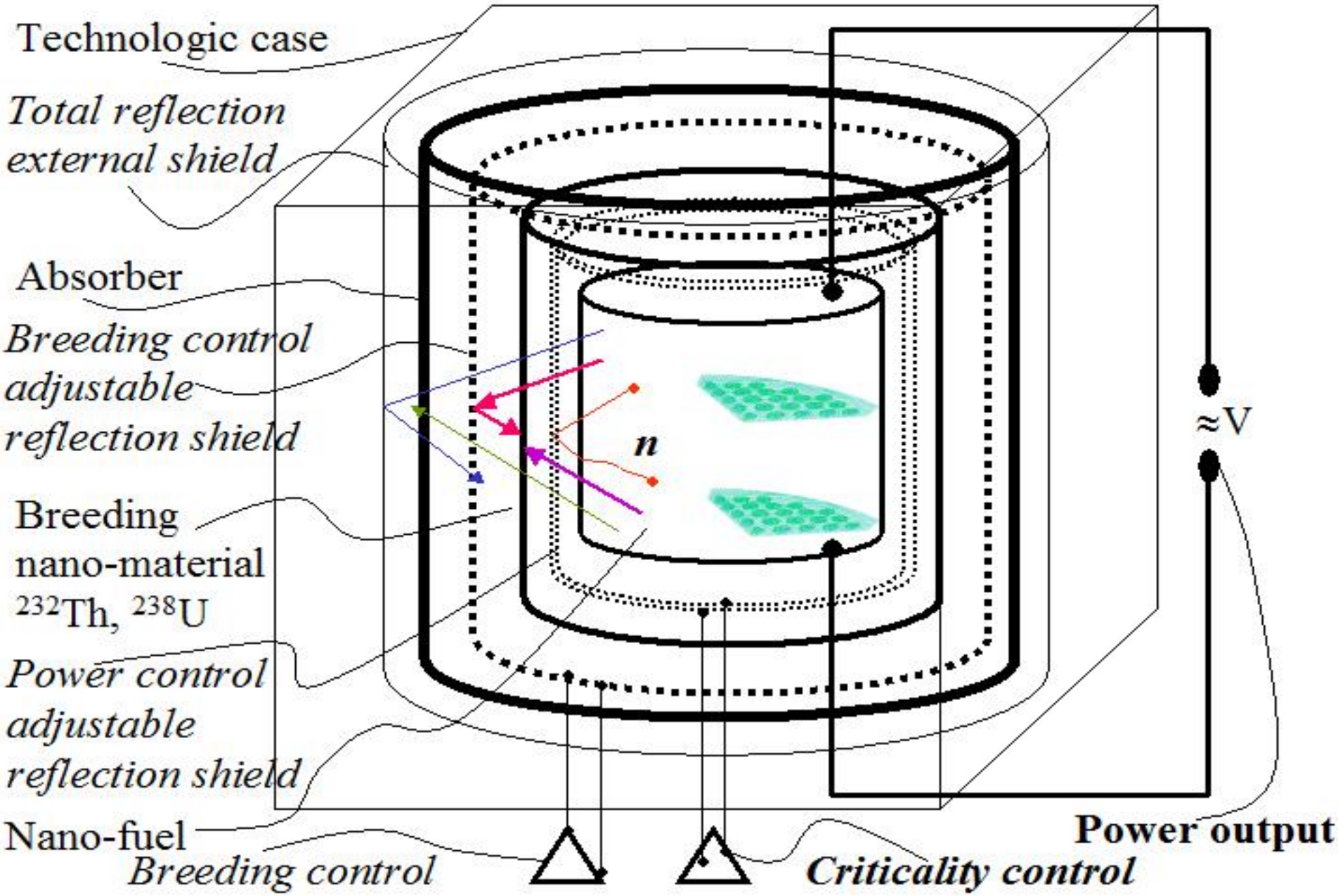


$\tau \approx 1$ s

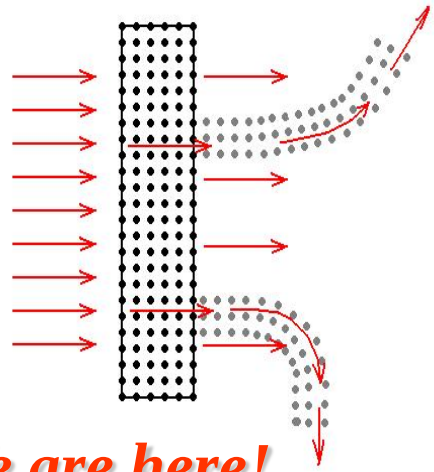
The following nano-technology applications have the potential to improve **the "harmony"** between the nuclear processes and the nuclear reactor structure

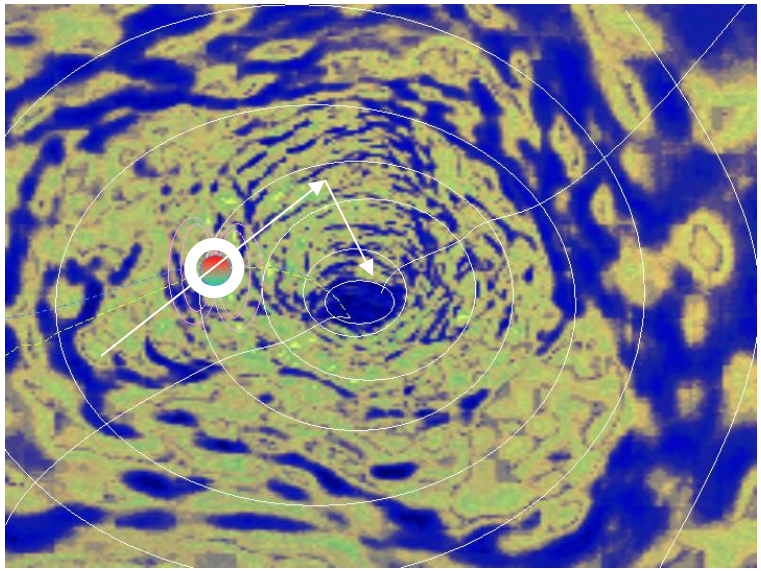


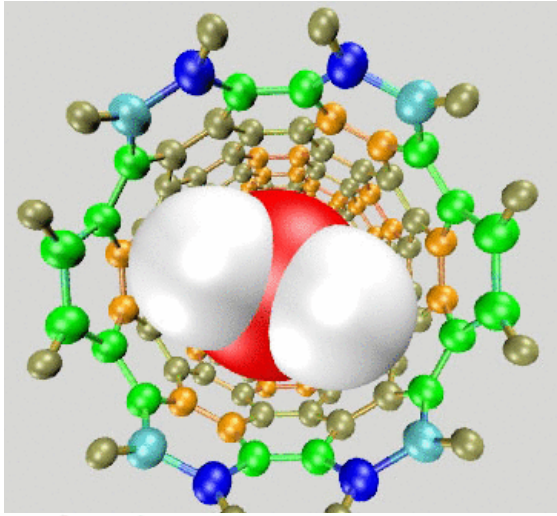
Compact, Solid-state Nuclear fission structure

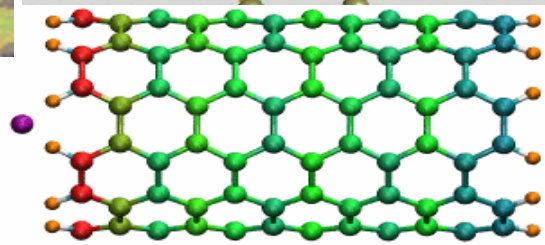


Fundamentals

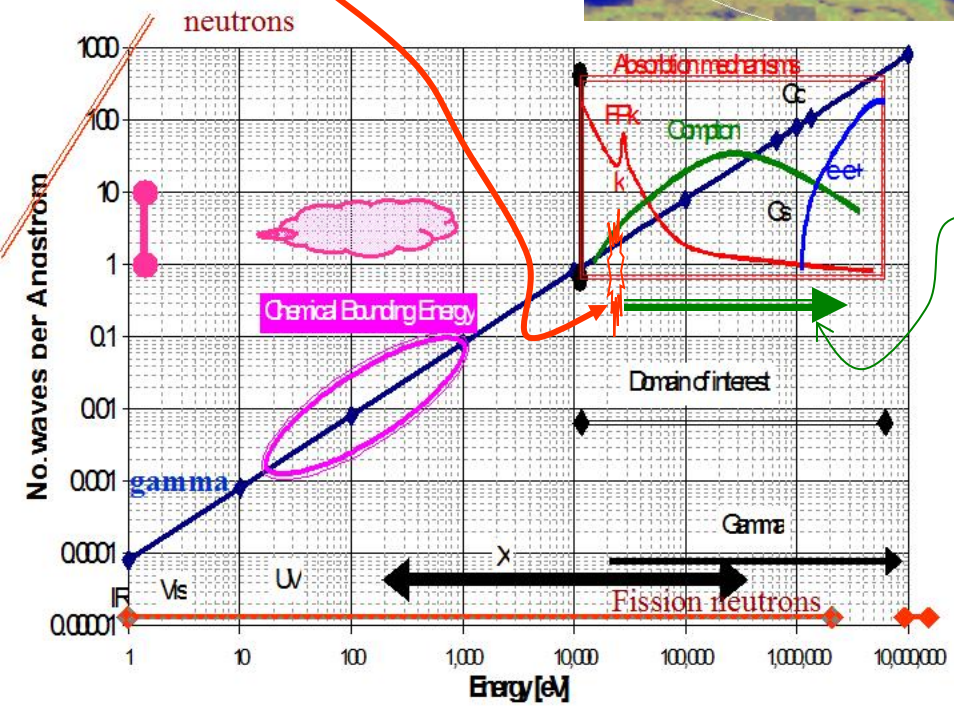




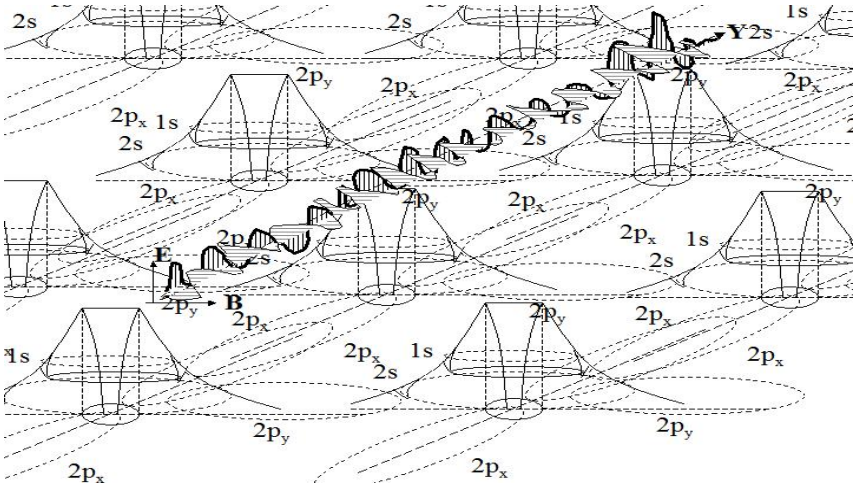




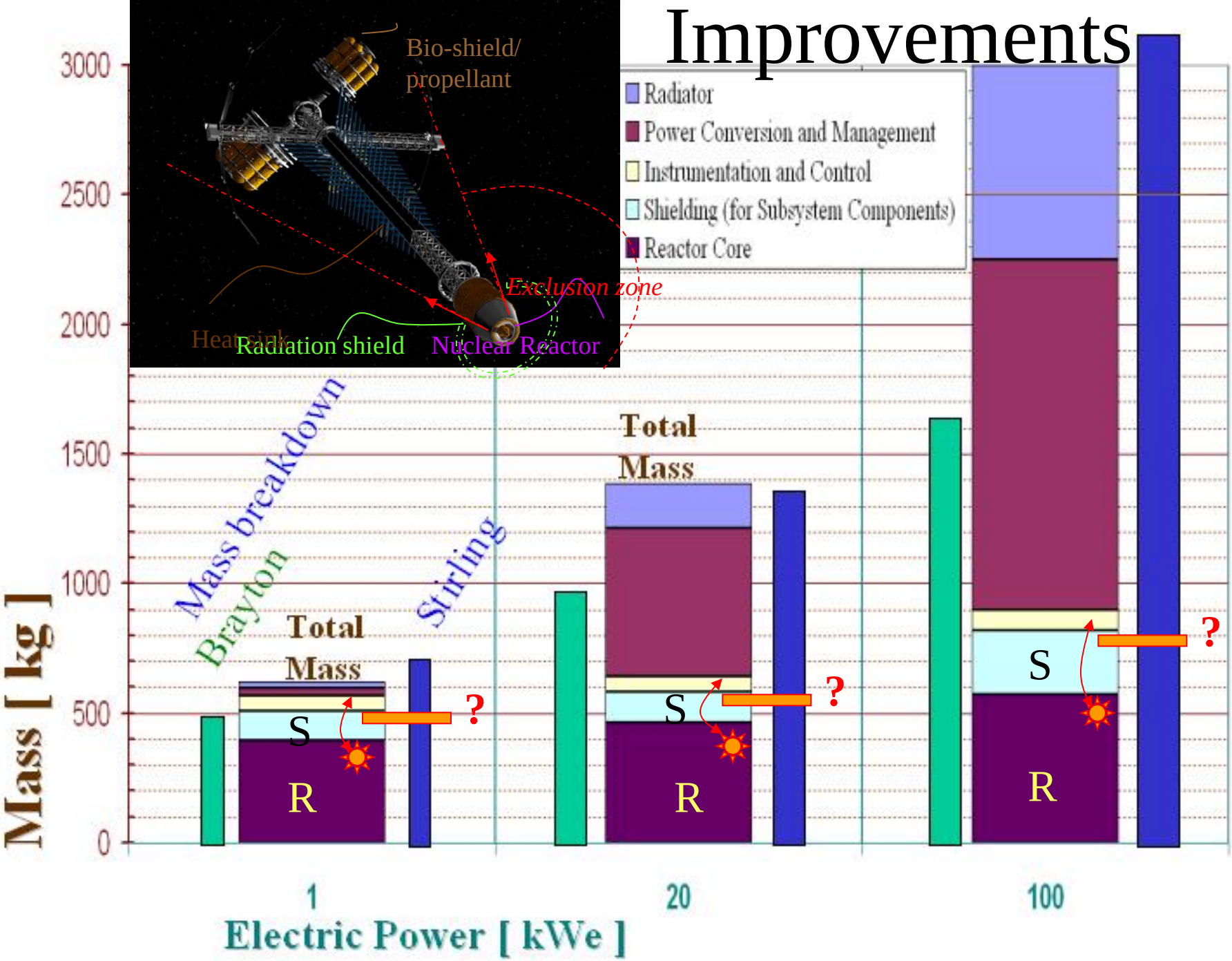
We are here!



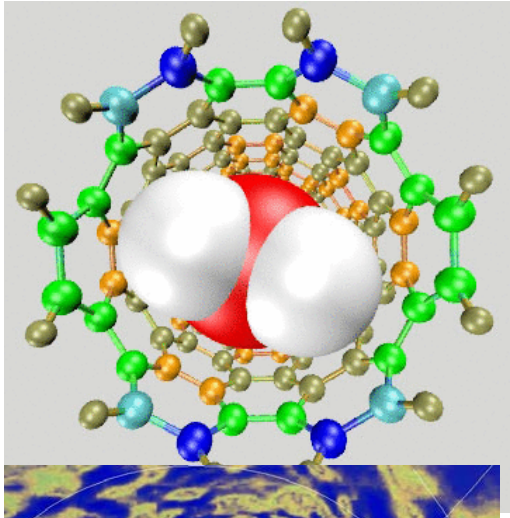
The research objective.



Improvements



Radiation nano-guiding structures



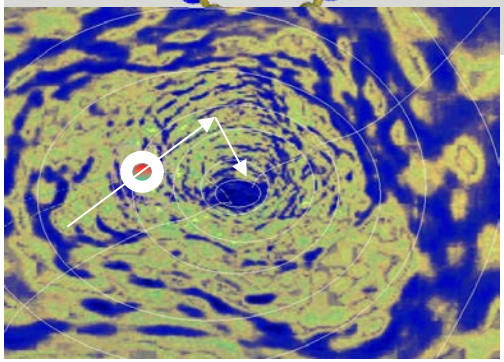
Shielding and Criticality Control

Shielding is bulky, and requires several ft to stop neutrons

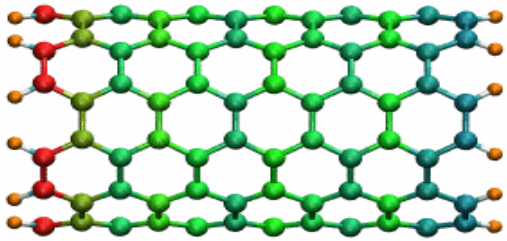
Even the reactor is small the shielding is BIG !

Solution:

Make a nano-structure that to guide inside and bend the radiation (neutrons, gamma) turning back towards the absorbing material.



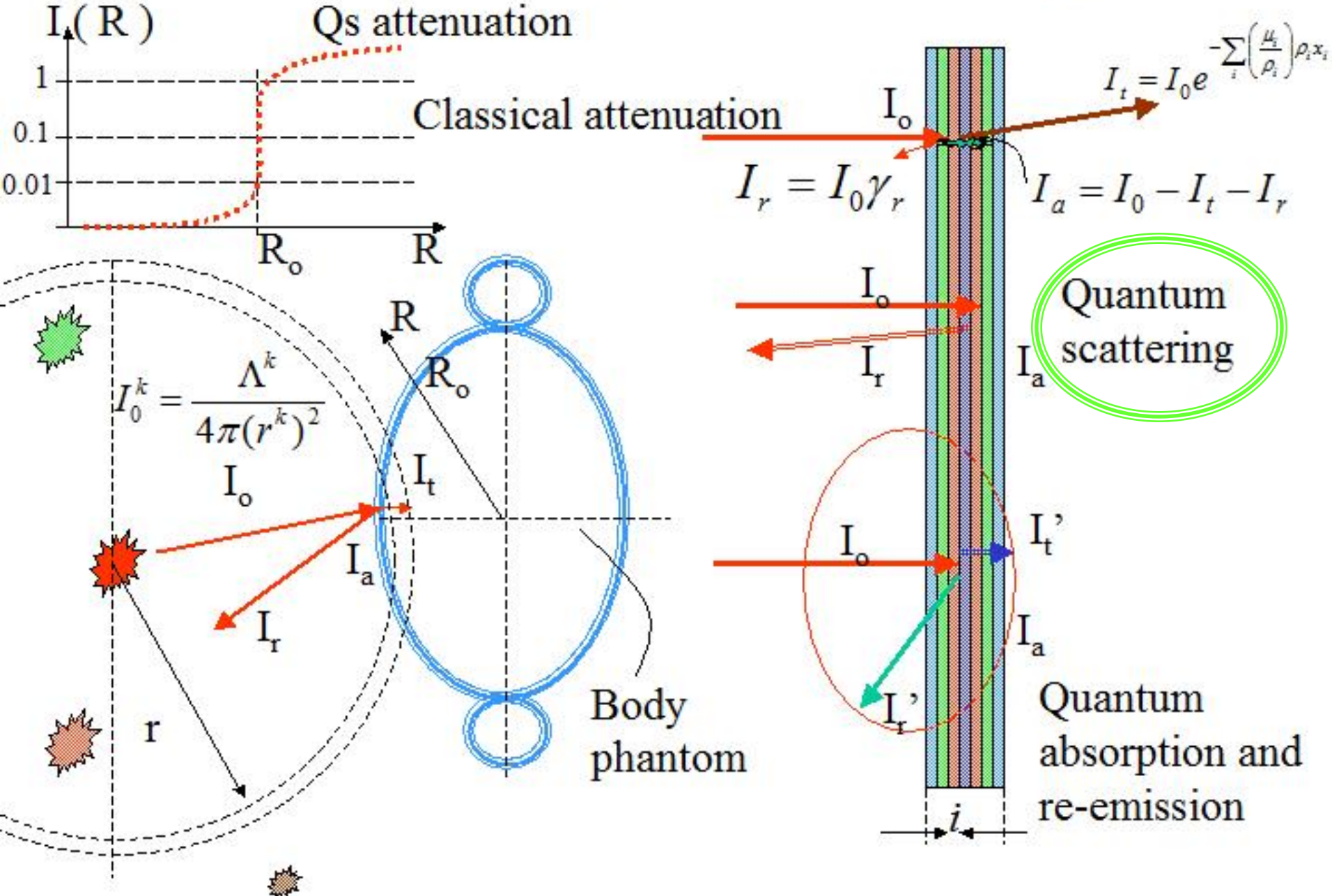
Nuclear reactor control is slow, based on absorption rods mechanically actuated using mainly the delayed neutrons that represent <0.5%

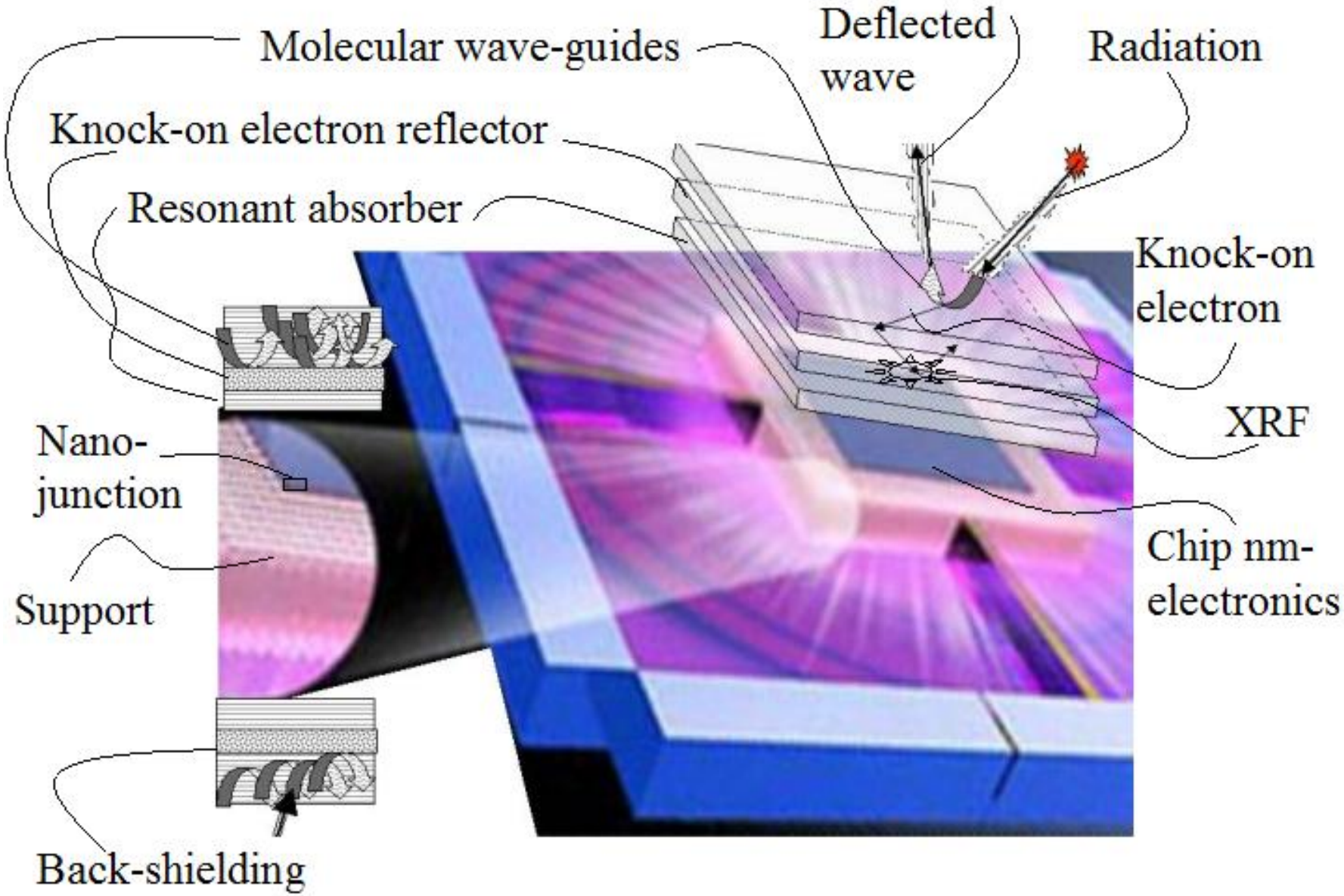


Solution:

Use nano-structure neutron guiding effect, adding an electro-sensitive material that may switch the pass, from turning back towards active zone or let pass along into an absorbent material.

The principle of shielding

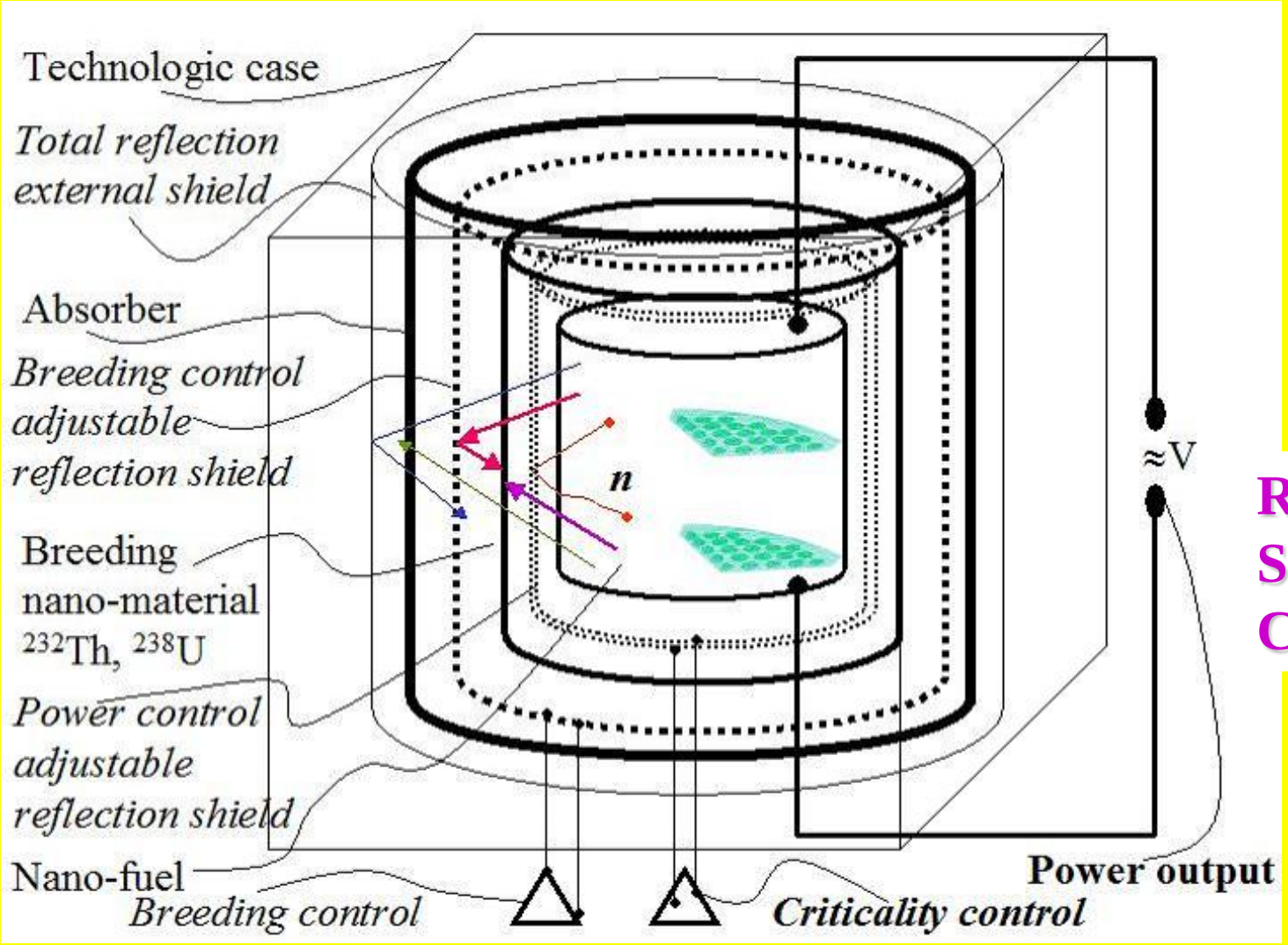




Nano-materials nuclear radiation back-gyration based shielding

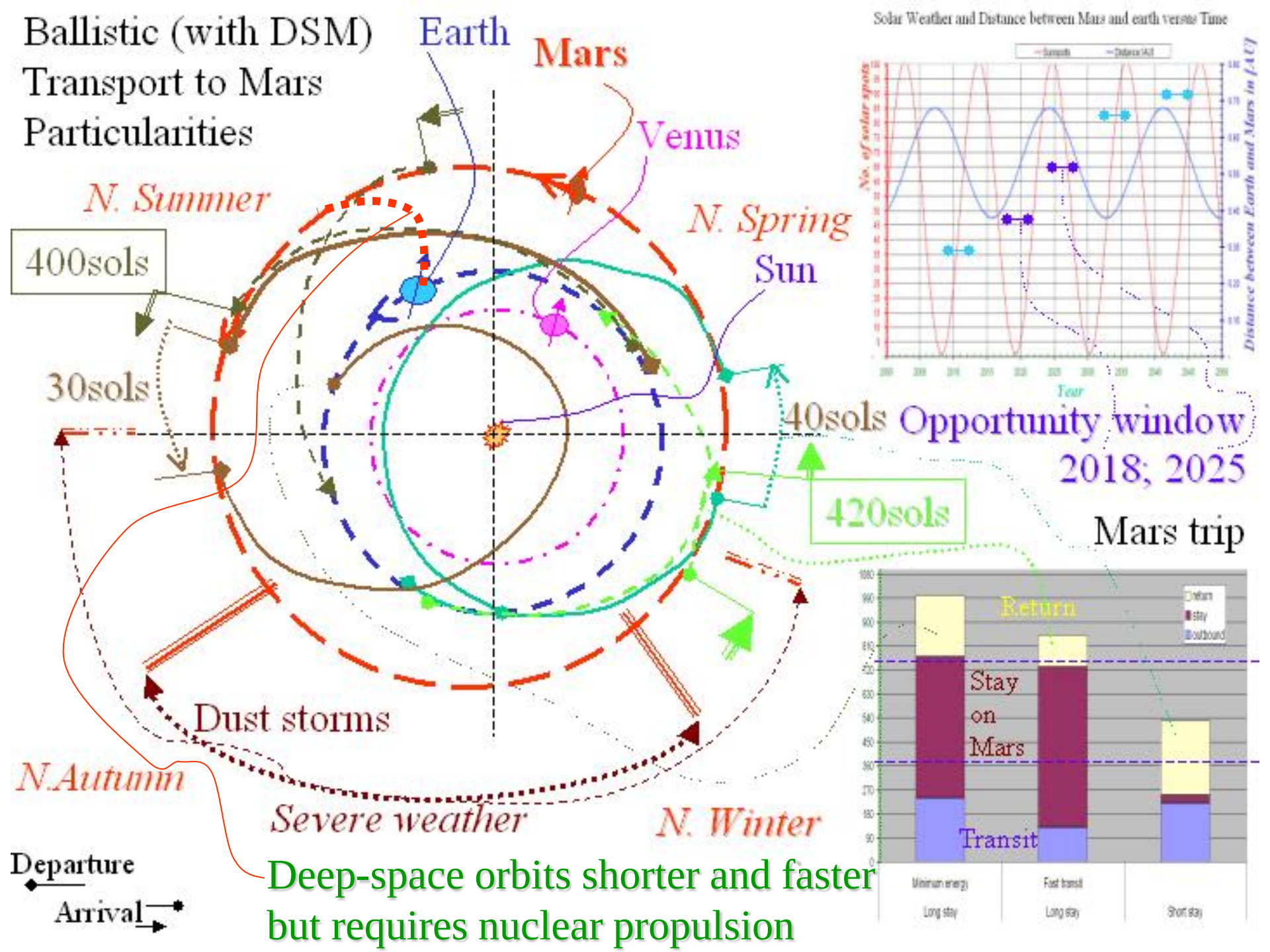
Applications

This is the goal: an electronically controlled compact nuclear reactor.



Radiation Detectors and Imagers

Radiation Shields and Concentrators


Ballistic (with DSM)
Transport to Mars
Particularities
Earth
Mars
Venus
N. Summer
N. Spring
Sun
400sols
30sols
40sols
420sols
Opportunity window
2018; 2025
Mars trip
Dust storms
N.Autumn
Severe weather
N. Winter
Departure
Arrival
Deep-space orbits shorter and faster
but requires nuclear propulsion
Solar Weather and Distance between Mars and earth versus Time
Year
Return
Stay
on
Mars
Transit
Minimum energy
Long stay
Fast transit
Long stay
Short stay

Thank you!

Questions?