HEP

04 June 2010

Applications in Medicine

Past and Future

Paul M. DeLuca, Jr.
Provost & Vice Chancellor for Academic Affairs
UW-Madison

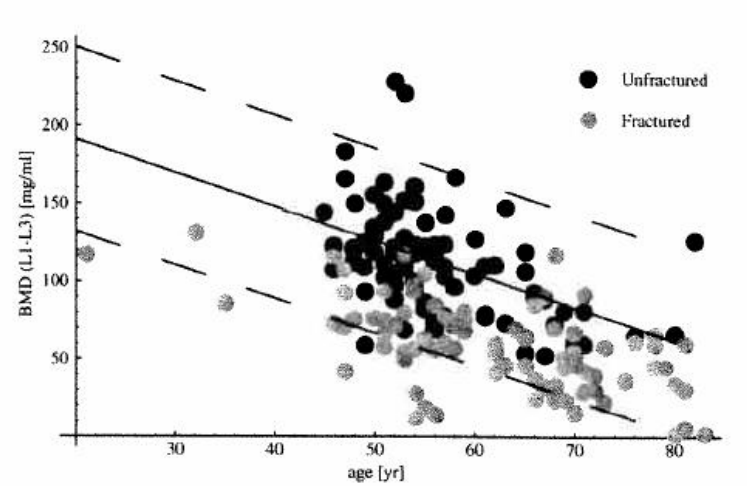
Societal Impact: Medical Imaging Digital Subtraction Angiography

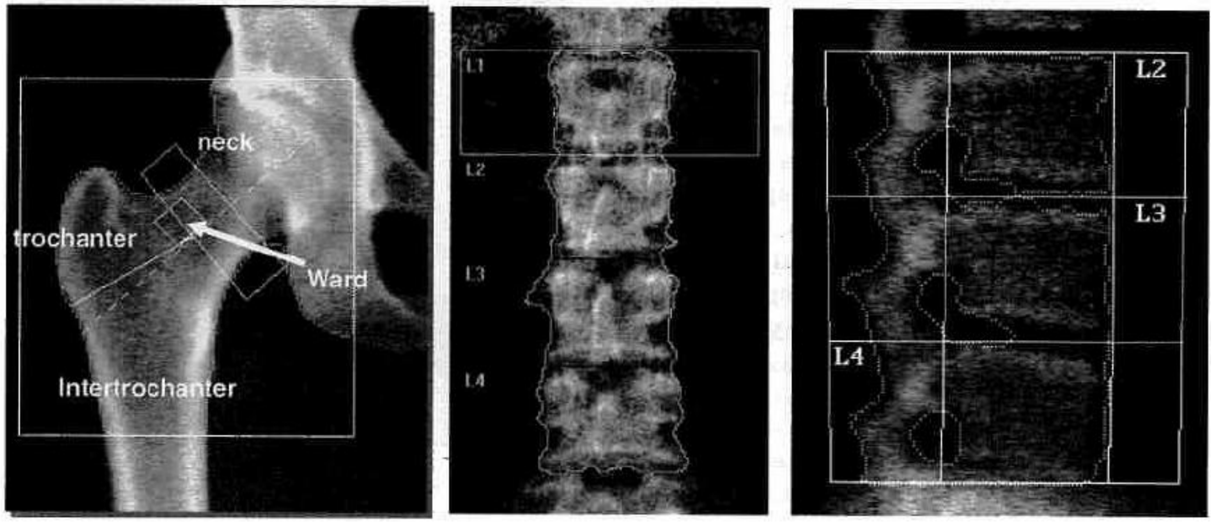
Charles Mistretta
Prof of Medical Physics

Kidney transplant and a stent placement.

Societal Impact: Medical Imaging

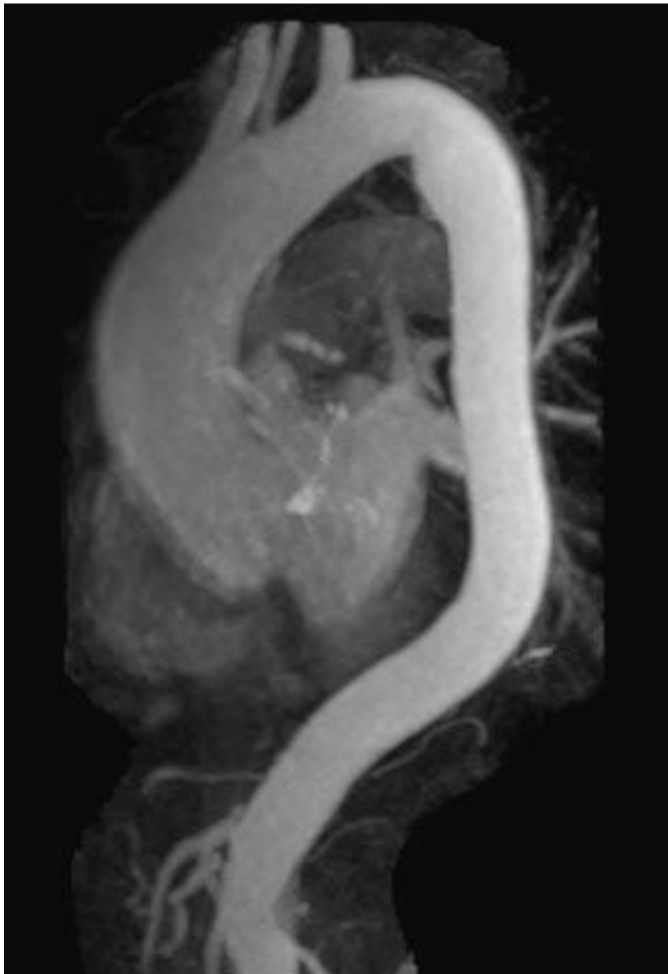
Osteoporosis and bone mineral densitometry

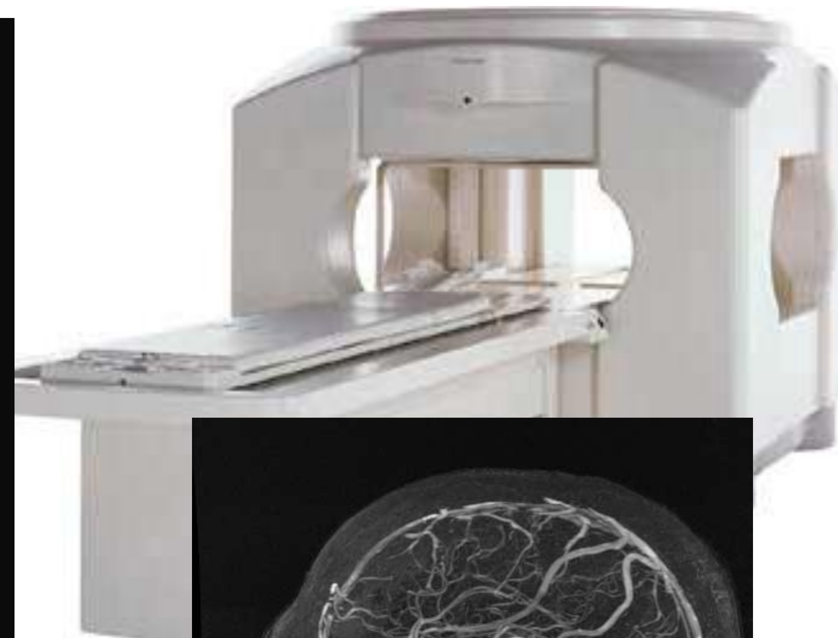


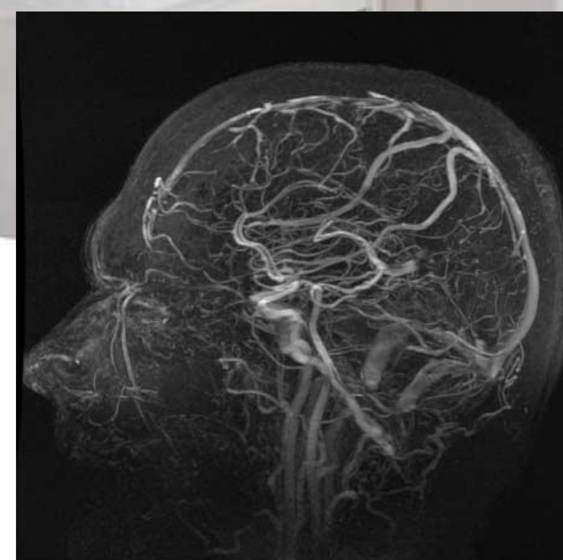


ACRU Report 81, 2009

Societal Impact: Medical Imaging
MRI Flow Contrast Angiography

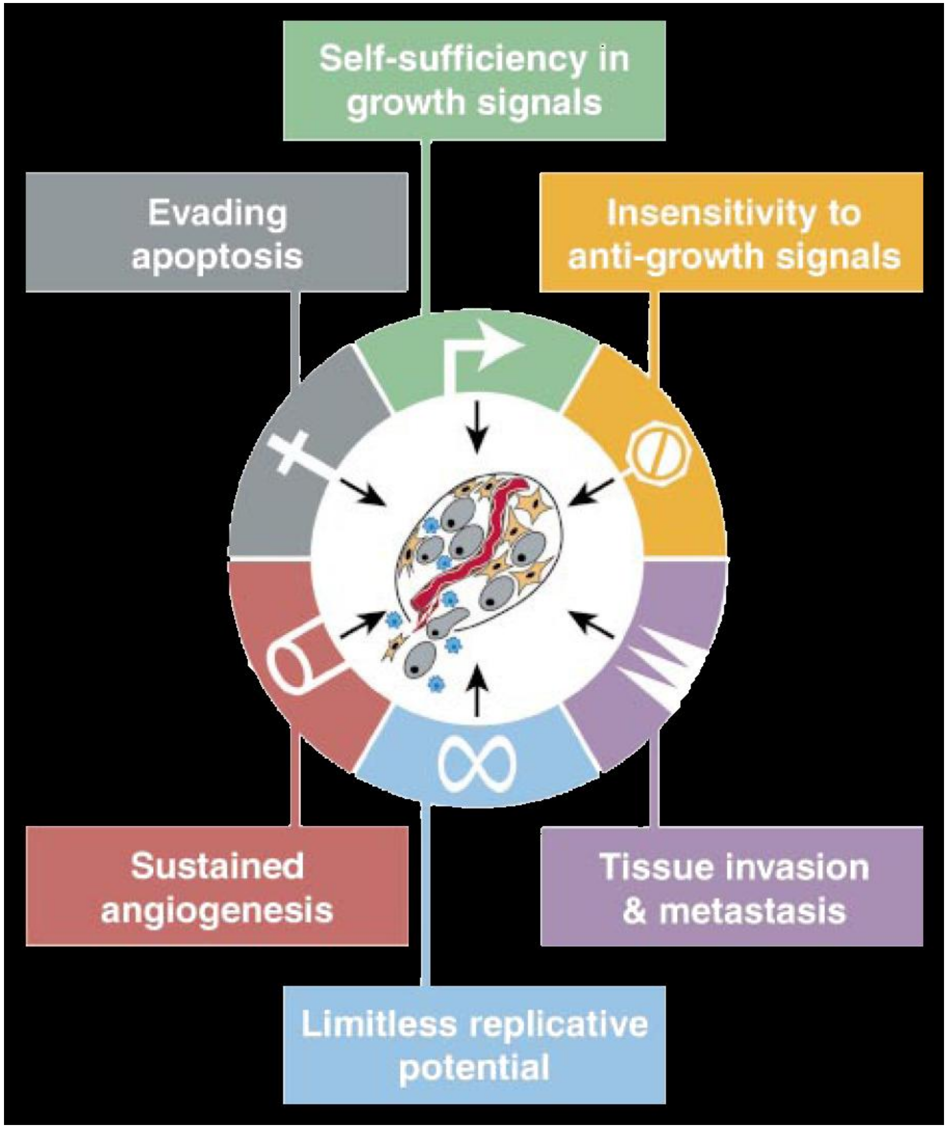






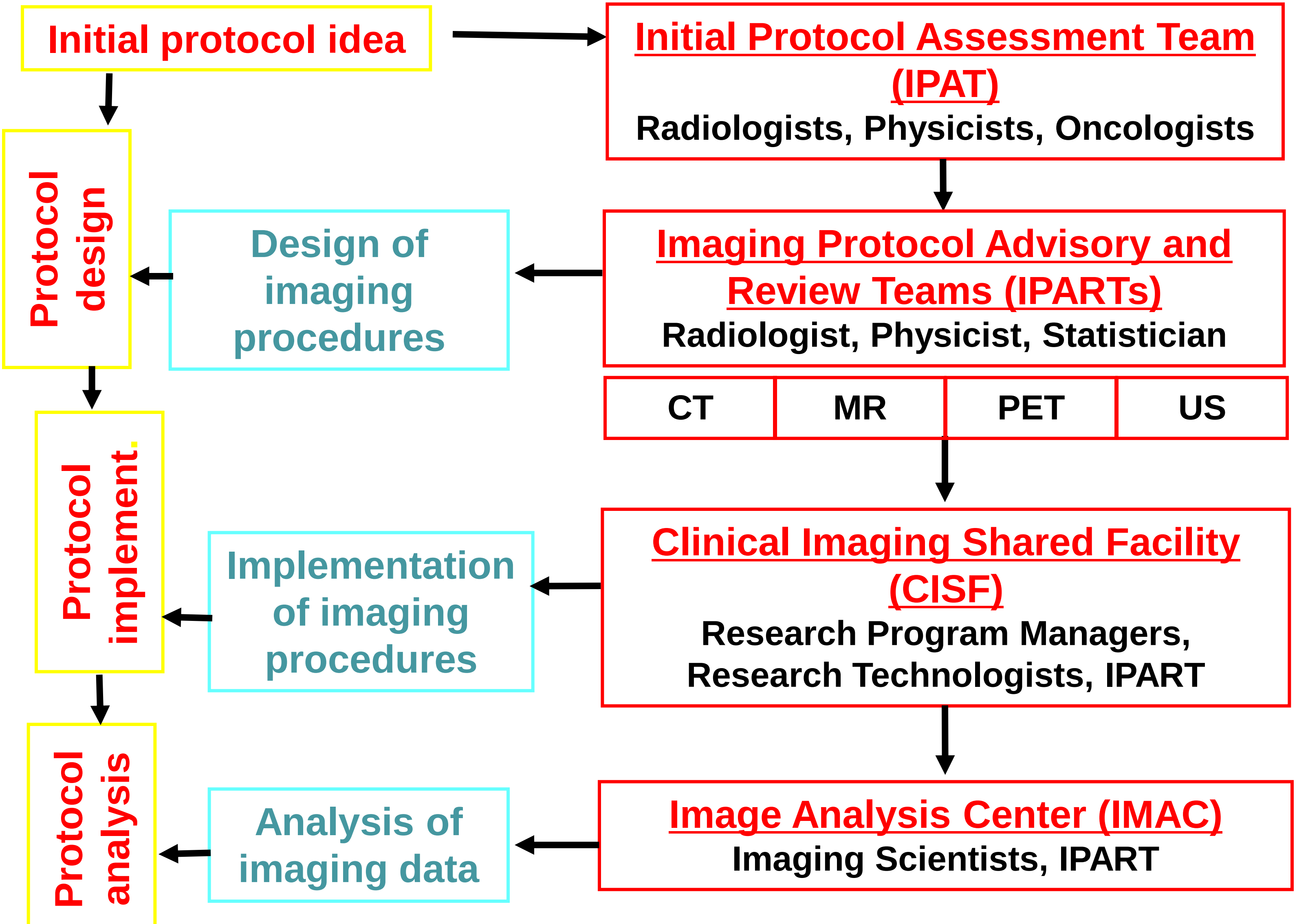
Imagers: ACR RSNA

Molecular imaging in oncology – targeting hallmarks of cancer



Hanahan, Cell, 100, (2000), 57

UW-IRAT

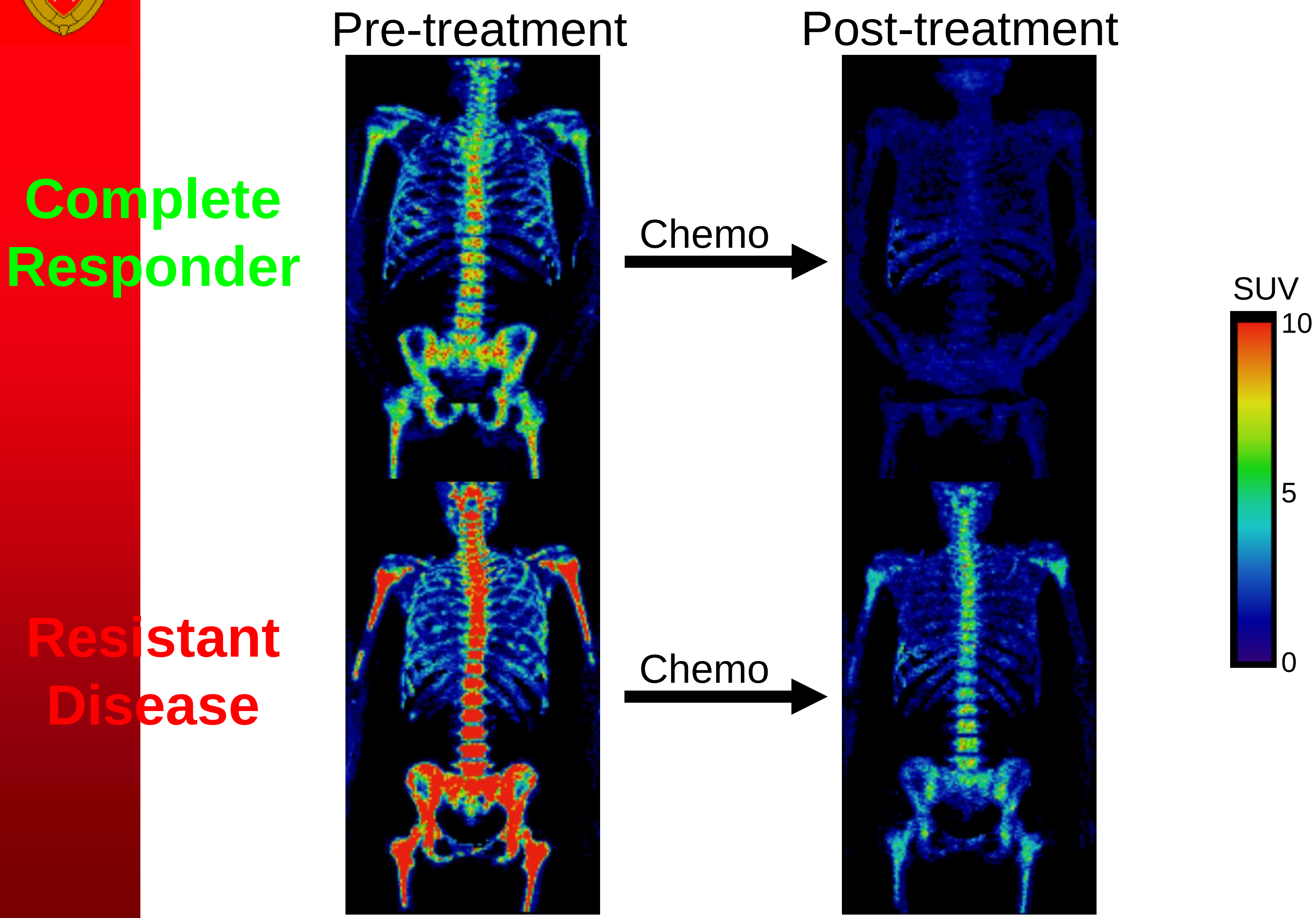

Initial protocol idea
Initial Protocol Assessment Team (IPAT)
Radiologists, Physicists, Oncologists
Protocol design
Design of imaging procedures
Imaging Protocol Advisory and Review Teams (IPARTs)
Radiologist, Physicist, Statistician
CT
MR
PET
US
Protocol implement.
Implementation of imaging procedures
Clinical Imaging Shared Facility (CISF)
Research Program Managers, Research Technologists, IPART
Protocol analysis
Analysis of imaging data
Image Analysis Center (IMAC)
Imaging Scientists, IPART

Acute myeloid leukemia (AML)

- **Standard treatment of AML**: induction chemotherapy for 7 days, bone marrow aspirate and biopsy at 2 wks, repeat chemotherapy if needed

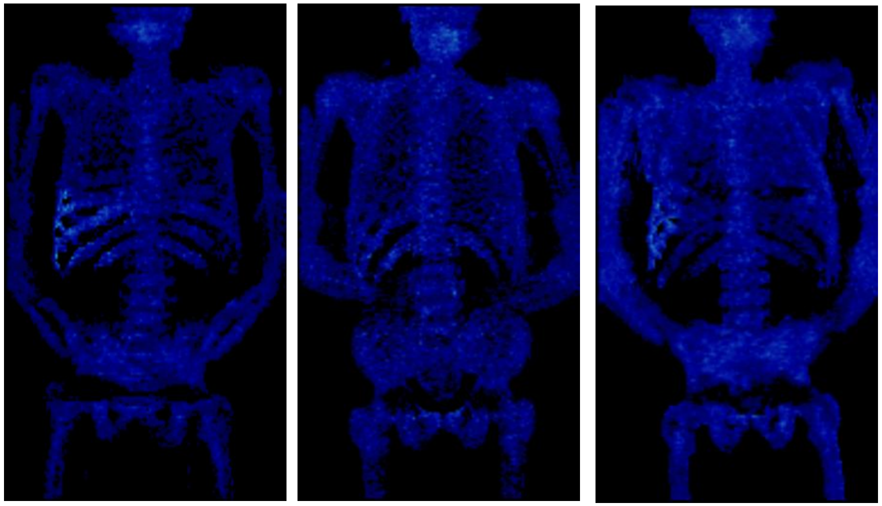
- The results of the bone marrow biopsy are often **difficult to interpret** and the **predictive power is poor**
- **Use imaging as a predictive biomarker to segregate patients into high and low risk groups**

FLT PET response



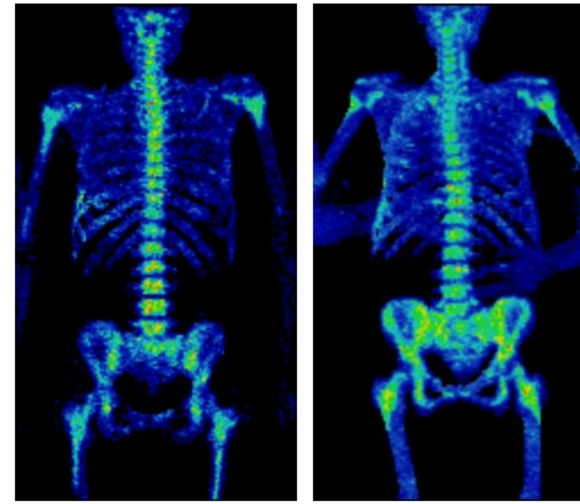
Timing of the scan does not matter

Complete Remission
(aplastic, day 14)



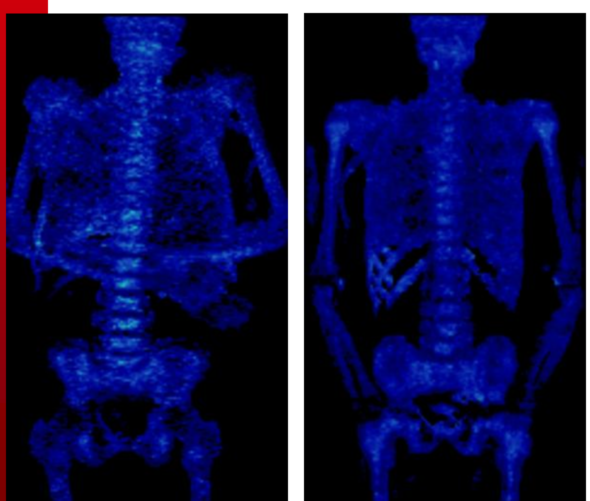
post-therapy **day 6** **day 4**

Resistant Disease



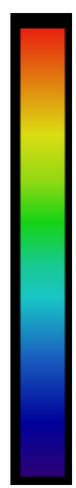
post-therapy **day 2**

Complete Remission
(residual disease, day 14)



day 5 **day 2**

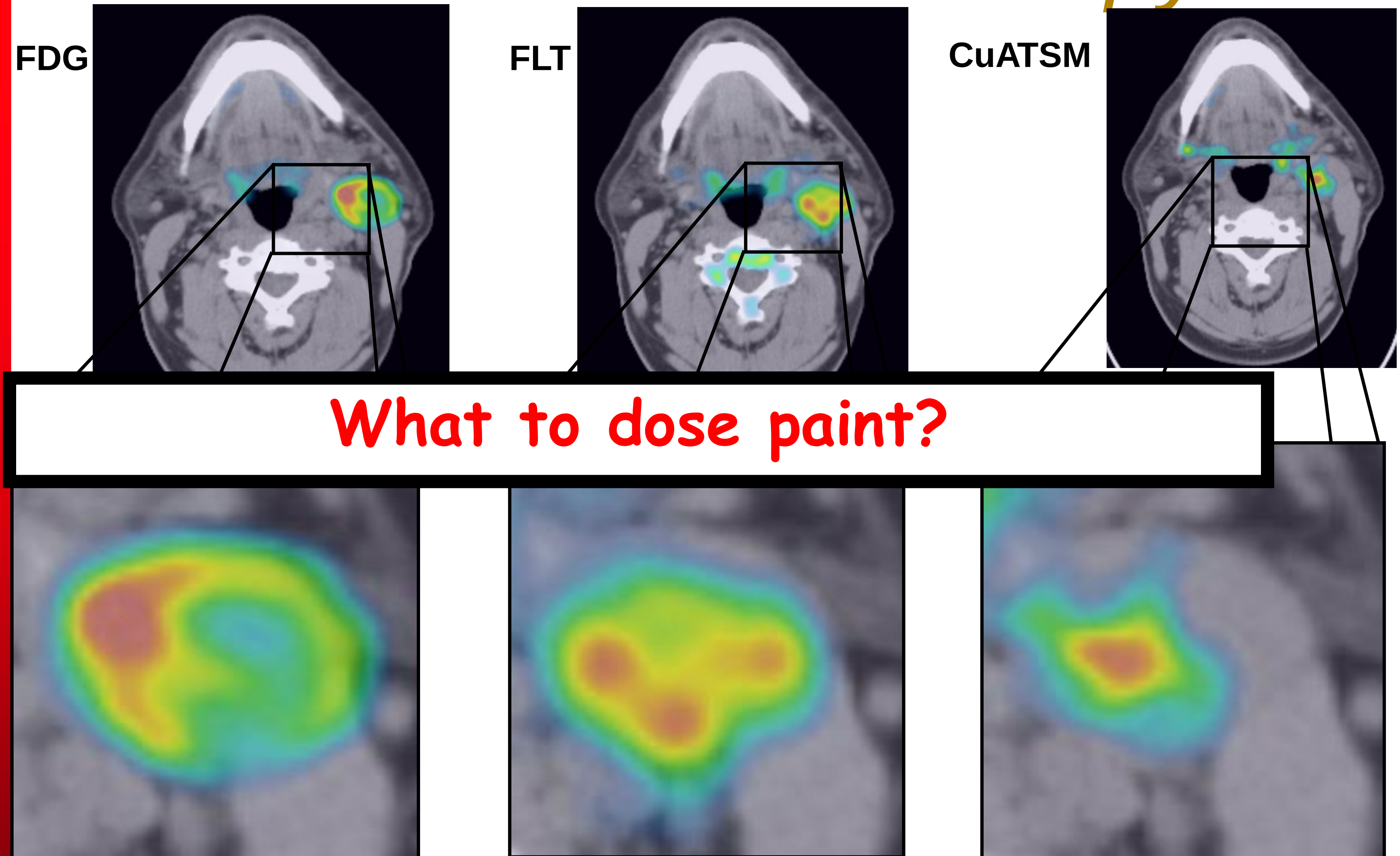
SUV



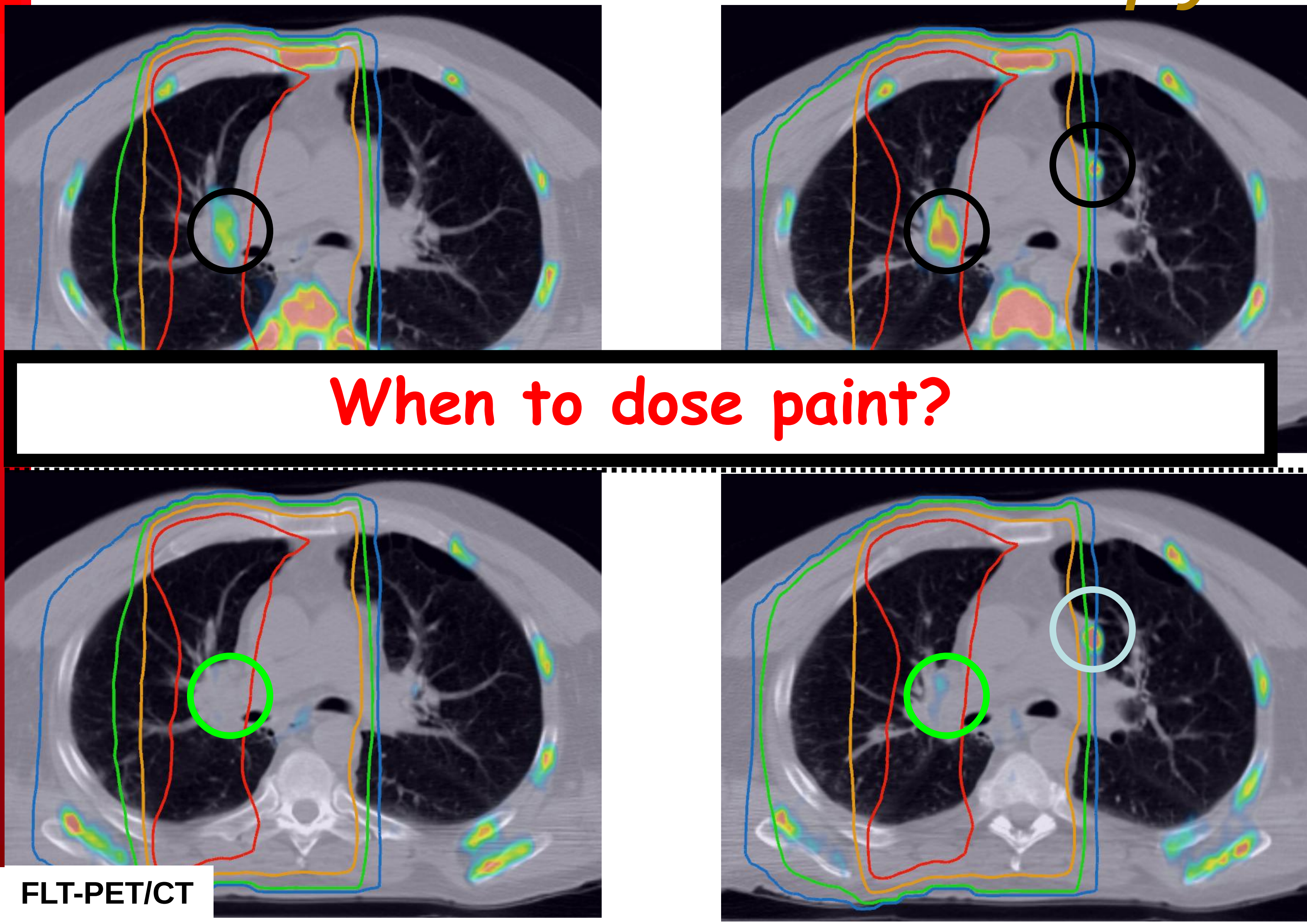
	SUV_{mean}	SUV_{max}	Coef. Of Var
Complete Remission	0.81 ± 0.03	3.6 ± 0.4	0.33 ± 0.02
Resistant Disease	1.60 ± 0.14	11.4 ± 0.8	0.71 ± 0.04

$p < 0.001$

Personalization of therapy



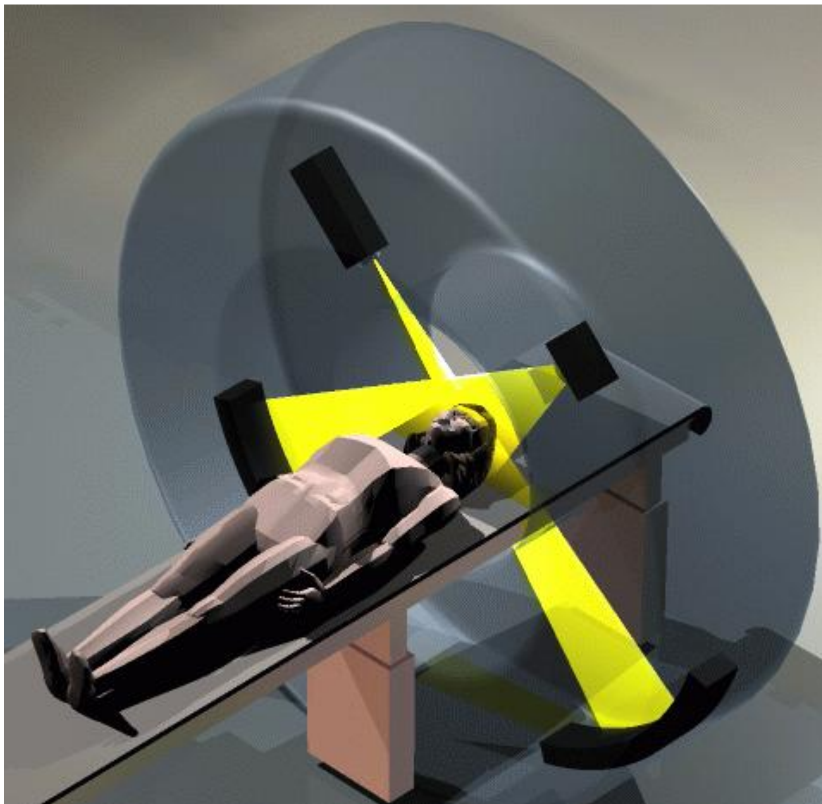
Personalization of therapy



Pre-treatment

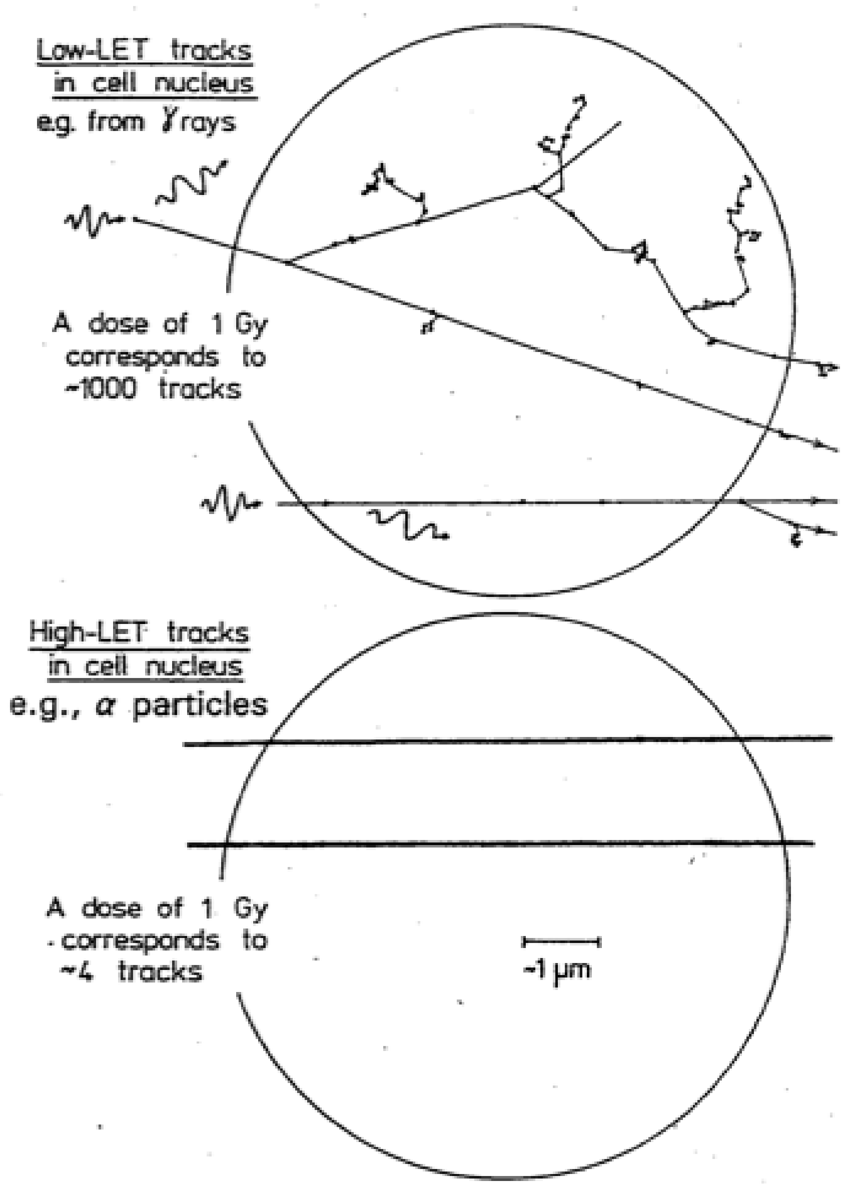
Mid-treatment
(1 wk of XRT)

Societal Impact: Medical Imaging Tomotherapy

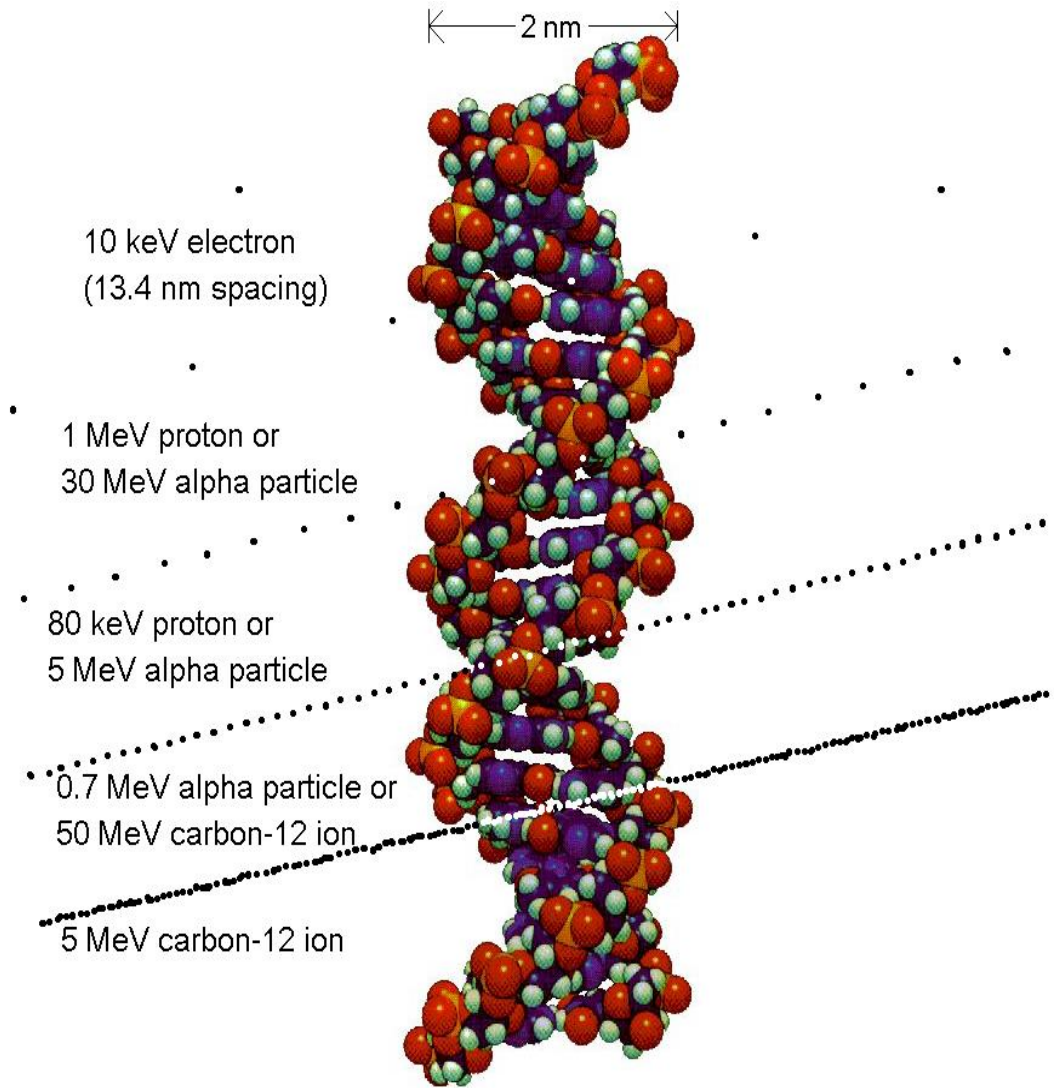


Photos: http://www.psl.wisc.edu/projects/large/tomo

Microscopic Energy Deposition



Direct Damage to DNA

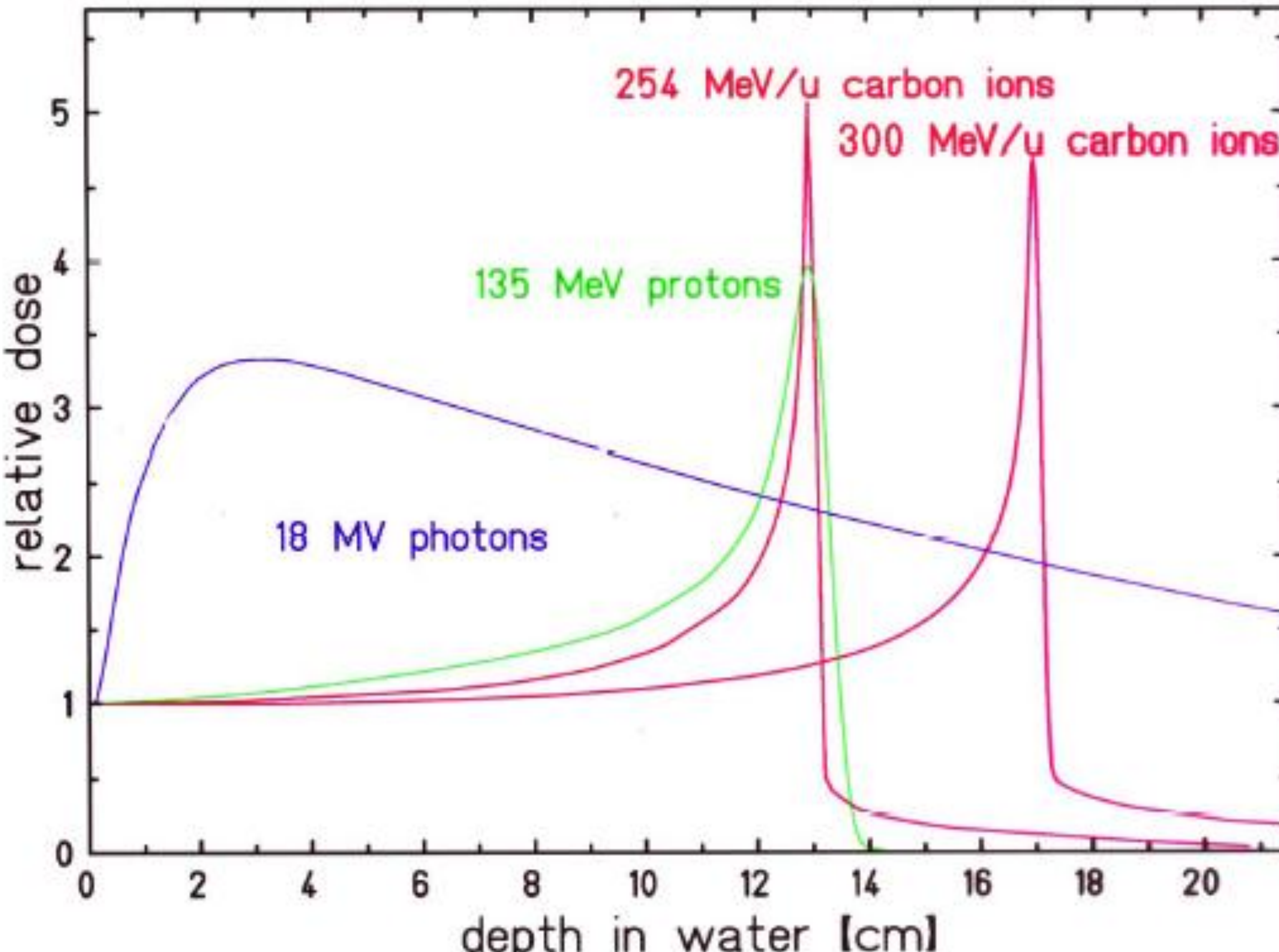


Genius Starts Early!

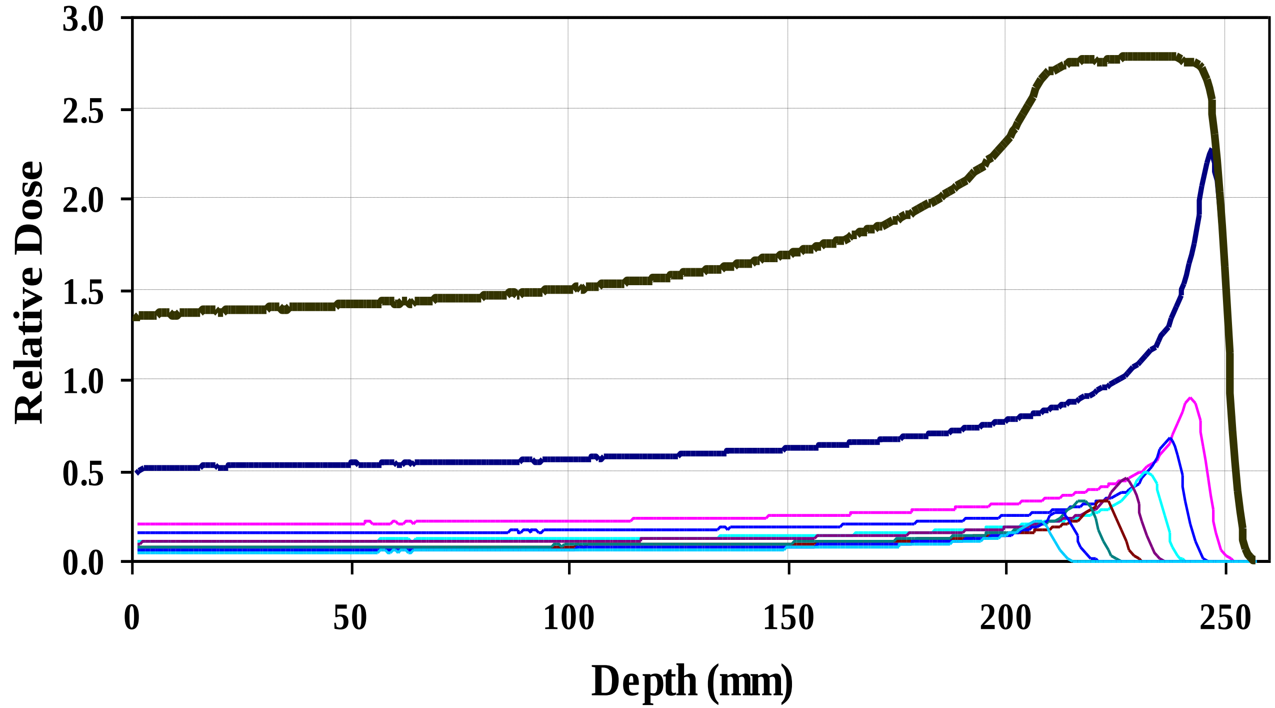
Radiological Use of Fast Protons
Robert R. Wilson
Research Laboratory of Physics, Harvard University
Cambridge, Massachusetts
(Radiology, 47 (1946) pp 487-491)

- **It must have occurred to many people that the particles themselves now become of considerable therapeutic interest.**
- **… specific ionization or dose is many times less where the proton enters the tissue than it is in the last centimeter …**
- **These properties make it possible to irradiate intensely a strictly localized region…**
- **Thus the biological effects near the end of the range will be considerably enhanced due to greater specific ionization…**
- **It will be possible to treat a volume as small as 1 c.c. anywhere in the body and to give that volume several times the dose of any neighboring tissue.**
- **In treating large volumes … accomplished by interposing a rotating wheel of variable thickness, corresponding to the tumor thickness, between the source and patient.**
- **Heavier nuclei, such as very energetic carbon atoms, may eventually become therapeutically practical.**

Depth dose distribution of various radiation modalities

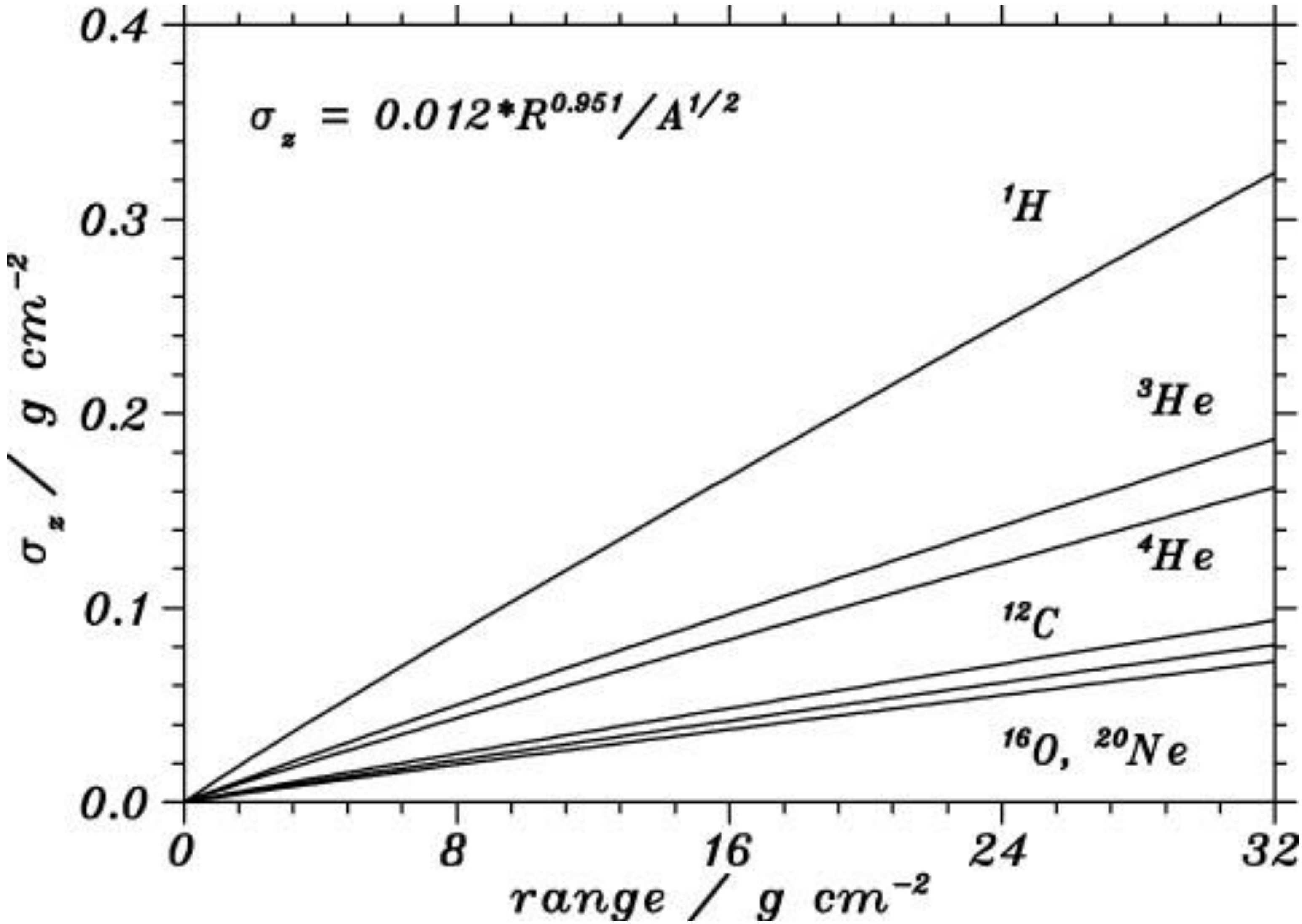


Spread-out Bragg peak

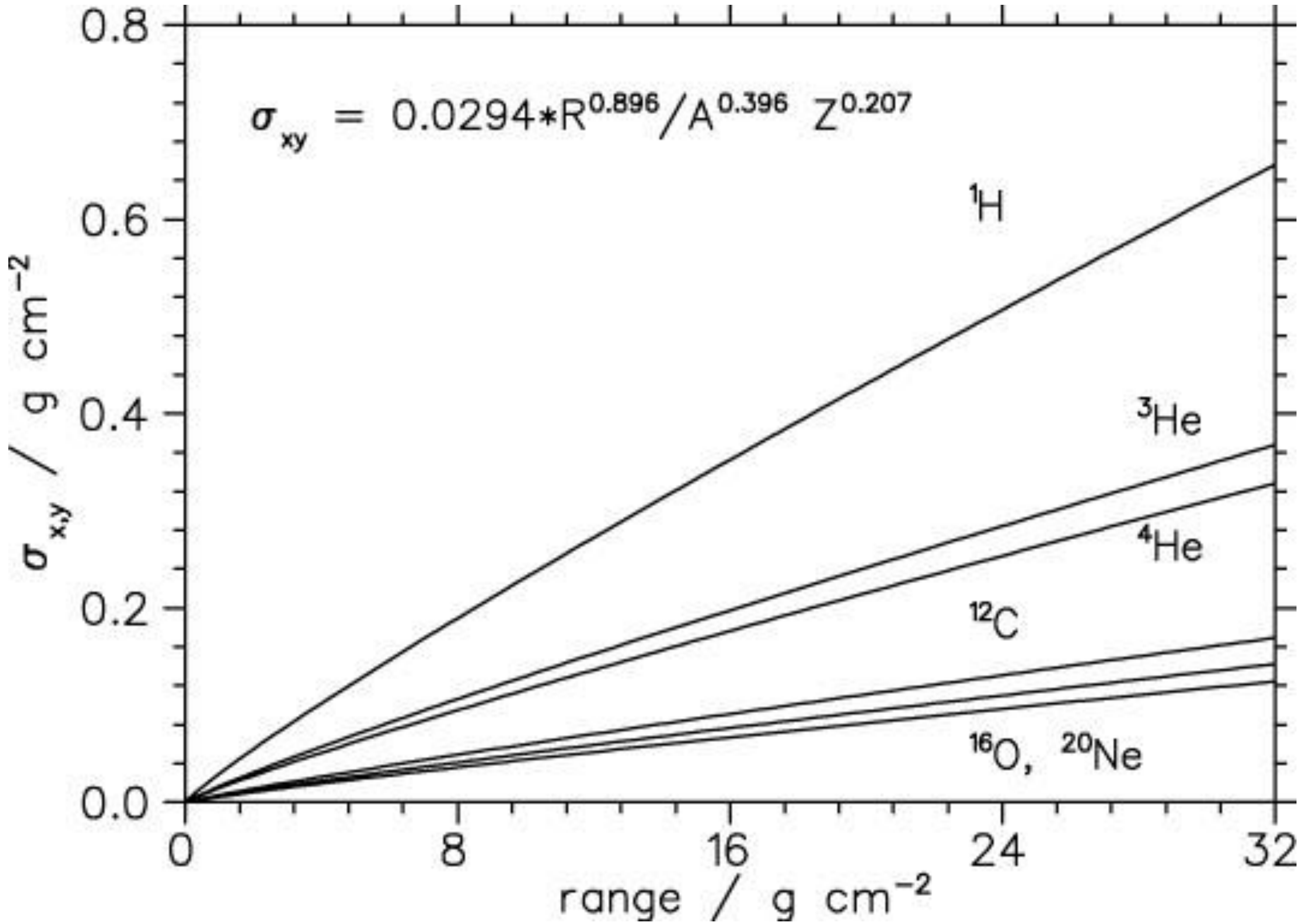


Adding together Bragg peaks from multiple beam energies with independent weights can generate a flat region at the tumor at the expense of increasing the entrance dose

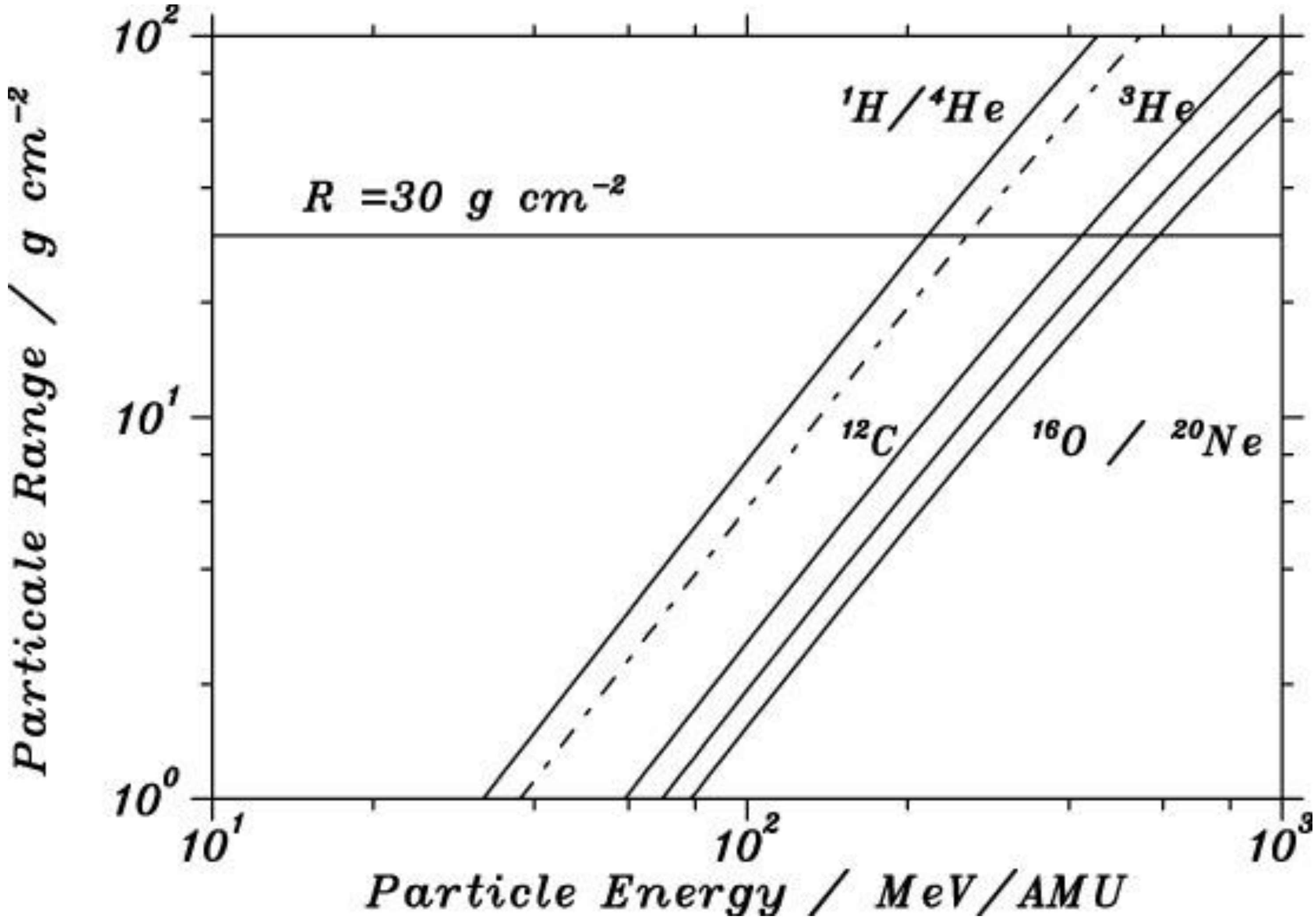
Range Scattering with Penetration in Water



Lateral Scattering with Penetration in Water

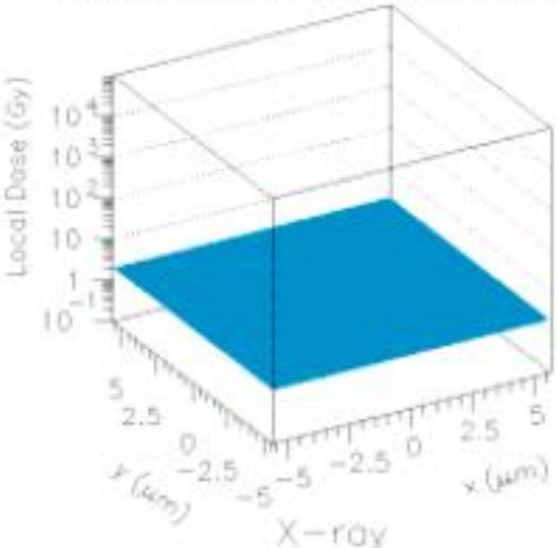


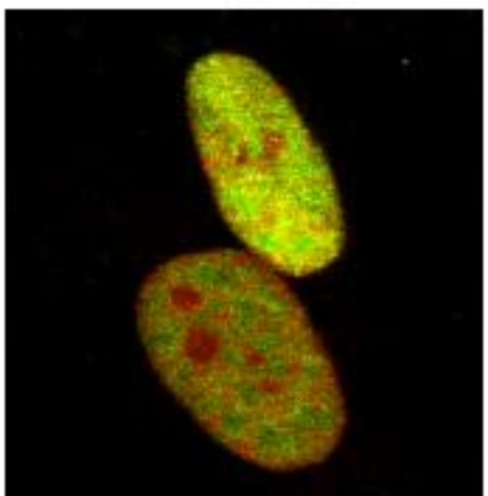
Particle Range versus Particle Energy Scaled From Water



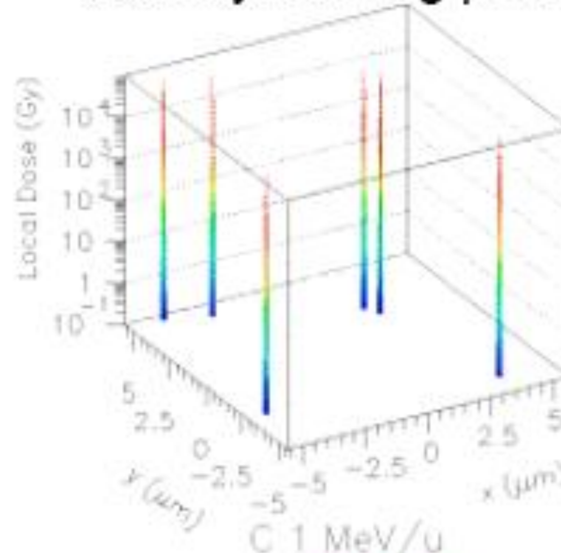
Dose distribution in micrometer scale

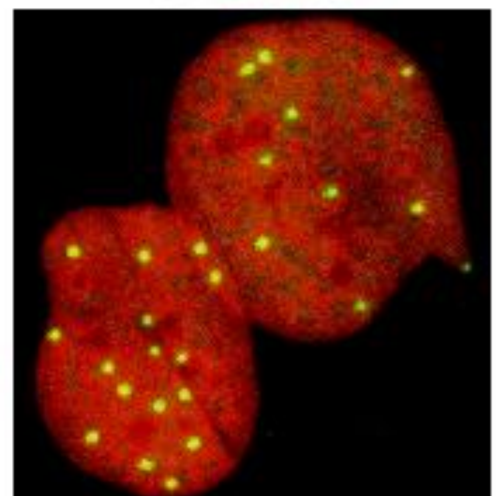
sparsely ionizing photons





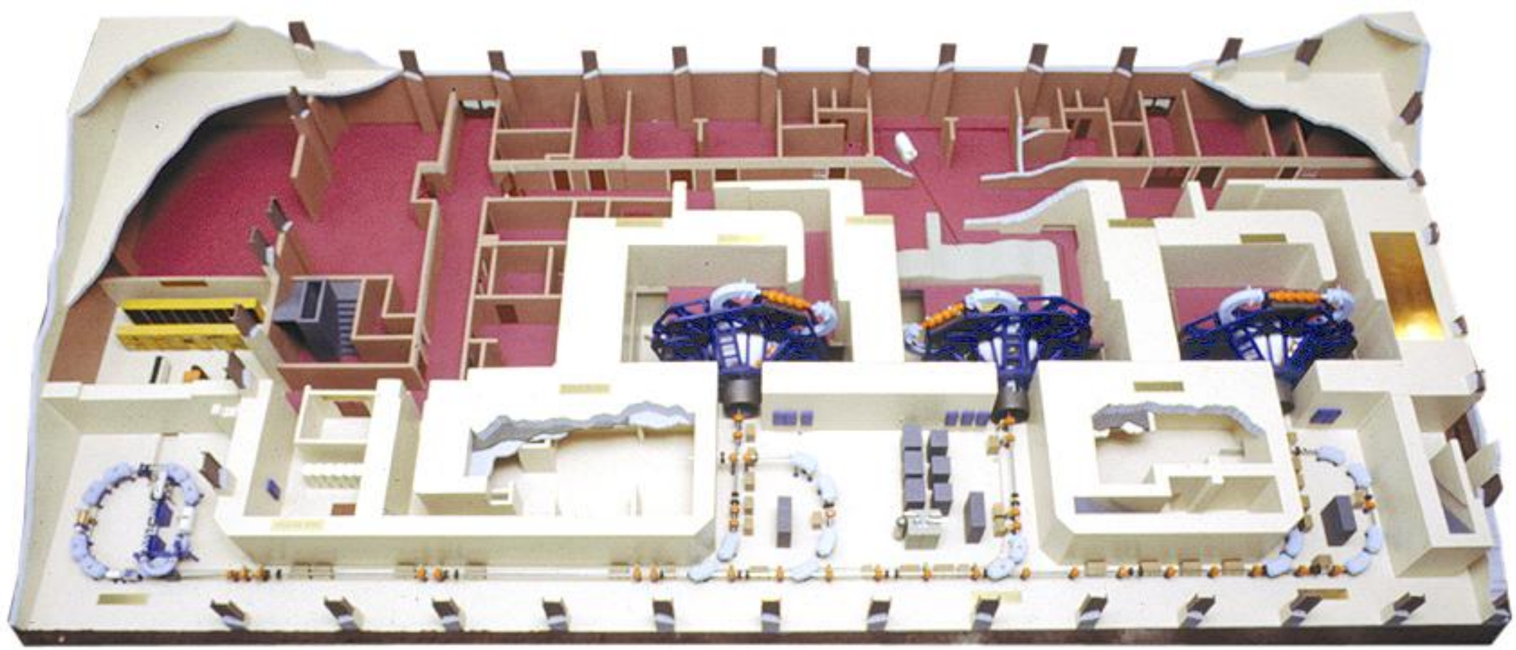
densely ionizing particles





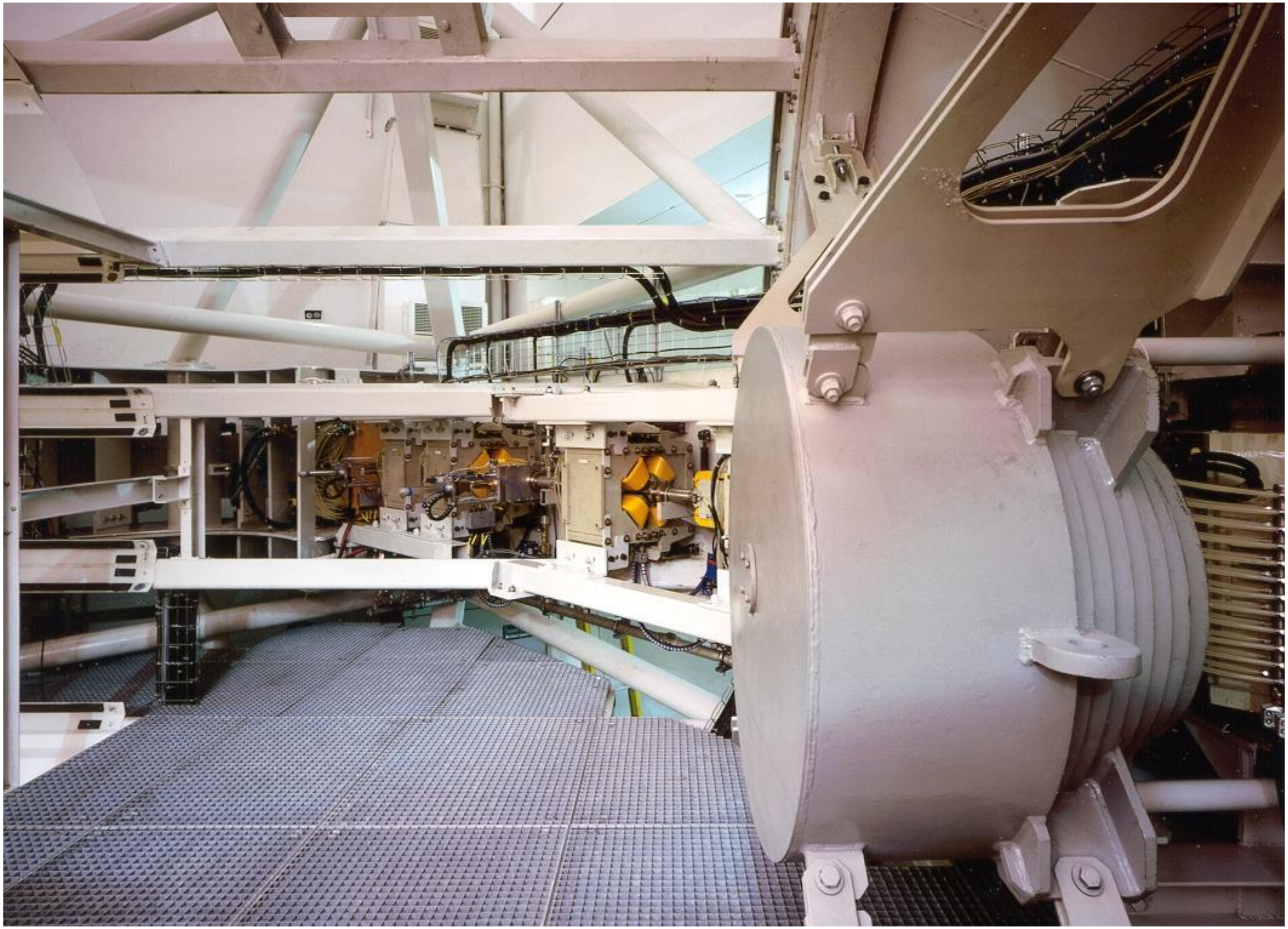
LLUMC Facility Layout

The Loma Linda University Medical Center
Proton Treatment Center



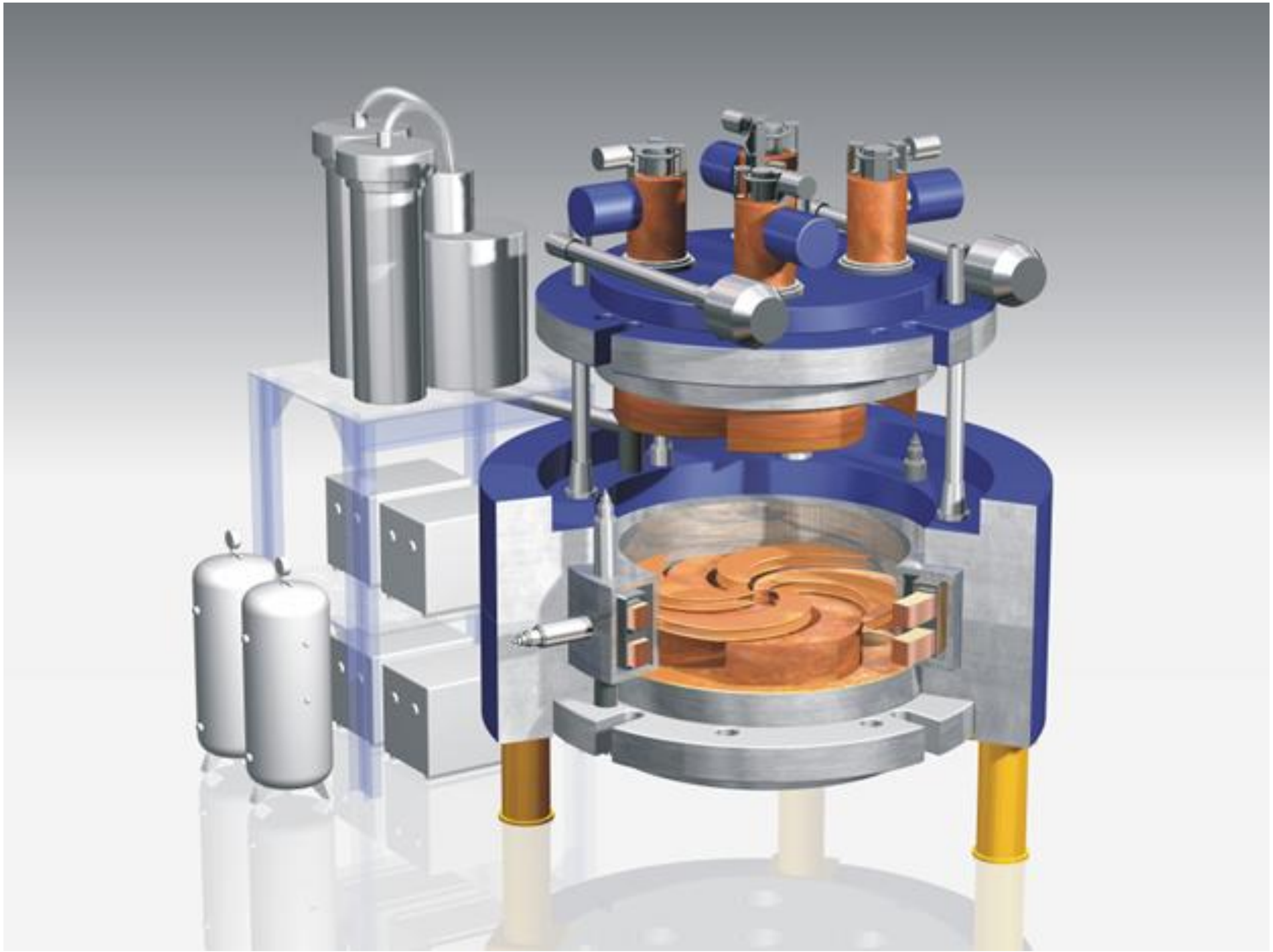
Slide courtesy of B. Arjomandy, LLUMC

IBA Gantry at NPTC



NPTC Treatment Room

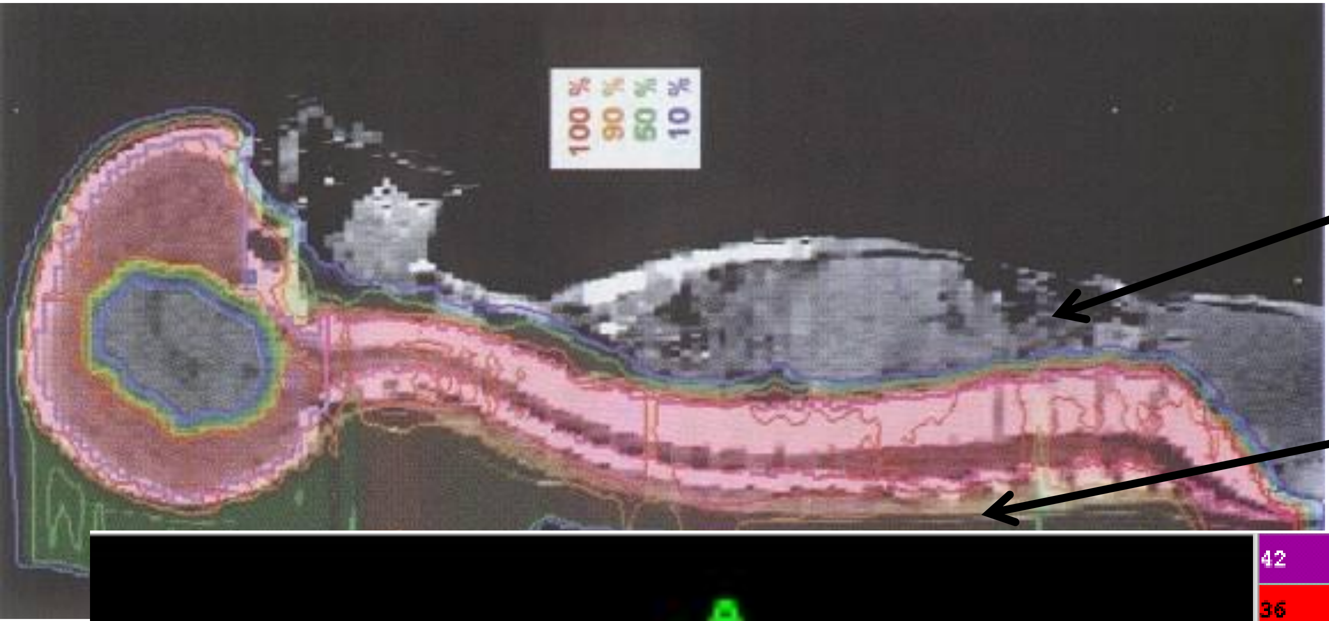
Superconducting Cyclotron for Paul Scherrer Institute (PSI), Villigen, Switzerland



Beam Transfer Line

HIT Heidelberg Ion-beam Therapy
GSI Technology
Siemens Tech Transfer

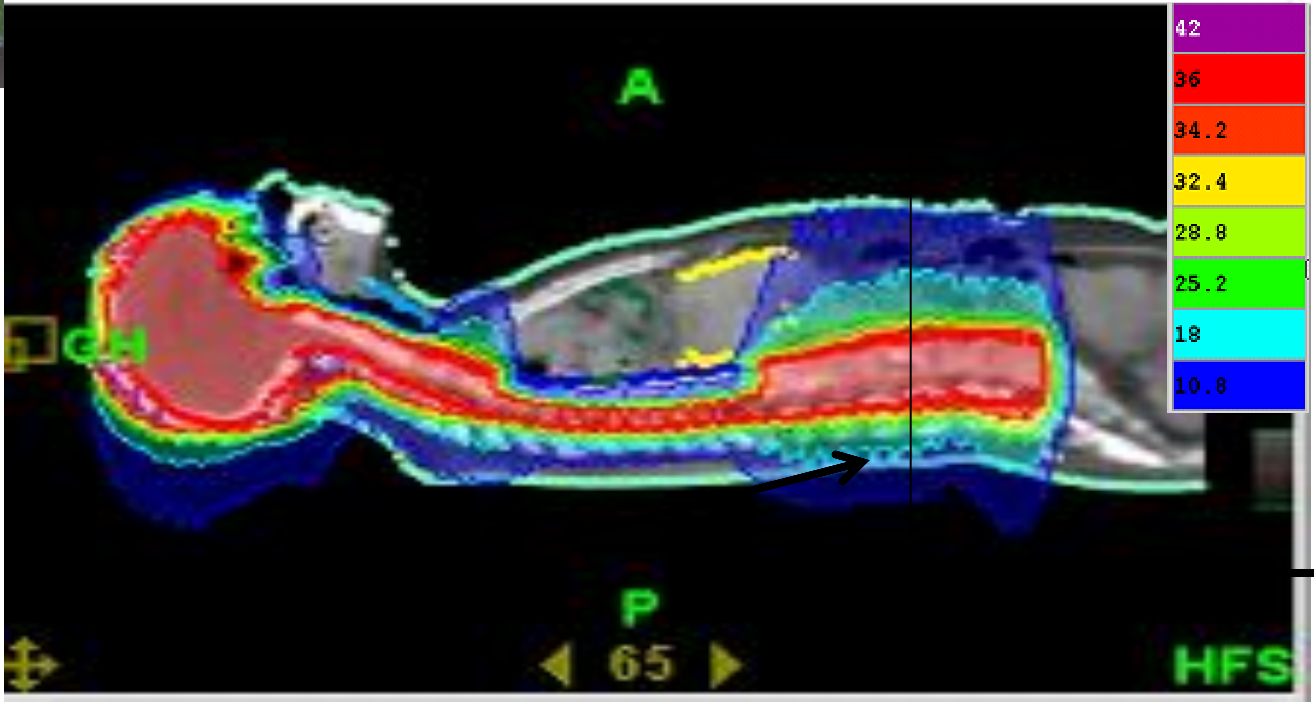
Dose Distribution Comparison



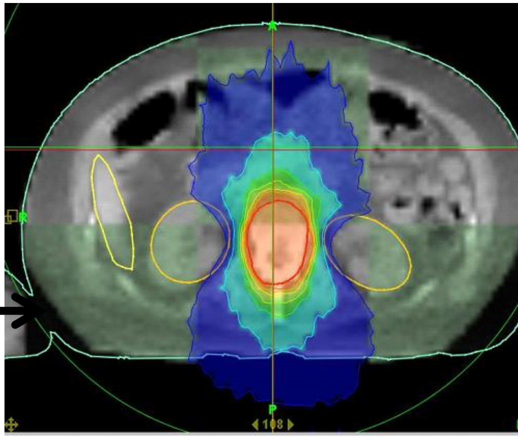
Protons

Low integral Dose.

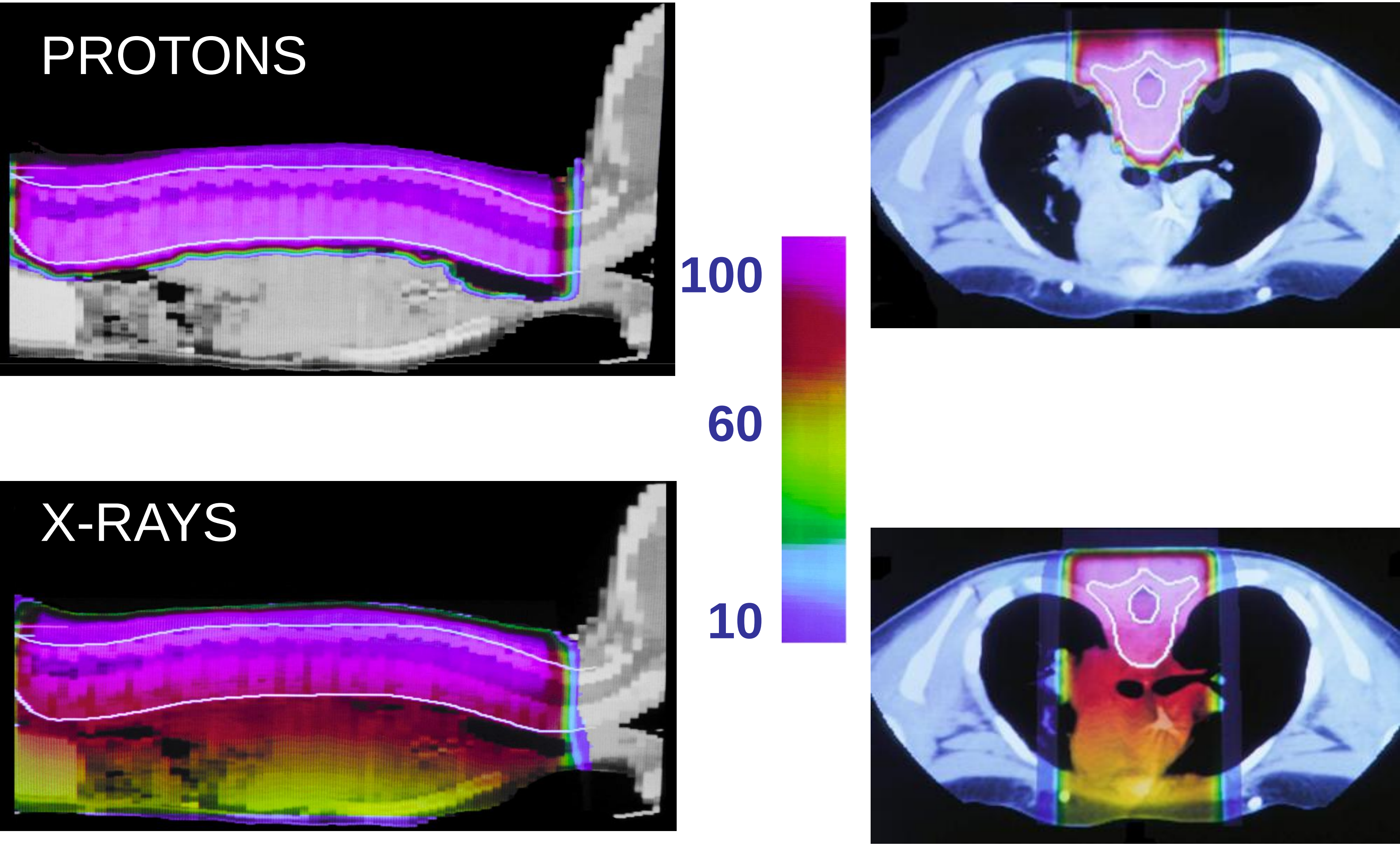
90% line



Photons (Tomotherapy)



MEDULLOBLASTOMA

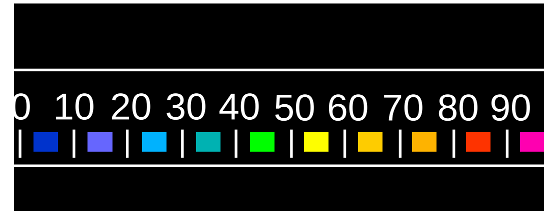


Slide courtesy of A. Smith, MGH

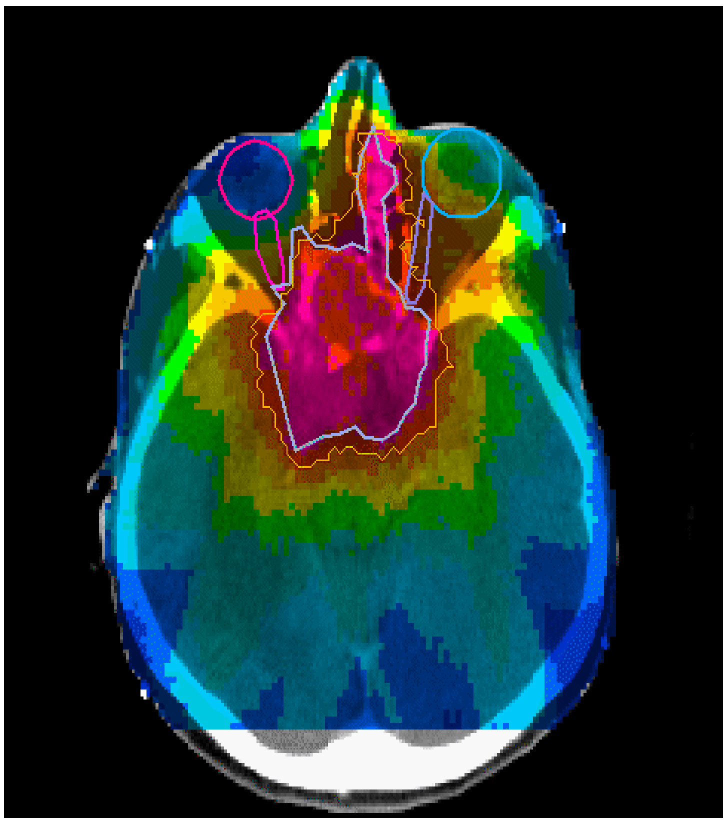
Comparison study

Relapsing Pituitary Adenoma

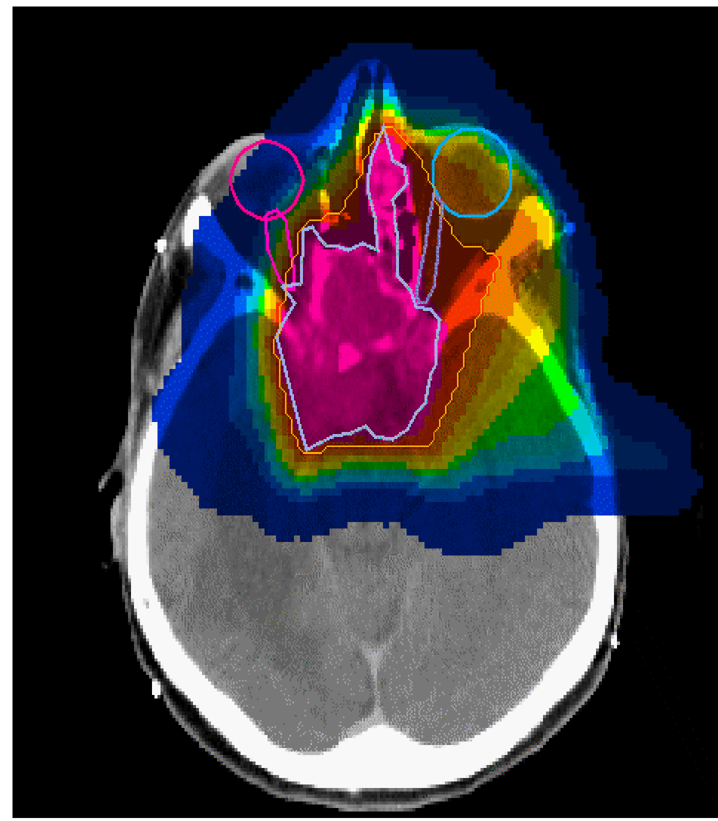
Dose distribution in transversal slice



Photons



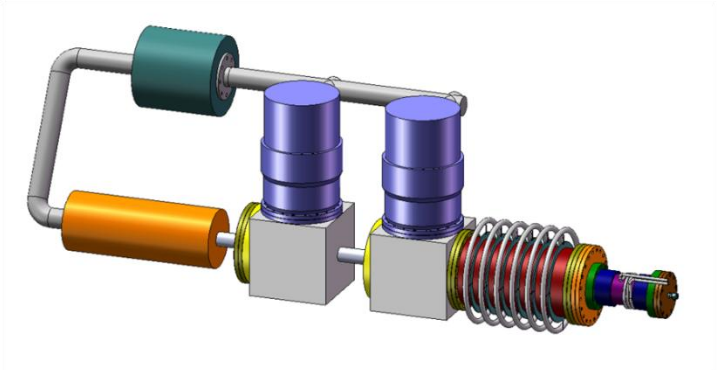
Protons



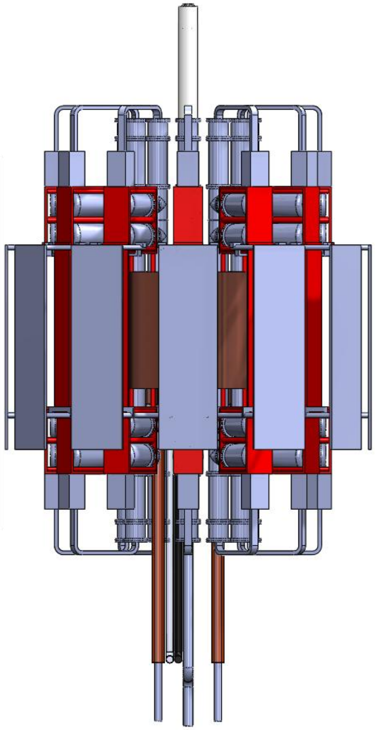
PHOENIX NUCLEAR LABS

PROVIDING NUCLEAR TECHNOLOGY FOR THE BETTERMENT OF HUMANITY

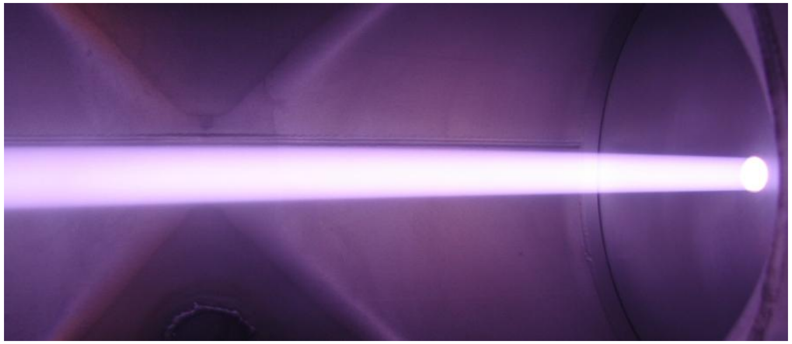
A Better Way to Produce ^{99}Mo (and Other Medical Isotopes)



Single Beam Neutron Source



SHINE Isotope Production System



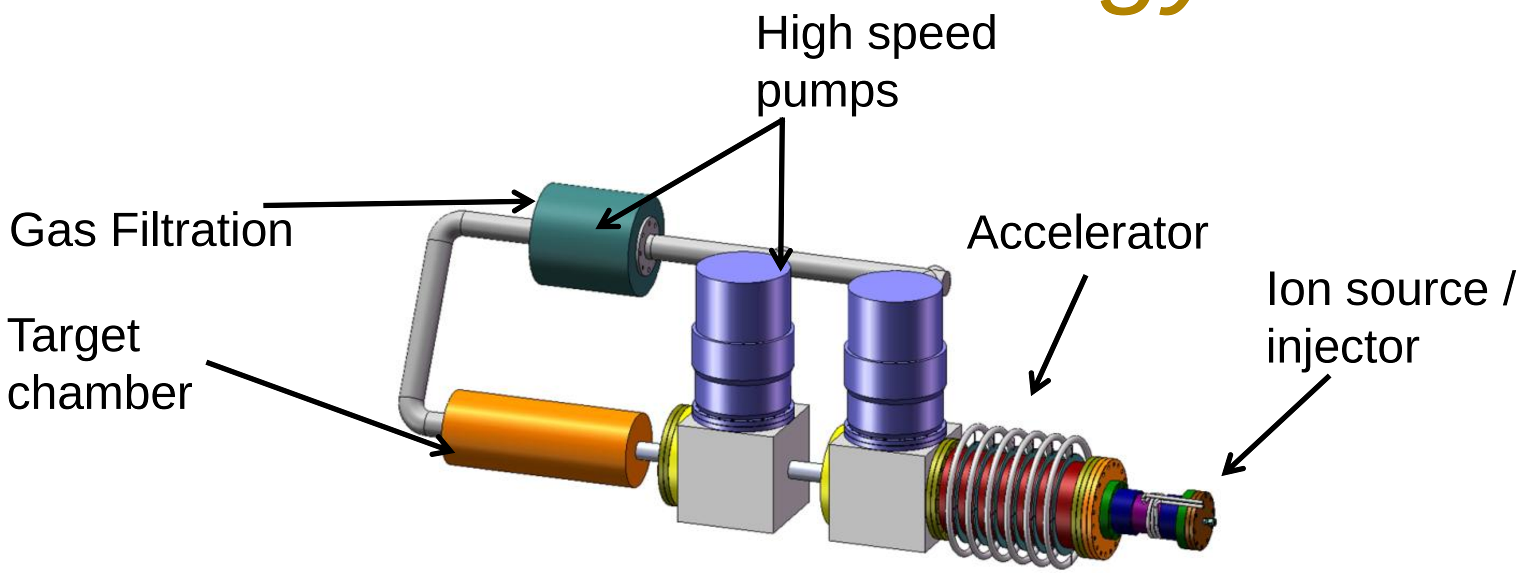
Deuterium ion beam

May 14th, 2010—Dr. Gregory Piefer

Overview

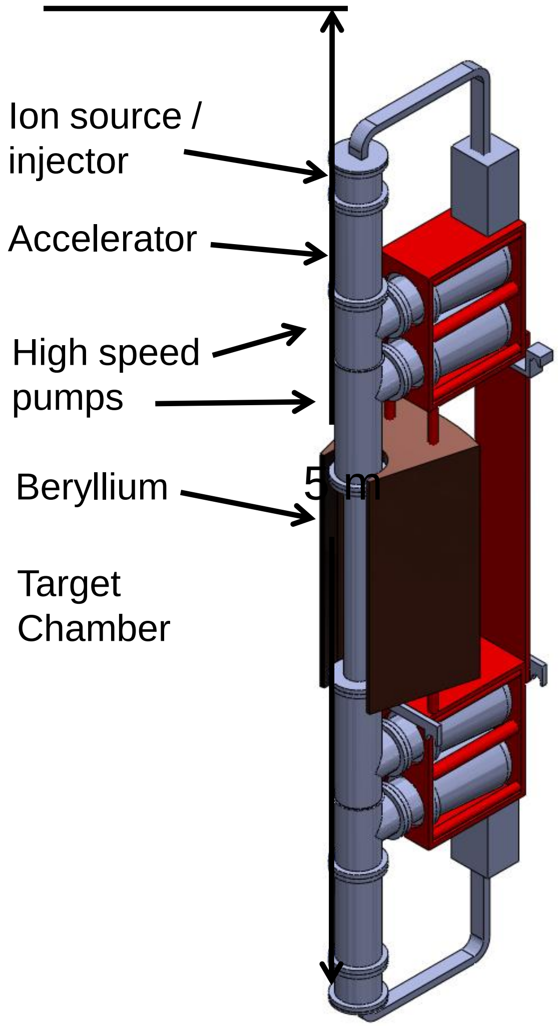
- The Morgridge Institute for Research and Phoenix Nuclear Labs are developing a system to produce reactor grade medical isotopes without a traditional reactor
- System is capable of helping end the medical isotope crisis quickly and relatively inexpensively
- Technology has two key aspects
  - Primary neutrons created by high output D-T source
  - Neutrons enter aqueous LEU solution where they multiply subcritically and create medical isotopes
- Single device could produce nationally relevant quantities of ^{99}Mo and other medical isotopes (>40% ^{99}Mo)

Driver Technology



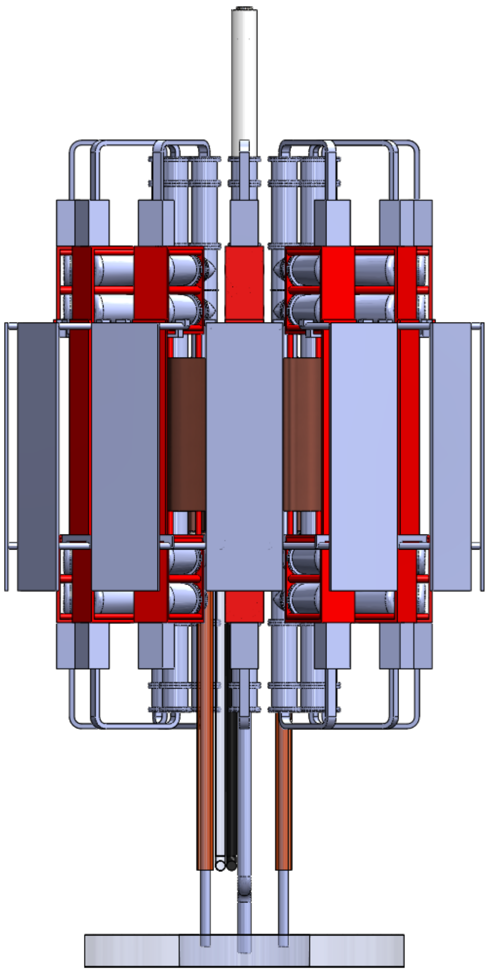
- Neutrons are made by reactions between deuterium and tritium atoms
  - Deuterium gas flows into ion source, is ionized by RF or microwaves
  - Simple DC accelerator pushes ions toward target chamber (300 keV)
  - Accelerated deuterons strike tritium gas in target chamber, creating neutrons
  - Proof of high efficiency and yield already demonstrated (> $2*10^9$ n/s per watt)
  - High energy neutrons allow for (n,2n) multiplication on beryllium
  - Only reaction products from this process are neutrons and ^4He

SHINE Driver Specifications



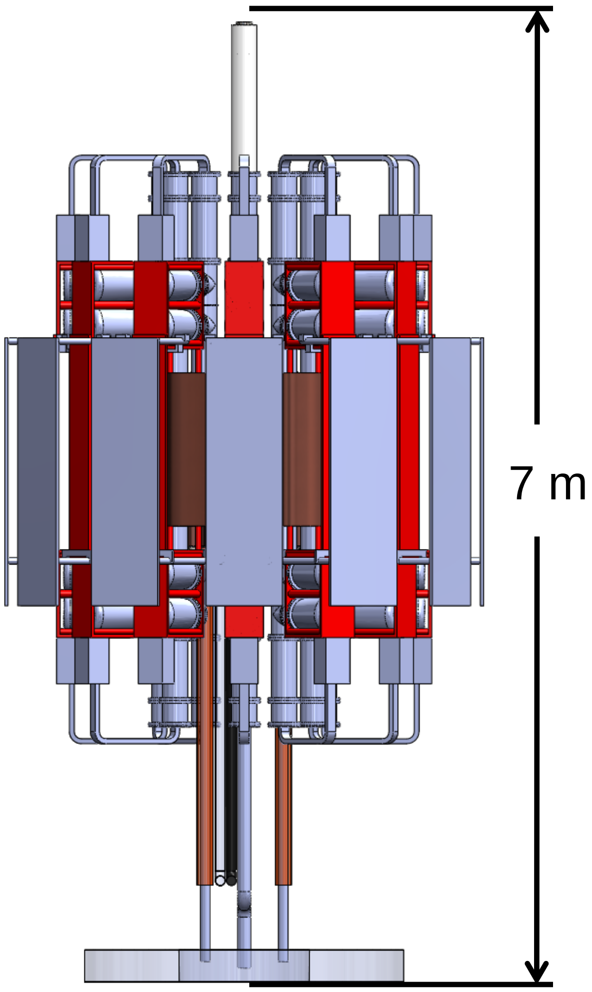
- Physical
  - Consists of two ion injector / accelerator pairs discharging into a common target chamber
  - Structure held together with aluminum frame
  - Integrated beryllium multiplier ~ 1000 lbs
  - Total driver weight ~ 2000 lbs
  - Ion source, pumping power supplies, cooling systems fully integrated
  - High voltage delivered externally
- Operational
  - Deuteron / triton current: 100 mA (50 mA per injector)
  - Beam energy: 350 keV
  - Beam power: 35 kW
  - Neutron output: $5*10^{13}$ n/s (14.1 MeV)
  - Tritium inventory: 0.015 g (< 150 Ci)
  - Tritium consumption (per year): 0.007 g (~ 60 Ci)
  - Wall power (with pumping): 50 kW

SHINE Overview



- SHINE (Subcritical Hybrid Intense Neutron Emitter)
  - Consists of an aqueous pool of uranium nitrate or sulfate
  - Pool driven by 12 D-T drivers
  - Beryllium surrounding pool provides neutron reflection and multiplication
  - Isotopes made from fission of uranium in solution
  - Uranium concentration controlled to keep pool subcritical
  - Solution chamber partitioned so sections may be drained on different days
- Key Benefits
  - No criticality
  - No instability as demonstrated with all previous aqueous reactor systems
  - Inherent safety-needs to be driven to operate
  - Greatly reduced nuclear waste-no reactor needed
  - Utilizes low enriched uranium (19.5%)
  - Aqueous process improves chemical extraction efficiency
  - Simplified regulatory approval process

Specifications



- Physical
  - Size: 7m long by 3.5 m diameter
  - Weight: 20 tons
  - Materials: primarily Zircalloy, aluminum, beryllium
- Safety
  - Subcritical, criticality monitored by in-core neutron detectors
  - Large negative power coefficient caused by radiolysis
  - Neutron poisons to be added if criticality exceeds operational limits
  - Dump tank if reactivity exceeds safety thresholds with passive and active valves
- Key parameters
  - Fission power: ~ 250 kW
  - ^{99}Mo production rate: 2500 6-day kCi / wk
  - Driver neutron production: $6*10^{14}$ n/s @ 14.1 MeV
  - Driver power consumption: 600 kW
  - Multiplication factor from Be: 2-3
  - Maximum K_{eff} : ~ 0.95
  - Neutron flux: ~ 10^{13} n/cm^2/s average flux in solution

Present Status

- PNL, in collaboration with the Morgridge Institutes for Research, and UW-Madison is seeking $25 M DoE grant to assist with construction of SHINE production facility
- Several key partners secured or in negotiation
  - Los Alamos National Laboratory
  - Lawrence Berkeley National Laboratory
  - TechSource
  - MDS-Nordion
  - GE
  - Lantheus Medical Imaging
  - INVAP-Argentina
- Goal is to commercialize SHINE by Jan. 1, 2014, use revenues to expand into other applications

Keep still; very, very still!