

Future Challenges to Accelerator Health Physics Program Administration and Management

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This Presentation Provides:

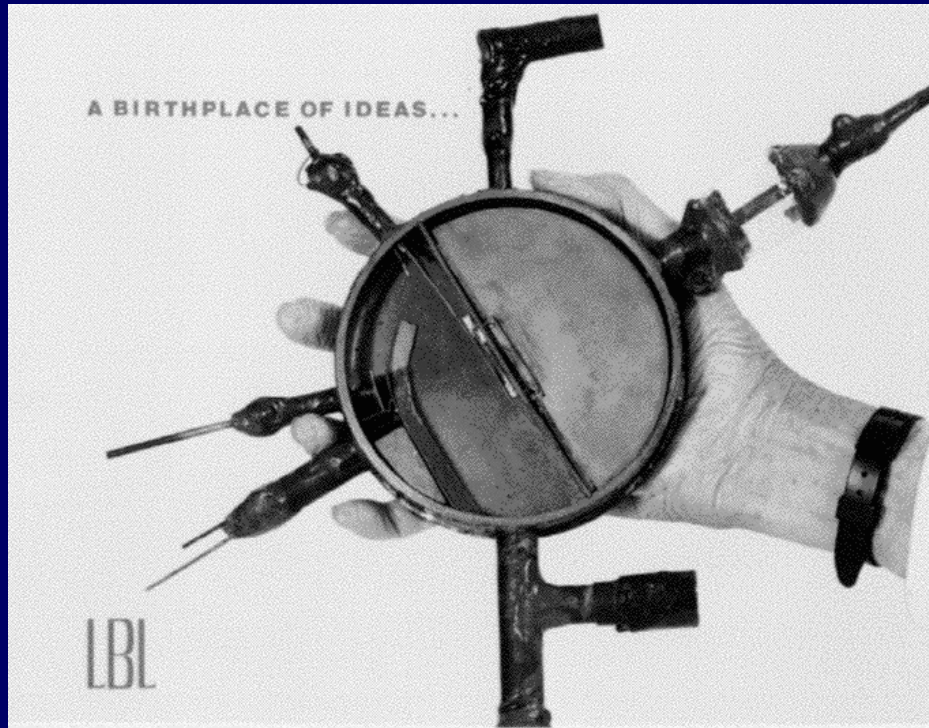
Review the

- technological,
- operational, and
- regulatory

advances that pose

Future Challenges to Accelerator Health Physics
Program Administration and Management

- Technology advances at such a rapid pace that much of what we encounter in the modern workplace was not yet invented when we first learned our trade in college, and that pace is accelerating not slowing down.



From Lawrence's first cyclotron, to the 2-mile long 50 GeV Stanford Linear Accelerator



- Operational advances change the ways we operate or use accelerators, which have evolved from small scale research projects in themselves to large scale scientific factories in which large numbers of users, on site or remote, can collaboratively operate and use an accelerator facility.

- Regulatory advances have and will continue to change the landscape of how accelerators are managed and operated to ensure the safety of workers and users alike.

Technology advances

- Laser wakefield acceleration
- The Diocles laser
- Linac Coherent Light Source
- Other emerging technologies

Laser wakefield accelerator

- Principle of laser wakefield acceleration (from Wim Leemans, et al., LBNL 2007)
- Accelerating electron bunches to 1 GeV energy in a distance of 3.3 cm

Laser wakefield accelerator

Principle: extremely high peak-power laser pulses, ~ several terawatts (1 TW = 10^{12} watts), with short pulse widths ~ femtoseconds (1 fs = 10^{-15} sec)

1. “Igniter pulse” ionizes a plume of hydrogen gas to create a plasma channel in which ionized hydrogen atoms briefly coexist with free electrons.
2. “Heater pulse” further heats and shapes the plasma.

Pop quiz

- How far does a pulse of laser light travel in a femtosecond?

$$3 \times 10^{10} \text{ cm/sec} \times 10^{-15} \text{ sec} =$$

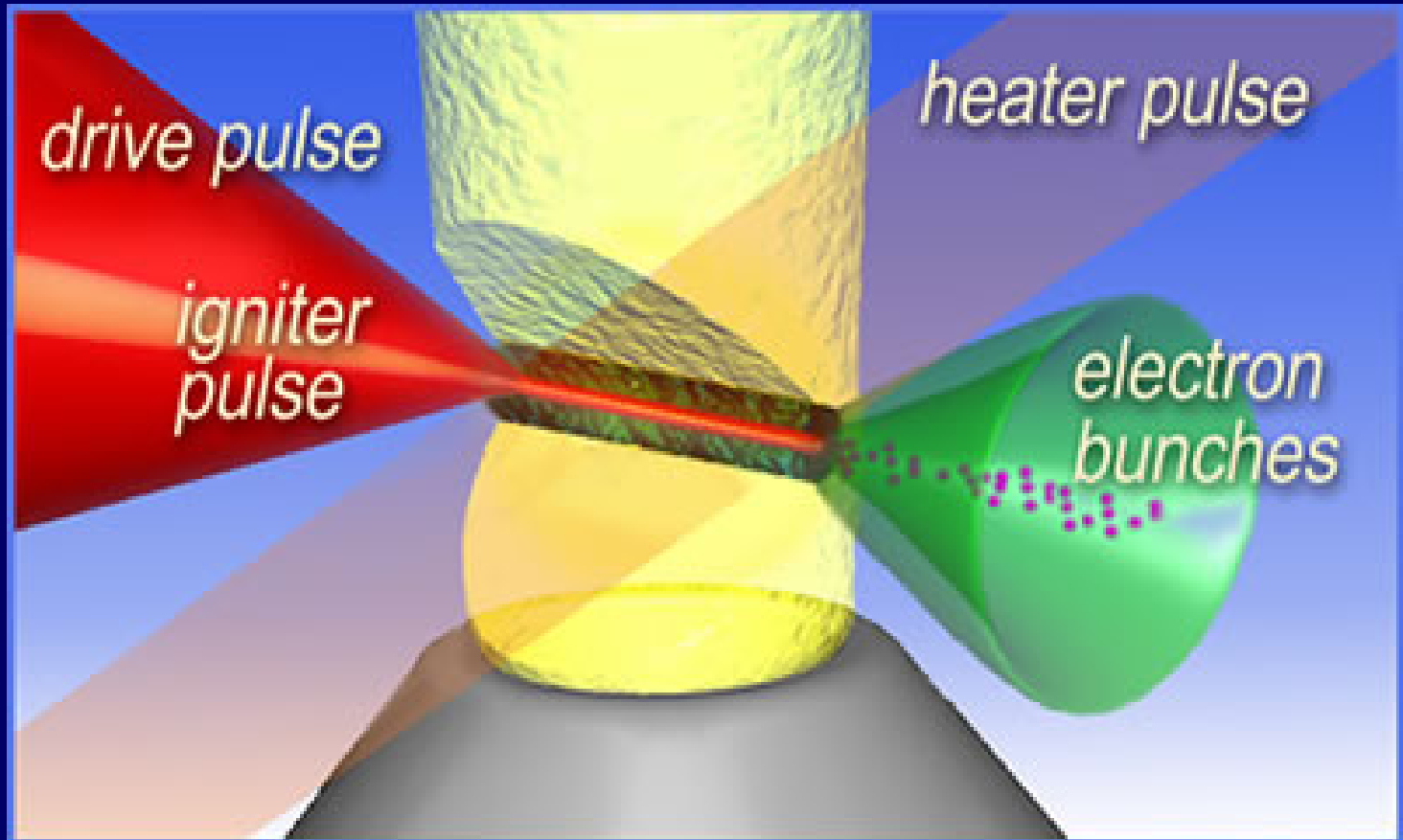
$$3 \times 10^{-5} \text{ cm}$$

Pop quiz #2

- What is the wavelength of 400 nm laser light?

$$400 \times 10^{-9} \text{ m} \times 100 \text{ cm/m} =$$
$$4 \times 10^{-5} \text{ cm}$$

Laser wakefield accelerator



3. Laser “drive pulse” traverses the plasma creating an electromagnetic wake.

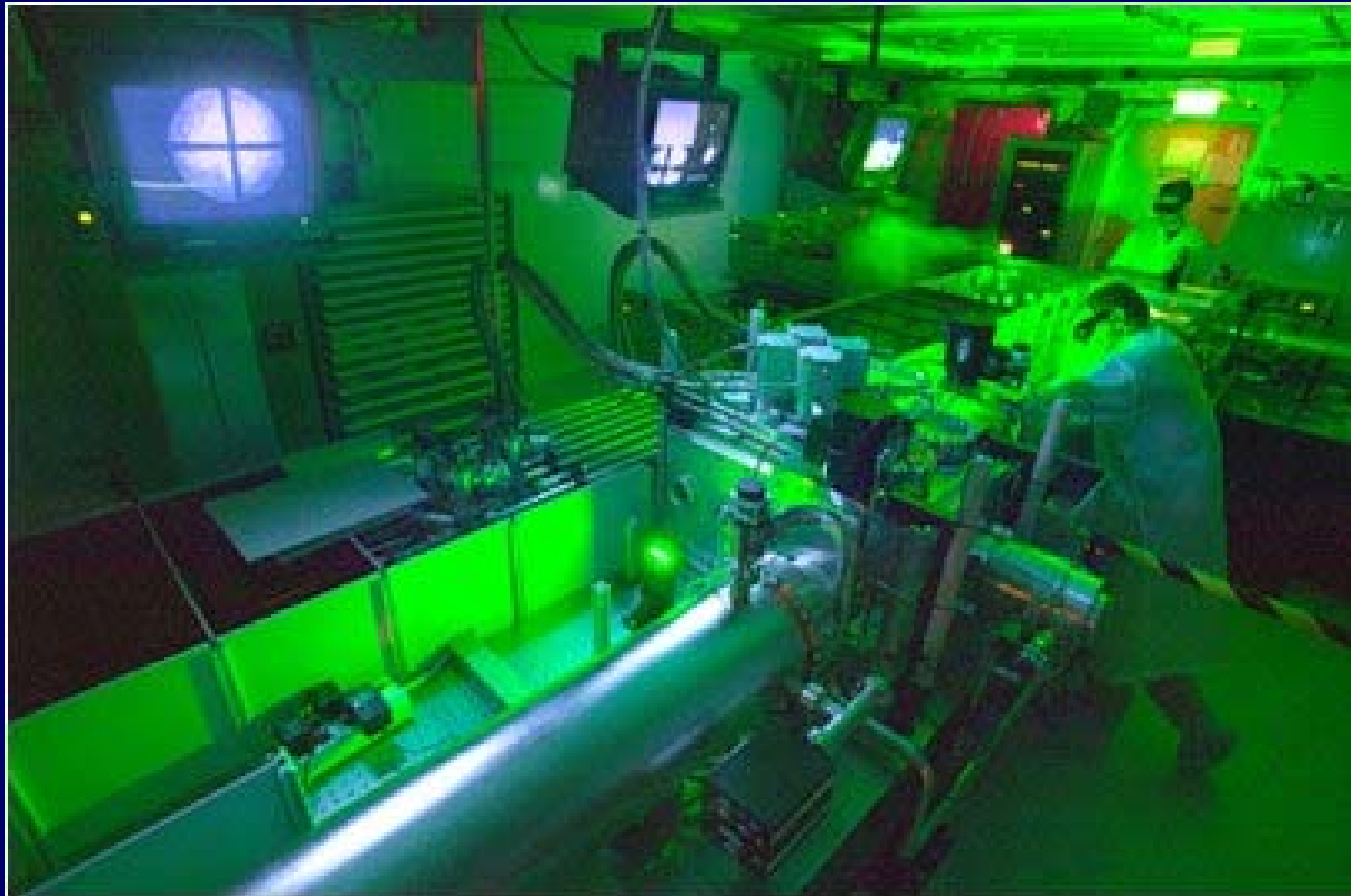
Bunches of free electrons are accelerated at the speed of light along with the laser pulse.

Laser wakefield accelerator

Further research:

- Achieve even higher energies by using the laser wakefield concept to accelerate high energy electron bunches injected into the accelerating cavity, and
- By staging, the sequential handoff of an energetic electron beam from one cavity to the next, until a even higher energy beam is achieved.

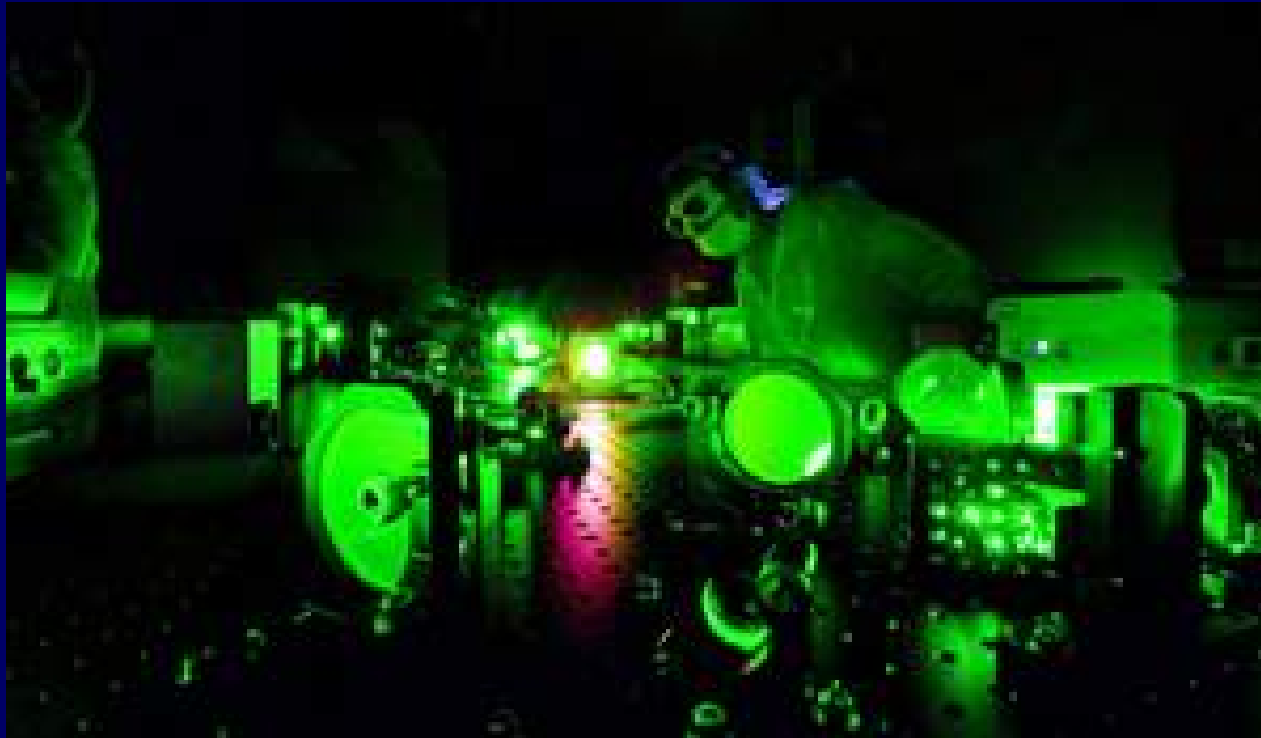
Laser wakefield accelerator



Wim Leemans Laser Lab
XBD200306-00338-08

University of Nebraska, Lincoln (UNL) the Diocles laser

- **What is special about the Diocles laser?**
- 100 TW system with 30 fs pulse width: highest combination of peak and average power of any in the U.S.
- Research is directed at generating x-rays:
 - To see through the walls of cargo containers;
 - To diagnose cracks in turbine blades before they can lead to catastrophic jet engine failure;
 - To accelerate protons with lasers for the treatment of cancer; and to develop x-ray pulses that are so brief in time that they can be used to freeze the motion of atoms and molecules.



- A technician adjusts the Diocles laser in the Extreme Light Laboratory at UNL.
- The laser has the potential to reach the highest light intensity ever produced by any laser. (UNL University Communications)

Health physics challenges posed by laser wakefield technology

- Interface issues posed by ionizing radiation hazards in a high technology laser laboratory
 - class-4 laser hazards
 - electron beams have sufficient energy to produce high energy bremsstrahlung
 - photoneutron interactions
 - neutron activation of laser optics

Health physics challenges posed by laser wakefield technology

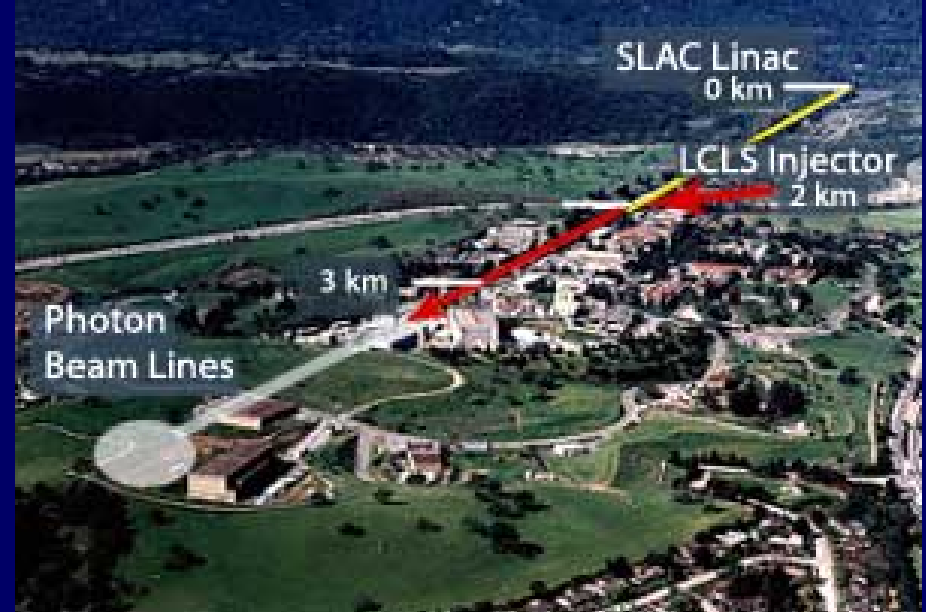
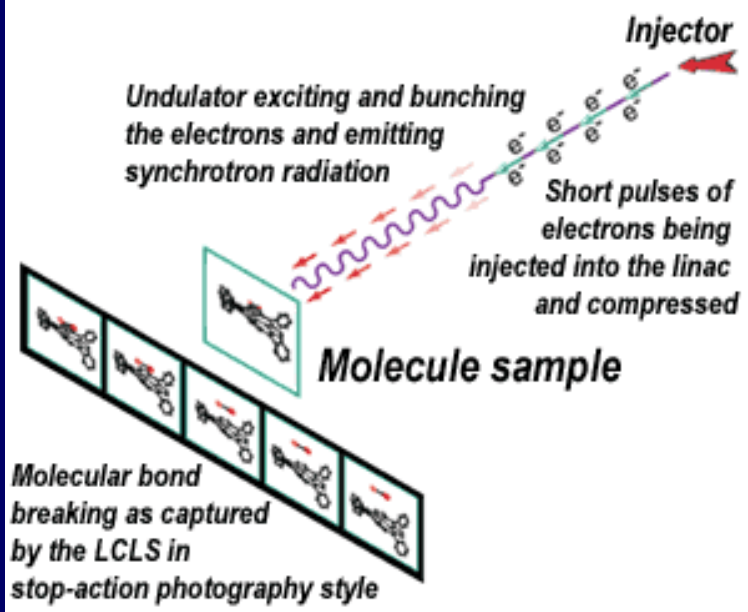
- Laser safety professionals and ionizing radiation specialists must work together.
- Measurements of ionizing radiations produced in extremely short pulses can be complicated by potential recombination of the secondary radiations.
- Engineered safety systems such as shielding, sensors, and interlocks will have to be designed in such a way as to deal with the combination of hazards posed by the lasers and ionizing radiation beams.

X-ray Laser?



Stanford Linear Accelerator Center (SLAC) Linac Coherent Light Source (LCLS)

- When it becomes operational in 2009, will be the world's first x-ray free electron laser,
- The pulses of x-ray laser light will be a billion times brighter than any that can be produced by the x-ray sources available now.



- **Coherent x-rays produced as LINAC-accelerated a electrons pass through undulators.**
 - The oscillations produce a large number of x-rays.
 - The x-rays interact back on the electrons, forcing them to bunch at x-ray wavelengths.
 - When this occurs, the electrons emit their light coherently, causing a large gain in radiation power that raises the x-rays' intensity.

Other Emerging Technologies

- Tera-, peta-, and exa-watt lasers with femto- and atto-sec pulses
- Dynamic-particle accelerators, e.g. Rare Isotope Accelerator (RIA), muon, and neutrino machines where the primary particles change form within accelerator segments.
- CARIBU – Californium Rare Isotope Breeder Upgrade: Cf²⁵² fission fragments will be accelerated to provide short-lived neutron rich isotopes for nuclear physics research
- Nano-scale science – new technology is creating materials with previously unknown characteristics that may change the way we approach many aspects of science.

Operational Advances

This section will cover operational advances including such issues as

- complexity of accelerator systems,
- interlocks,
- forward-looking design,
- user safety, and
- quality assurance.

Complexity

- Accelerator systems are becoming ever larger and more complex as far as operational systems, safety systems and user systems. Complexity and its affect on safety are very much leading issues as we try to manage risk in increasingly diverse machines.
- Complex systems place increasing importance on well defined management systems for ensuring the safety of operating staff, users, and the environment

Experimental floor, National Synchrotron Light Source, Brookhaven National Laboratory



Complexity

- Configuration control of engineered safety systems ensure these systems are in place and functioning as intended 100% of the time.
- Administrative controls maintained under strictly defined conduct of operations ensure reliability.
- Quality assurance of software systems is an essential aspect of fault-free operation of safety systems.
- Human factors engineering is an emerging discipline to identify and remove organizational weaknesses and provide error-tolerant processes.

Complexity

- The organized approach health physicists take to control radiation hazards fits in well with the overall processes that are needed to manage risk in increasingly complex accelerator facilities.
- Health physicists may play an important role in the development of configuration control, conduct of operations, quality assurance, and human factors engineering to safety systems at increasingly complex accelerator facilities.

Interlocks

- As accelerators gain more users, accelerator safety systems for radiation protection, such as interlocked enclosures, will become more complex and sophisticated.
- To make them accommodate large numbers of users, designers will have to move toward
 - programmable electronics,
 - programmable systems and possibly
 - biometric systems.

Interlocks

- At most facilities, completely independent interlock systems exist for radiation beam safety, laser safety, x-ray unit safety, robotics, oxygen deficiency hazards, electrical safety, and possibly others.
- With increasing number and types of energy sources requiring protection by interlocks, it seems reasonable to ask if some of these systems can be integrated. Some integration of interlocks has already begun at selected accelerator facilities.

Interlocks

- For example, a single switch with isolated dual circuits has been used to support door interlocks for radiation beam safety as well as laser safety. A second such switch provides redundancy.
- This could likewise be expanded to include additional isolated elements for other hazards that require an interlock. With integration of separate systems, an increasingly strict management control system must obviously be in place to ensure that any change to one system is evaluated for impact on the other(s).

Aerial View, Advanced Photon Source (APS), Argonne National Laboratory



Forward-looking Design

New or upgraded accelerator systems should design for:

- Improved safety reliability and alara
- Simplicity to make equipment repairs and replacements easy and practical, and therefore reduce radiation dose to workers;
- Robustness to reduce the failure frequency (e.g. radiation hard designs);
- Modularity with well rehearsed remote removal, storage and replacement capability;

Forward-looking Design

- Failures should not cascade down or upstream to other elements;
- Easy accessibility to defunct equipment;
- Possibility of selective redundancy in the beam line to extend operations until an opportune time for repairs;
- Integral simulations projecting the future conditions of the whole complex of the beam line, equipment, structure, and the equipment, training and tools requirements;

Forward-looking Design

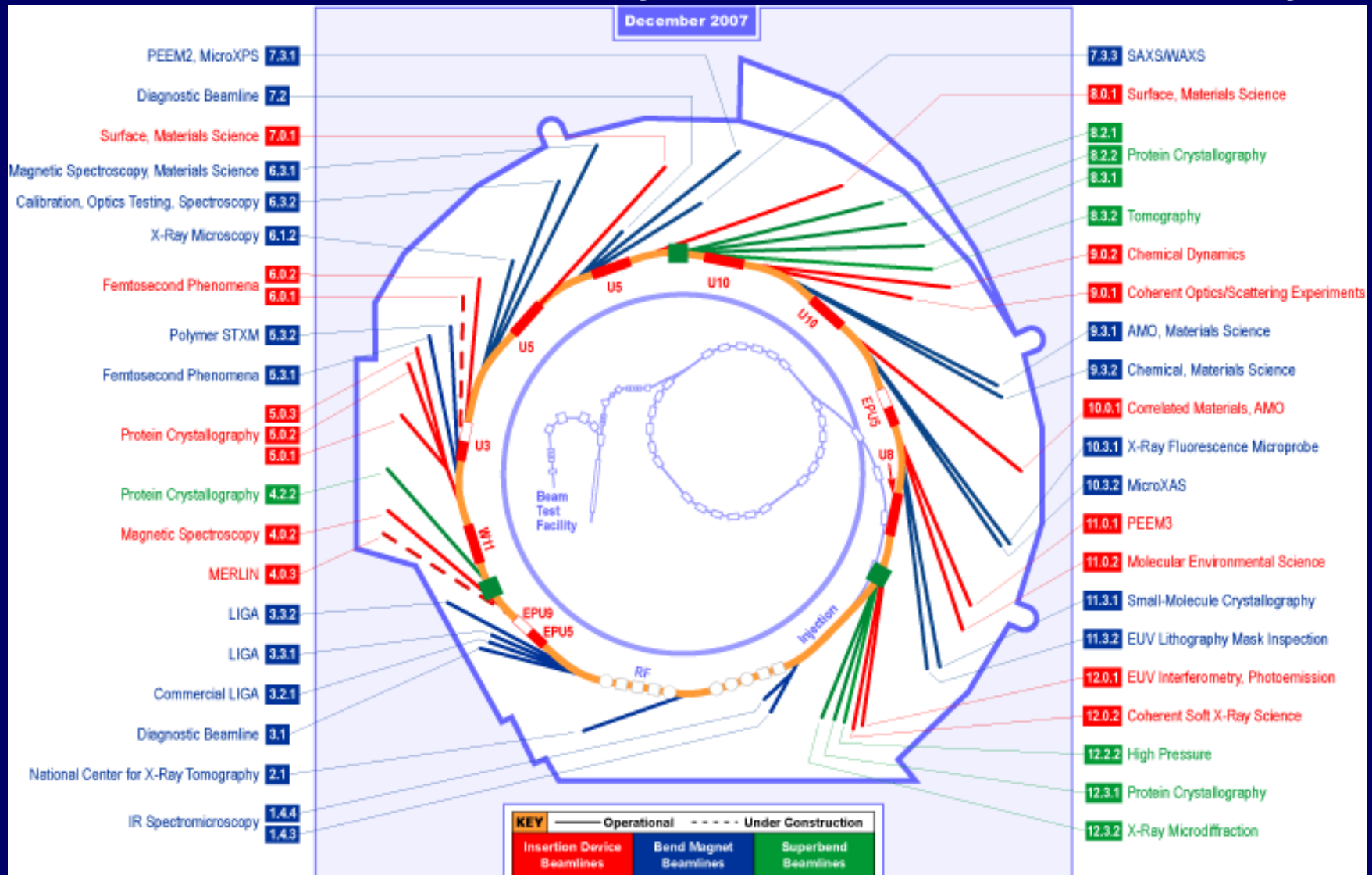
- Planning for evolution. History shows that accelerators may evolve well past the original scope over tens of years. It is important to try to anticipate radiation management life-cycle considerations to be included in the up-front planning process.
- Taking full advantage of inherently safe design features. The physics of beam transport or accelerator operation will often limit the magnitude and duration of fault conditions. Inherently safe design means that such features are planned in advance, and identified as equivalent to other engineered safeguards

User Safety

Large modern accelerator user facilities:

- may accommodate 2000-4000 users per year,
- each onsite for only days, or hours,
- to complete experiments utilizing their defined allocation of beam time.
- Extensive advance planning and review go into the scientific design of each experiment, as well as to the safety aspects of each users' visit to the facility.

Beamline Diagram Advanced Light Source Lawrence Berkeley National Laboratory



User Safety

- Formal experiment safety review processes are in place at most major facilities to ensure that radiological and other hazards are identified and controlled.
- Users are required to complete safety training, often available online in advance of arrival at the facility, before commencing onsite work.
- User-owned equipment brought to the facility is generally inspected, and onsite repairs or modifications are made if necessary to assure safe operation with no negative impact on the facility or its operations.

User Safety

- Experience has shown that radiological risks to users are small compared to other hazards, such as electrical and laser.
- Facility managers are aware of the potential vulnerability created by a user community comprised of a larger and larger numbers of users with highly diverse backgrounds, operating in larger facilities with little or no staff-contact time.
- Diligence by all and continued management attention are the important elements to create the atmosphere which can establish a proper attitude regarding safety. It does require exactly that – diligence and management attention.

Remote operation of large accelerator facilities

- “Global Accelerator Network” (GAN) concept has been put forward as a means for inter-regional collaboration in the operation of internationally constructed and operated frontier accelerator facilities. (LBNL 2007(b)).
- The GAN concept would allow for remote control of some parameters such as instrumentation and data collection, but not the radiation beams.
- Presumably appropriate controls would be put in place to ensure that GAN operation does not impact essential accelerator safety systems.

Quality Assurance (QA)

- Complex protective systems depend on good QA methods, including software QA, in a way that is much stricter than many of the other accelerator components.
- With higher beam intensities, reliability of sensors, system testing, system verification, and operating practices will need to be better defined and controlled.
- With Programmable Logic Controllers (PLCs) replacing electromechanical relays in interlock circuits, software QA becomes an increasingly important issue.

Regulatory Changes

- Changes in regulatory requirements can affect implementation of health physics programs at accelerator facilities.
- The following developments underway in mid-2007 should be tracked by accelerator health physicists to assess the potential impacts on the facilities they support.
 - US NRC
 - DOE
 - OSHA

US Nuclear Regulatory Commission (US NRC)

- Formerly the US NRC had jurisdiction to regulate only byproduct and source material, with NARM being regulated by the individual States and by the Occupational Health and Safety Administration (OSHA).
- In 2005, Congress assigned the US NRC the authority to regulate NARM to promote a nationally consistent and uniform regulatory environment for health, safety and security of these materials.

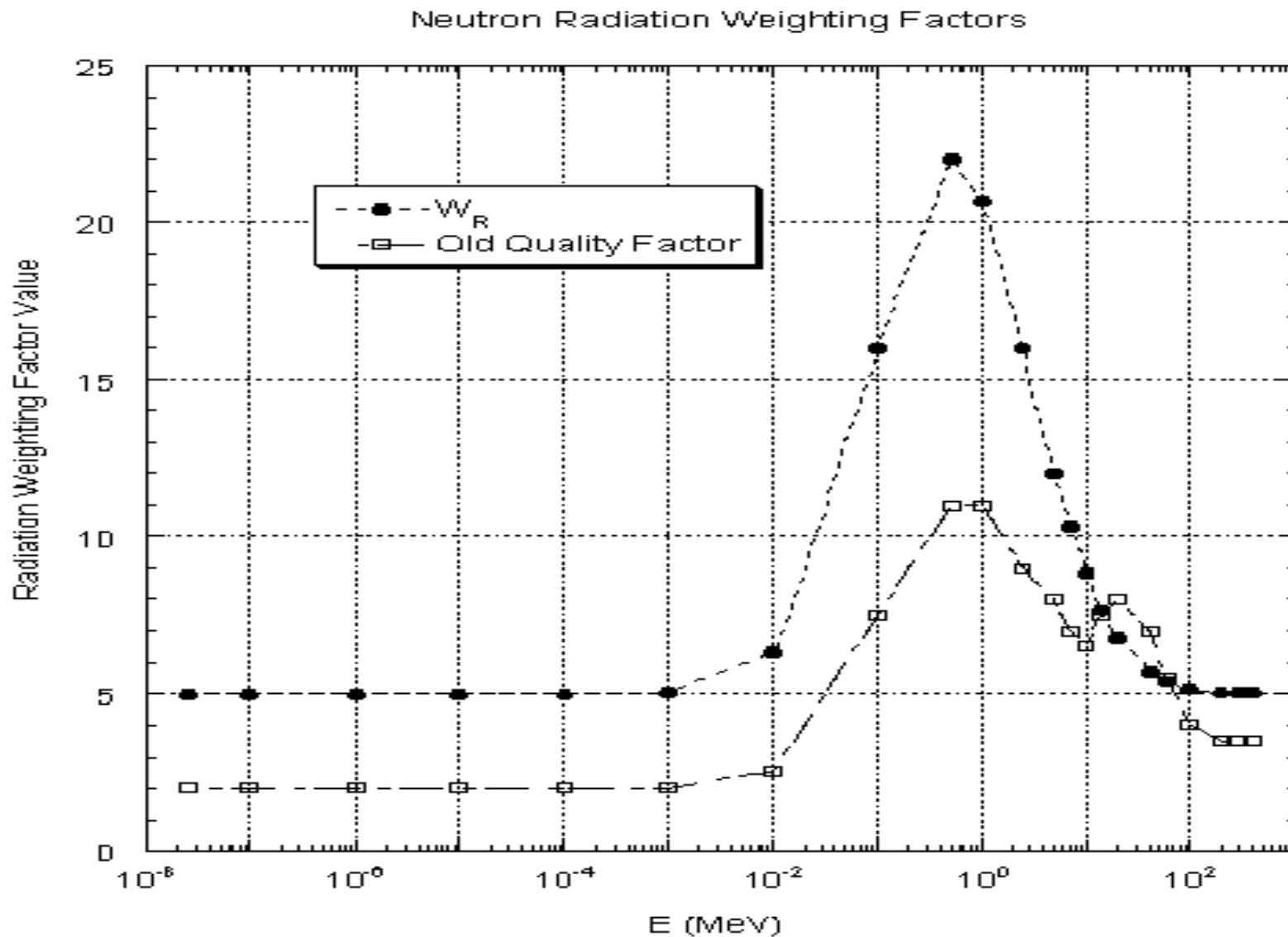
US Nuclear Regulatory Commission (US NRC)

- Section 651(e) of the Energy Policy Act of 2005 on "Treatment of Accelerator-Produced and Other Radioactive Material as Byproduct Material" expanded the US NRC's regulatory jurisdiction to include naturally occurring and accelerator produced radioactive material (NARM).
- The US NRC is currently in the process of developing and promulgating regulations for NARM.
- Health physicists supporting accelerator facilities would do well to follow these actions carefully at the US NRC website (US NRC 2007).

Department of Energy (DOE)

- In 2007 the DOE revised its occupational radiation protection standards, Title 10 of the Code of Federal Regulations, Part 835 (10CFR835)
- Adoption of the methodology for personal radiation dosimetry promulgated by International Commission on Radiation Protection, Report 60 (ICRP 1990).
- A major impact of this change for accelerators is that the decades-old system of fluence-to-rem conversion factors and quality factors for neutron radiation is being replaced by the ICRP-60 radiation weighting factors.

Impact on neutron dosimetry of Implementing ICRP 60



(courtesy J. D. Coissart and K. Vaziri)

Department of Energy (DOE)

- For most neutron energies the equivalent dose due to neutron radiation will, under the revised regulations, become approximately twice as large - only in DOE-regulated facilities.
- Unanswered questions:
 - Dual standards for neutron radiation in the USA
 - Calibration of instruments by manufacturers
 - Neutron dose-rates to use for shipments under DOT
- This remains an area for close attention by health physicists over the next three years

Occupational Health and Safety Administration (OSHA)

- OSHA has regulatory jurisdiction over worker exposure to radiation from accelerators.
- It has been decades since OSHA significantly updated its radiation protection regulations contained in 29CFR1910.1096.
- In May 2005, OSHA published a Fed. Reg. request for information (RFI) related to the increasing use of ionizing radiation in the workplace and potential worker exposure to it.

Occupational Health and Safety Administration (OSHA)

- OSHA stated it would use the data and information it receives to determine what action, if any, is necessary to address worker exposure to occupational ionizing radiation.
- In April 2007 there were two public meetings to continue OSHA's information collection efforts.
- It is not clear which direction this process is headed; but health physicists would be wise to keep abreast of OSHA's activity in radiation protection as any action taken could affect safety requirements for accelerators.

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