ES&H

Personnel Protection Systems for Particle Accelerators

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Joint Accelerator School: Beam Loss and Accelerator Protection

Newport Beach, California, USA, November 5-14, 2014

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Abstract

SLAC

- There are various hazards in different phases of the life-cycle of particle accelerators from construction to installation to commissioning to operation and finally decommissioning
- Majority of these hazards are also present in specific industrial and medical facilities
- Some of these hazards are more closely associated with particle accelerators (ionizing radiation)
- There are multiple control systems in place that manage risks from these hazards for the protection of personnel, environment, machine and equipment
- The focus of this talk will be on protection of workers during operation, primarily from prompt ionizing radiation hazard that are generated due to beam losses (both normal and abnormal conditions)

Table of Contents

- Personnel protection at accelerators
  - Hazard sources
  - Legal framework for personnel protection
- Radiation Safety Systems (RSS) for personnel protection
  - Access Control System (ACS)
  - Radiation Control System (RCS)
    - Passive and active systems
- Examples of safety system failures
  - Lessons learned from RSS failures
- Summary

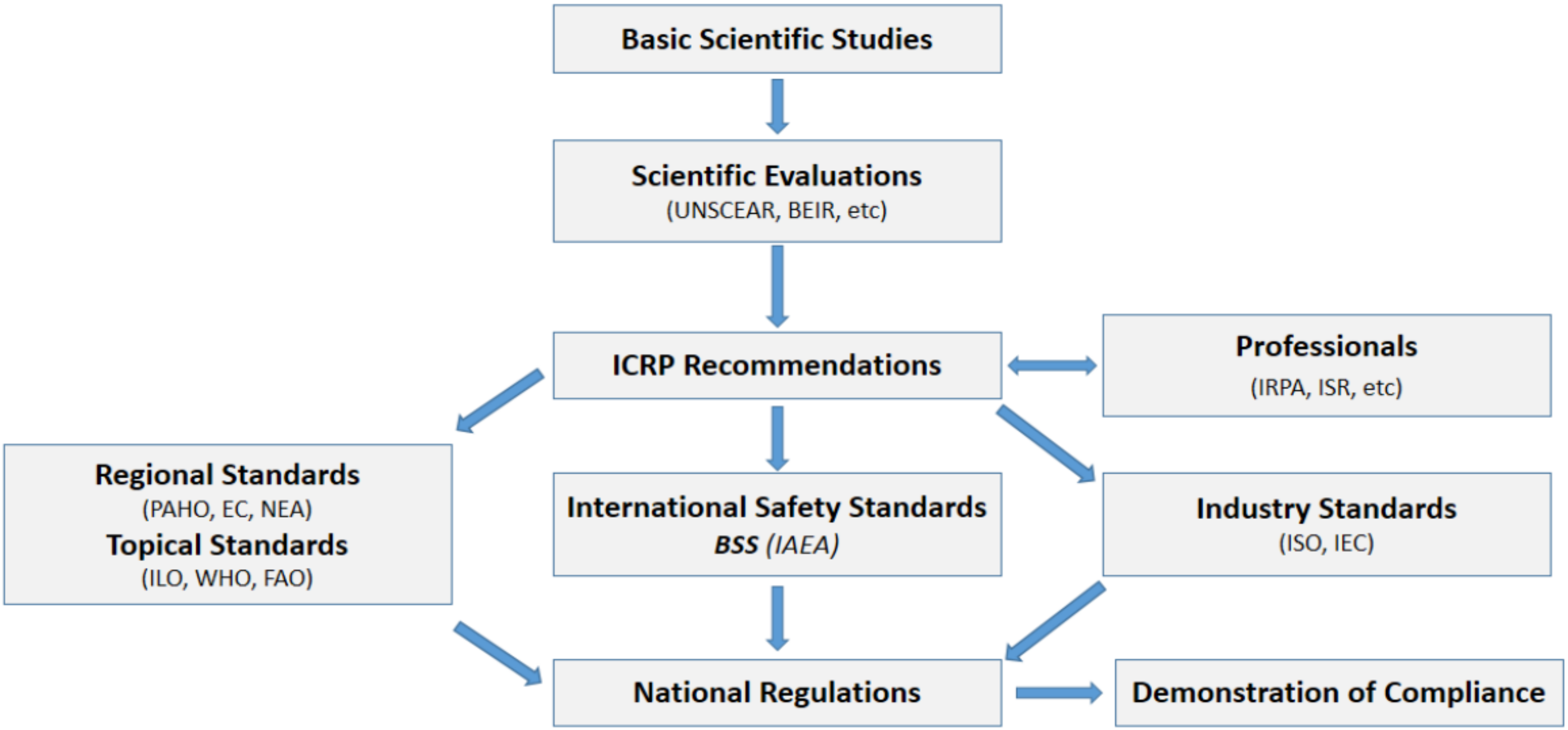
Hazard Analysis and Risk Assessment

SLAC

LCLS-II-1.1-PM-0004-R1 (July 2014)

- CONSTRUCTION
- NATURAL PHENOMENA
- ENVIRONMENTAL
- WASTE
- FIRE
- ELECTRICAL
- NOISE, VIBRATION, THERMAL, AND MECHANICAL
- CRYOGENIC
- CONFINED SPACE
- OZONE
- CHEMICALS AND HAZARDOUS MATERIALS
- ACCELERATOR/BEAMLINE
- IONIZING RADIATION EXPOSURE HAZARDS, INSIDE ACCELERATOR HOUSING AND EXPERIMENT HUTCHES
- IONIZING RADIATION EXPOSURE HAZARDS, OUTSIDE ACCELERATOR HOUSING
- NON-IONIZING RADIATION HAZARDS, RF Radiation ,High Power Lasers, Low-power Communications
- MATERIAL HANDLING HAZARDS
- EXPERIMENTAL OPERATION HAZARDS

International Policy Relationships for Radiological Protection



Legal Framework: Accelerators

- In France, accelerators are subject to an authorization from the French Nuclear Safety Authority (ASN)
- There are two distinct regimes with respect to the authorization of nuclear facilities
- The "Installation Nucléaire de Base" (INB), which includes all the nuclear power plants and associated facilities (e.g. radioactive waste treatment plants)
- There are clear criteria defining when an accelerator facility must be considered as INB:
  - For electron accelerators, to be an INB the energy must be > 50 MeV and the maximum beam power must be > 1 kW
  - For proton and ion accelerators, the energy must be > 300 MeV (for mass ≤ 4) or > 75 MeV (for mass > 4) and the maximum beam power must be > 0.5 kW
  - Below these limits, an accelerator facility is considered a simple nuclear facility

Legal Framework: Accelerators

- US Department of Energy (DOE)10 CFR 835 "Occupational Radiation Protection" (2011)
  - DOE G 441.1-1C, Radiation Protection Programs Guide for use with 10CFR835 (2011)
- **DOE Order 420.2C "Safety of Accelerator Facilities" (2011)**
  - **Accelerator Facility Safety Implementation Guide for DOE O 420.2C, SAFETY OF ACCELERATOR FACILITIES DOE G 420.2-1A (2014)**
  - DOE accelerators: SLAC, FNAL, JLAB, APS (ANL), ALS (LBNL), NSLS-II, SNS, RHIC,LANSCE,….

- 10 CFR 20 "Standards for Protection against Radiation" (2007)
  - Conference of Radiation Control Program Directors, Inc. Suggested State Regulations (CRCPD SSR) for U.S. Nuclear Regulatory Commission and States "Radiation Safety Requirements for Particle Accelerators" (1991)
  - Non-DOE accelerators: CESR, FRIB

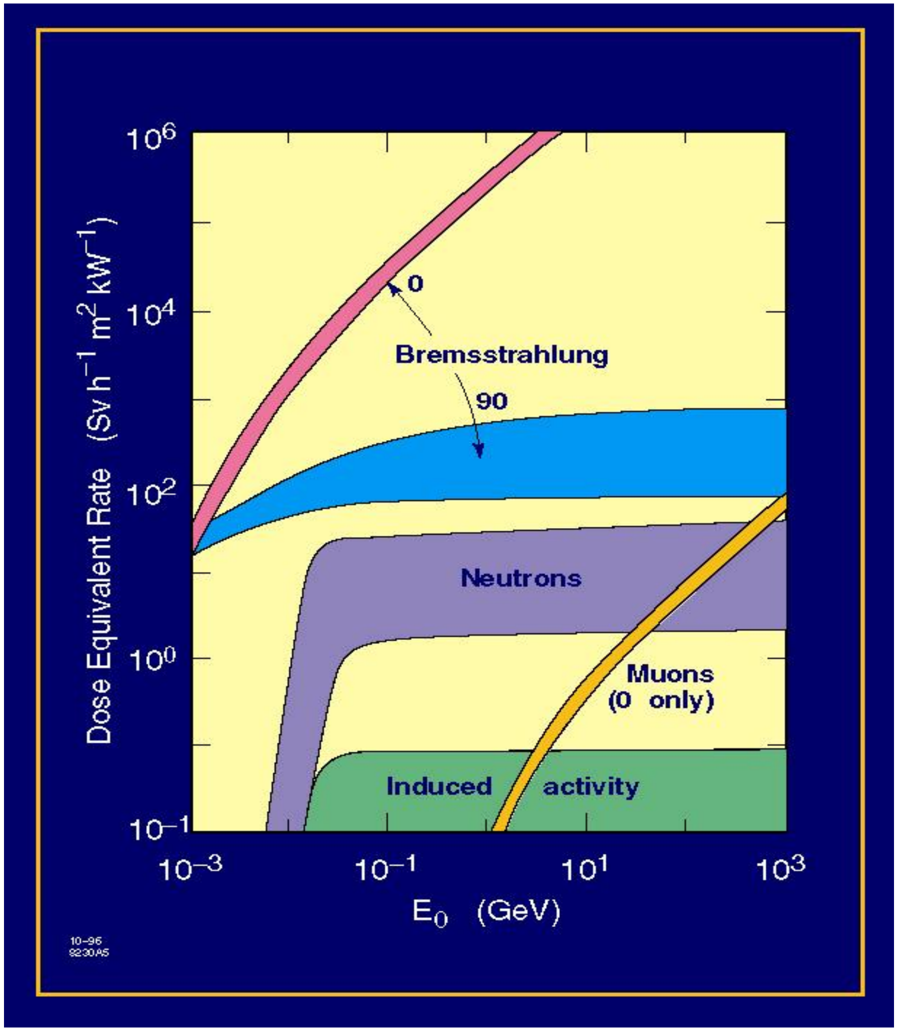
General requirements exist, specific guidelines for implementation focus on establishing processes; more emphasis on requirements and guidelines for Access Control System.

US DOE Accelerator Safety Order

- Approved Safety Envelopes
- Rigorous administrative procedures
- Test, Routine Maintenance, Unscheduled Repairs of RSS
- Interlock Bypasses
- Alternative Protection
- Formality of operations
- Staffing
- Trained operators
- Documentation
- Authorization
- Verification
- Audits system inspection
- Emergency response plan

Credited Safety System

Radiation Source Terms in Electron Accelerators



IAEA 188:
Radiological Safety Aspects of the Operation of Electron Linear Accelerators

Swanson's Rules of Thumb:
(for thick, high-Z targets)

At 0º, E_0 > 20 MeV:

$$\dot{D}\left[\mathrm{Gy.h^{-1}.kW^{-1}.m^{2}}\right] \approx 300E_0$$

At 90º, E_0 > 100 MeV:

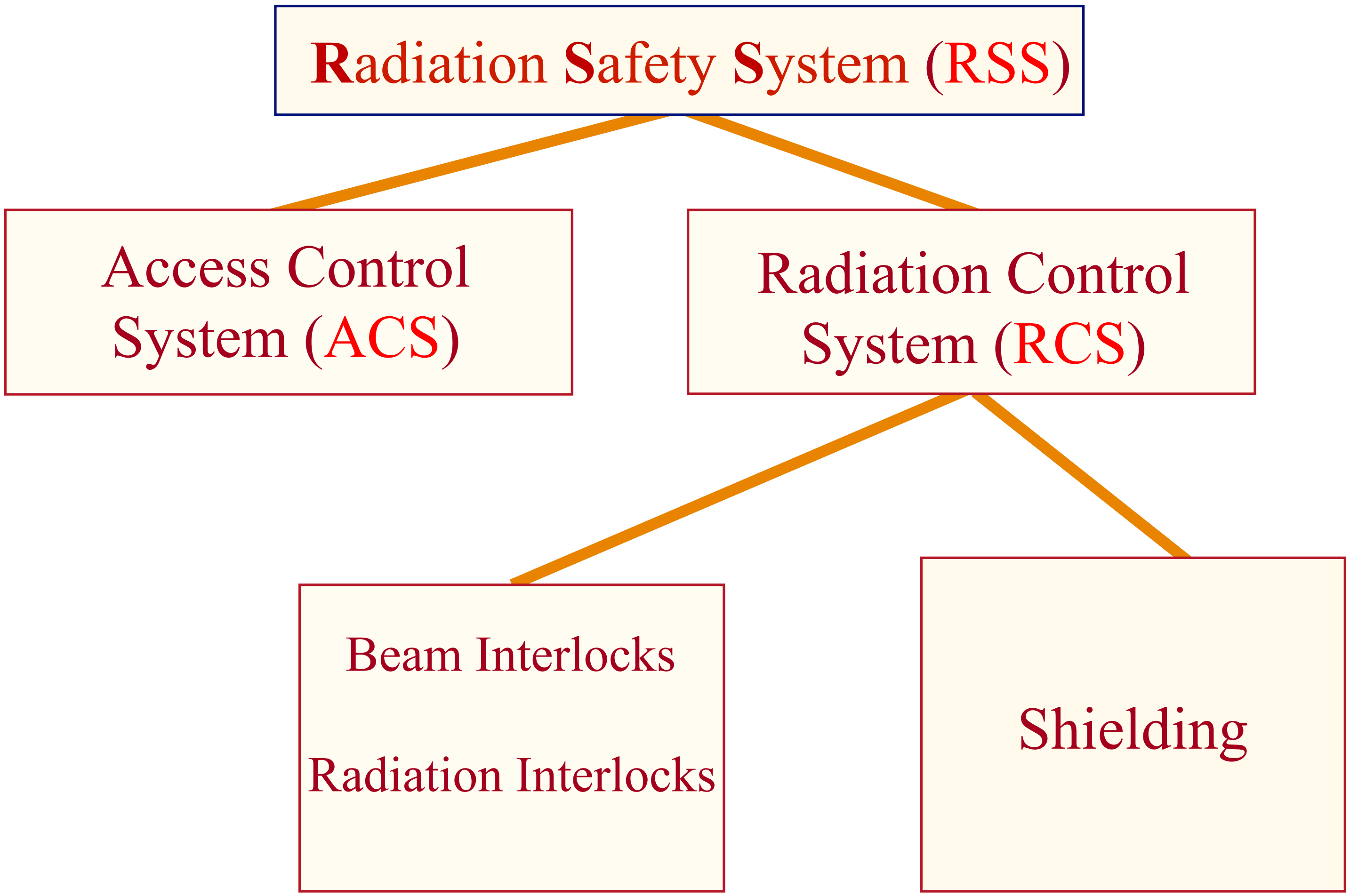
$$\dot{D}\left[\mathrm{Gy.h^{-1}.kW^{-1}.m^{2}}\right] \approx 50$$

Personnel Protection System in Accelerators

General Requirements:

- Control access to the accelerator housing, ensuring that personnel are excluded from the area where the potential for presence of beam exists
- Shield personnel outside the accelerator housing from radiation generated during the operation
- Many accelerator facilities are not shielded for loss of full beam along the entire facility
  - Need to ensure that beam is delivered to the main dump/target within the prescribed beam loss levels, and beam parameters do not exceed the preset values (operations envelope)
- Monitor access conditions, beam parameters and beam losses, target condition, radiation levels, and take action to limit and/or terminate abnormal conditions

Radiation Safety Systems (RSS)

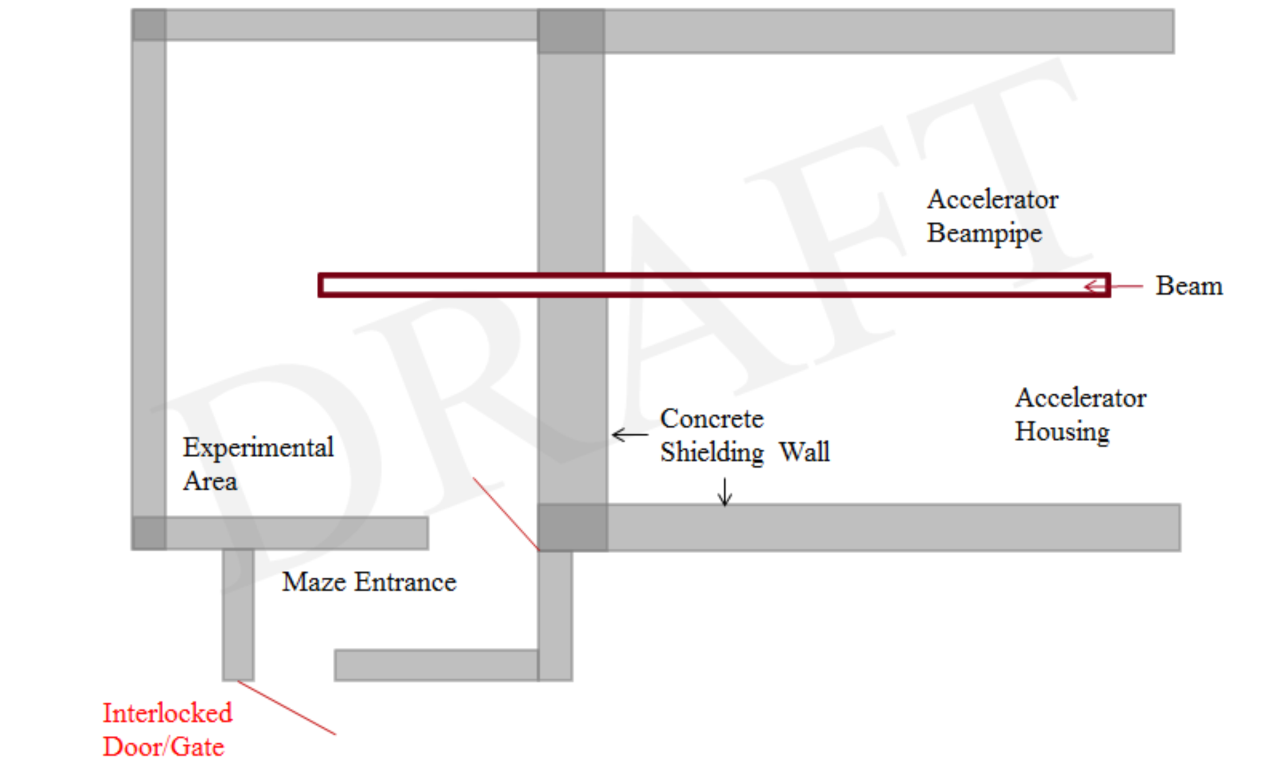


ANSI Standard N43.1 "Radiation Safety for the Design and Operation of Particle Accelerators", 2011

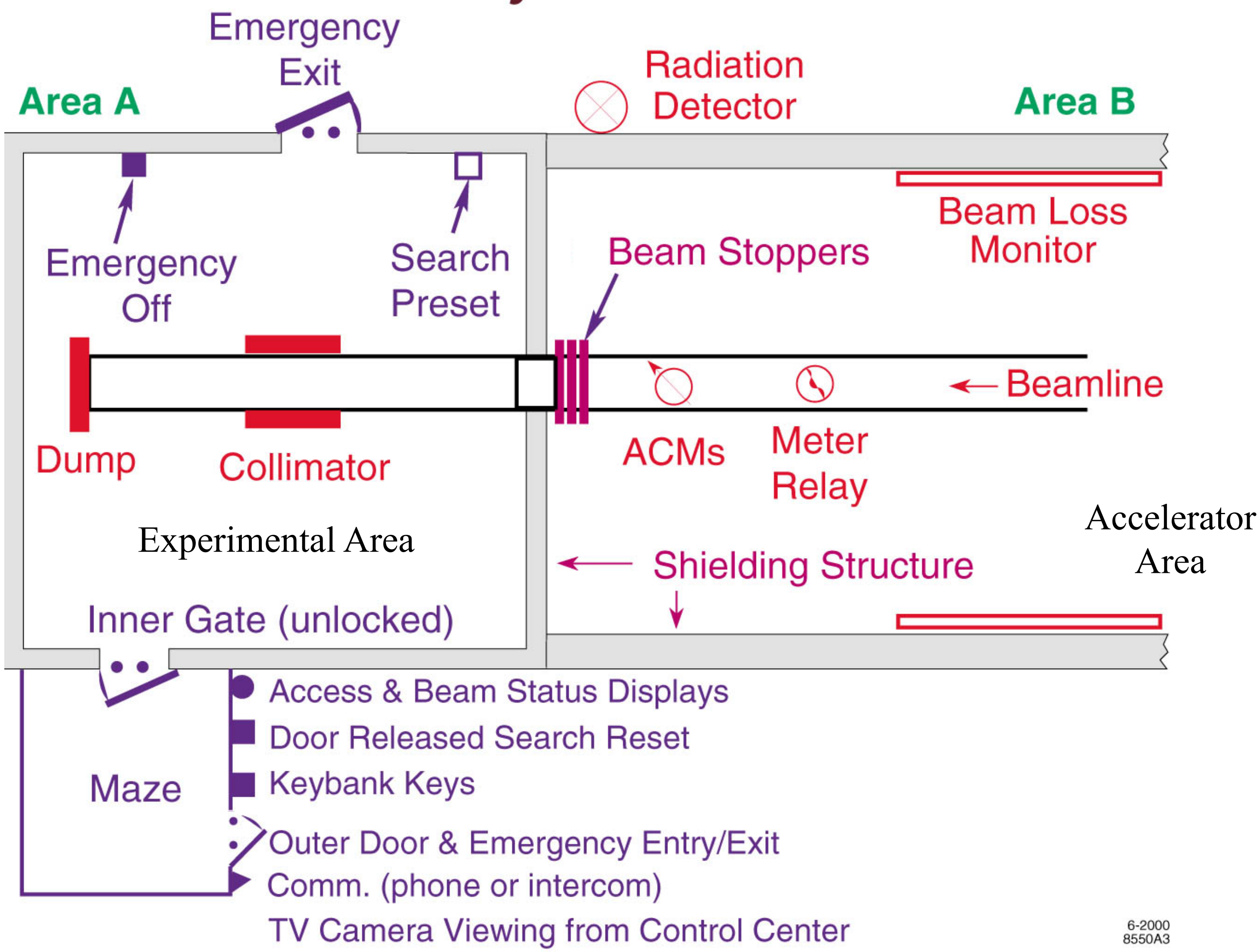
Radiation Safety System (RSS)

- RSS: Engineered safety systems to monitor, control and mitigate prompt radiation hazards
- ACS: keeps people away from radiation hazard
  - Access Control Modules
  - Beam Inhibiting Devices: stoppers
- RCS: keeps radiation hazard away from people
  - Shielding
  - Beam Interlocks
  - Radiation Interlocks

Radiation Safety System (RSS)



A Schematic Layout of ACS & RCS



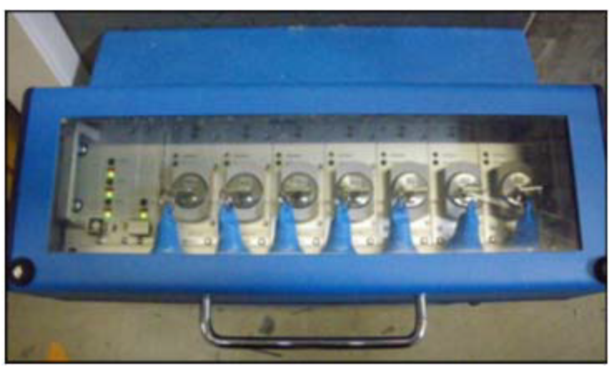
Access Control System (ACS)

keeps people away from radiation hazards

ANSI N43.1: A control system that prevents or controls access by personnel to hazardous areas deemed unsafe due to prompt radiation production

Access Control System (ACS)

- Entry and Access Control Modules
  - Enclosures
  - Personnel entry gates
  - Access and beam status display
  - Radiation warnings and signs
  - Communication and monitoring features
  - Emergency response features



Access Control System (ACS)

Sub-systems include:

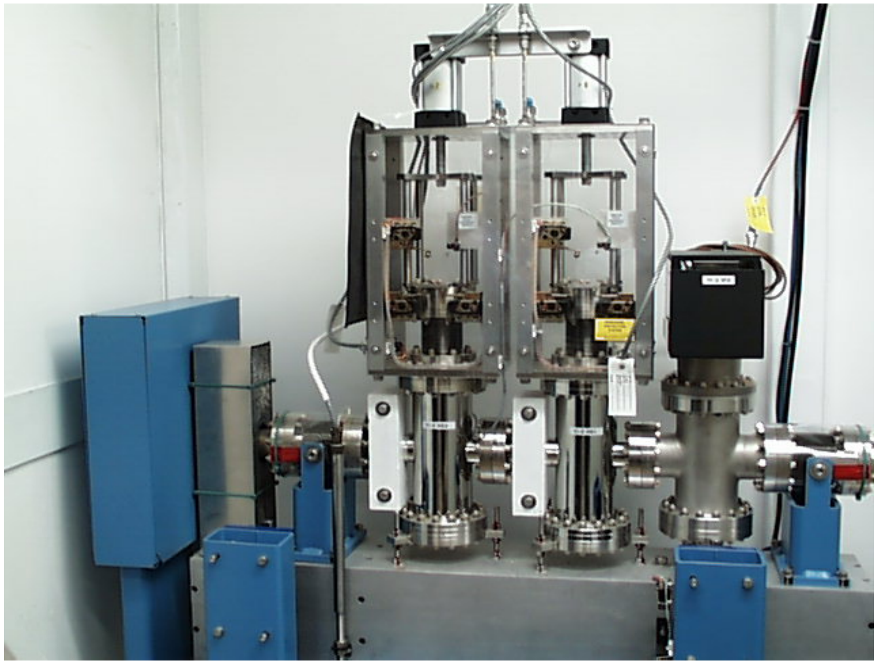
- key-banks
- TV camera
- access and beam status display
- search reset controls
- emergency off buttons
- beam stoppers

Interlocked with operation

- Guns, Klystrons, Stoppers

Access Control System (ACS)

- Beam Inhibiting Devices (BID)
  - Beam safety shutter, power supply for gun, RF, electromagnet, etc.
  - Normal access control function
  - Fault-response beam removal function



Beam Shutter Comparison

	SLAC	LANSCE	TRIUMF	TJNAF	DFELL
Number of Beam Shutter	3	2	3	3	2
Beam Shutter Failure Analysis	Yes	No	No	No	No
Protection of Beam Shutters	BTM & 2 devices	Fusible Beam Plug	Beam Spill Detectors	Beam Diffuser or ACM	

- Needs interlocks to terminate beam when excessive beam power (that may damage shutters) is detected

Radiation Control System (RCS)

Keeps radiation hazards away from people

A combination of passive system and active electronic systems that protects personnel outside the shielded enclosure from radiation hazard

- Shielding
- *Beam interlocks*
- *Radiation monitors*

Passive systems preferred over active systems

Maximum Allowable Radiation Levels and Doses

Table 2.9-2

Maximum allowable radiation levels and doses.

(a) Radiation Protection Instructions, DESY, June 2004.

(b) Radiation Safety Instructions, KEK, in Japanese, June 2004.

(c) Radiation Safety System, SLAC, April 2006.

(d) Fermilab Radiological Control Manual, FNAL, July, 2004.

	DESY (a)	TESLA	KEK (b)	SLAC (c)	FNAL (d)
Standard	20 mSv/yr	1.5 mSv/yr	20 mSv/yr	50 mSv/yr*	50 mSv/yr*
Operating Conditions					
Normal			20 μSv/hr (1mSv/week)	5 μSv/ hr (10 mSv/year)	
Mis-steering			20 mSv/event (20 mSv/year)	4 mSv/hr	
System failure			20 mSv/event (20 mSv/year)	250 mSv/hr for max. credible beam (30 mSv/event)	

***10 mSv/y shield design limit for new facilities**

From Toshiya Sanami (KEK)

SLAC Shielding Design Criteria

Bulk shielding	5 μSv/hr
Experimental hutch	0.5 μSv/hr
Ground water activity *	740 Bq/L for H-3
Site boundary	50 μSv/yr
Air activation**	10 μSv/yr

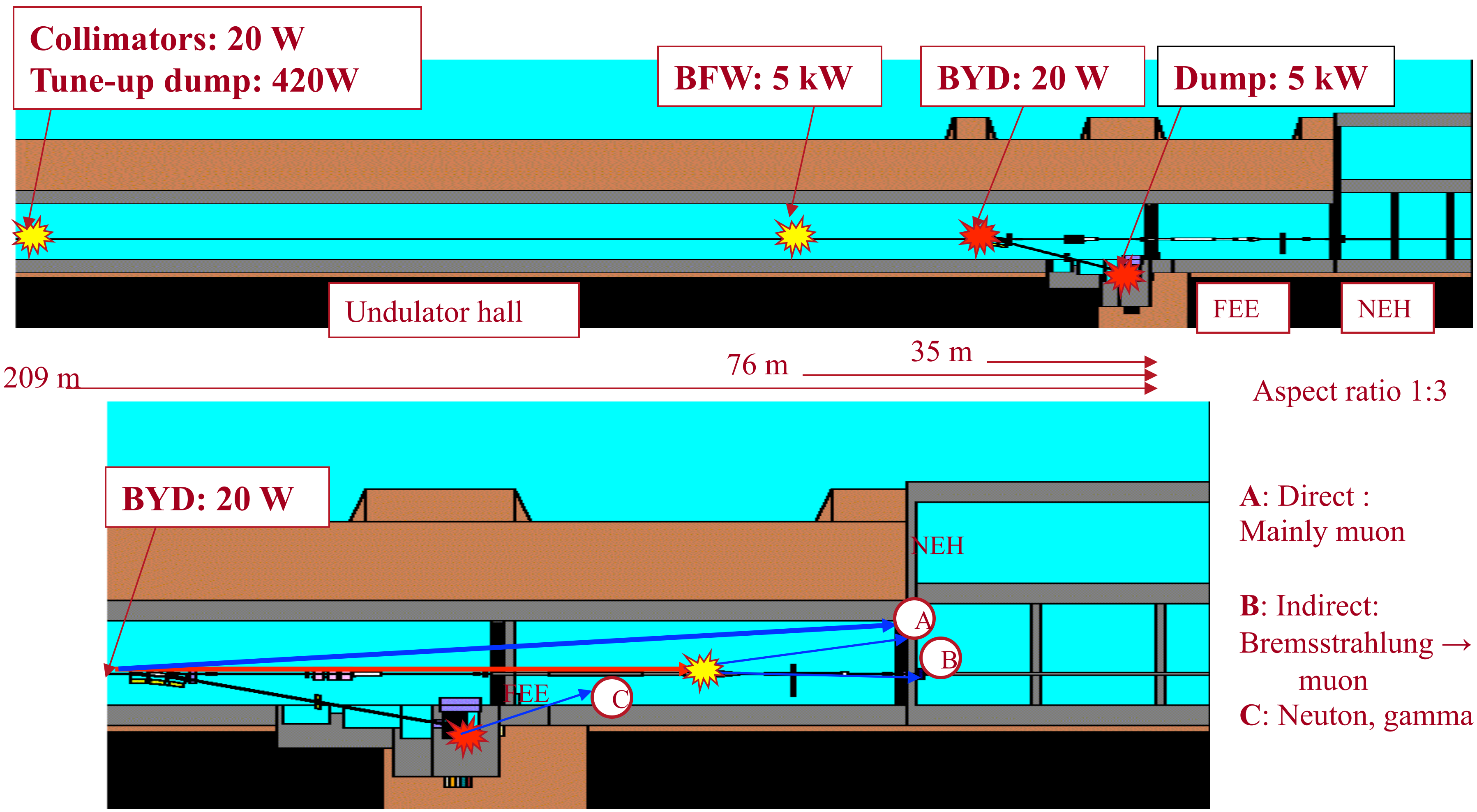
**non-detectable is the goal

* (1 μSv/yr from each release point)

Passive RCS (Shielding)

- Shield personnel outside the accelerator enclosure and public from prompt radiation generated during the operation
  - Inside the accelerator housing from highly activated components
  - Also used for protection of environment
- Shielding design needs to consider:
  - Many sources of radiation from different operation modes
  - Complex radiation fields (hadrons, electromagnetic shower, muons, multi-step processes)
  - Potential future upgrades
  - Cost effective
  - Conservative shielding design for both normal (allowed beam power) and abnormal (maximum credible beam power) operations
  - Designed and reviewed by qualified professional
  - Verification survey for normal and abnormal beam losses
  - Configuration Control program is crucial

Radiation Sources- Forward Angle



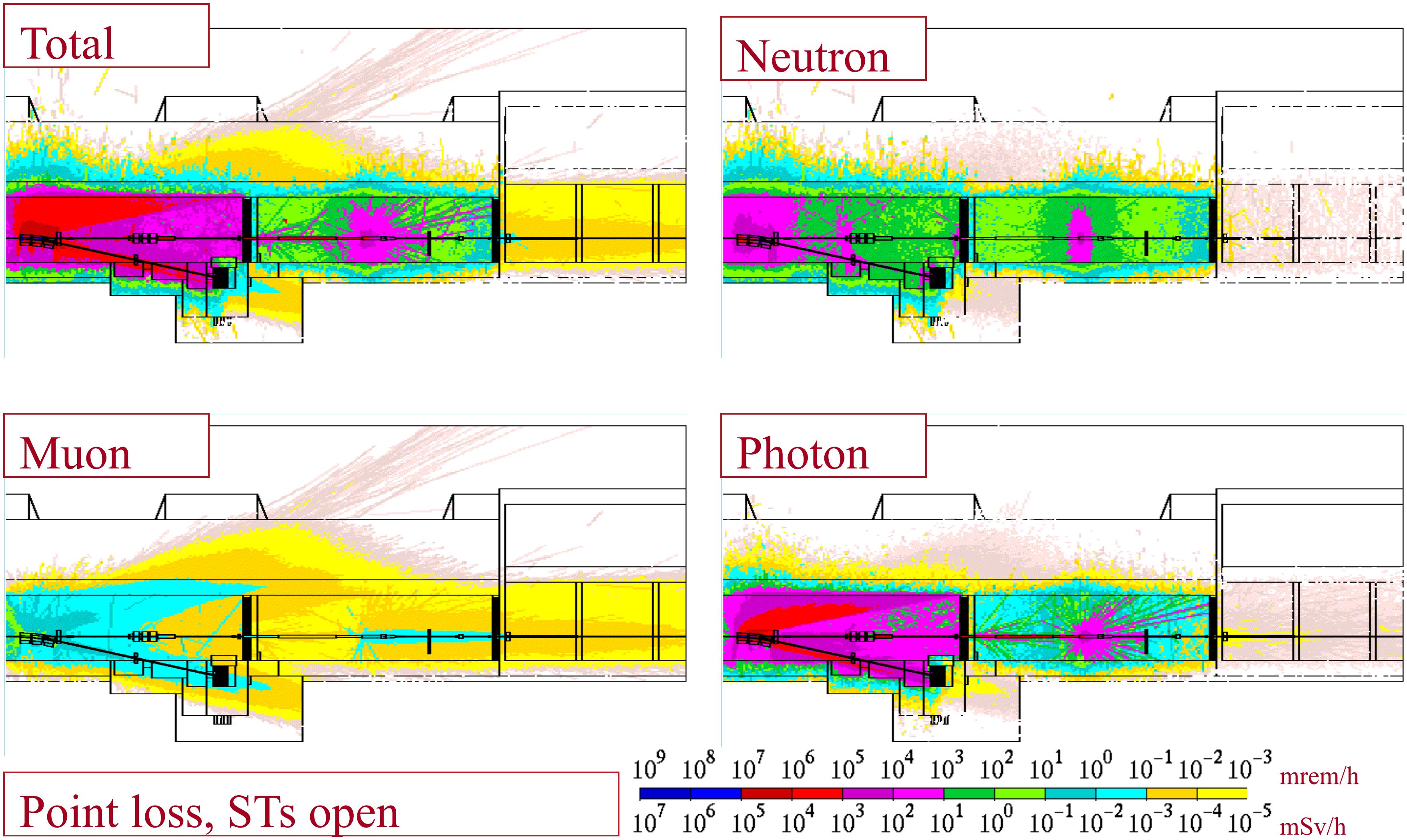
Aspect ratio 1:3

A: Direct :
Mainly muon

B: Indirect:
Bremsstrahlung → muon

C: Neuton, gamma

Radiation Components

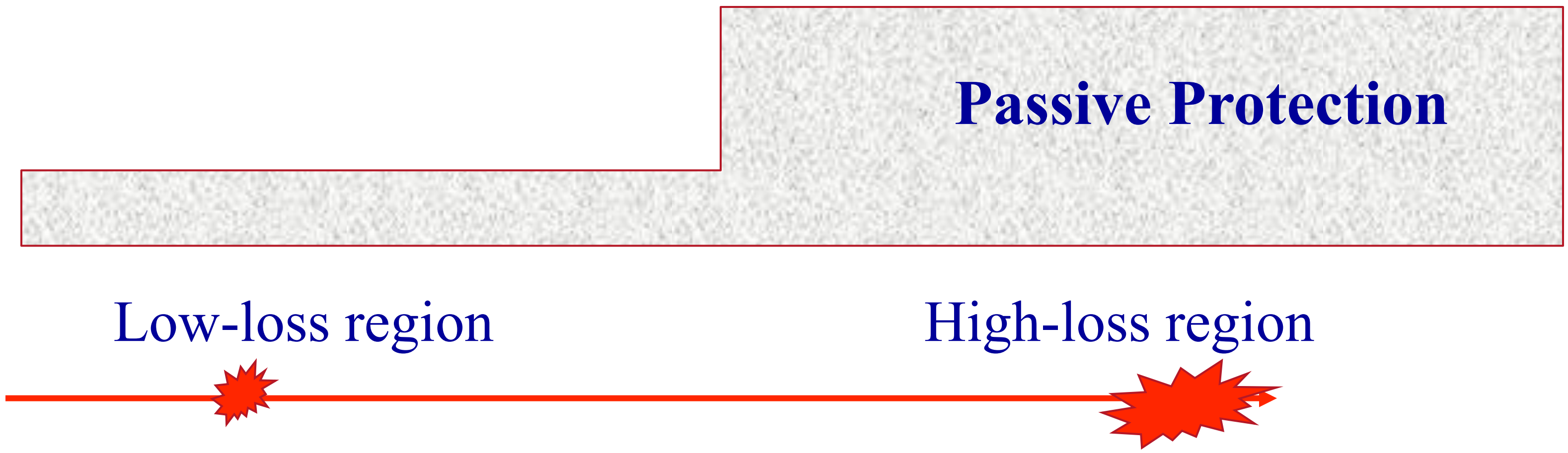


Shielding

- Importance of accurate beam loss estimates cannot be overstated
- Accelerator facilities are shielded sufficiently at high loss points (beam dumps, target areas, collimation sections, septa)
- But many facilities are not shielded for loss of full beam along the entire facility
- Some accelerator facilities can have high average beam power but with very low beam loss fraction

Dilemma of Shielding High-Power Accelerators

SLAC

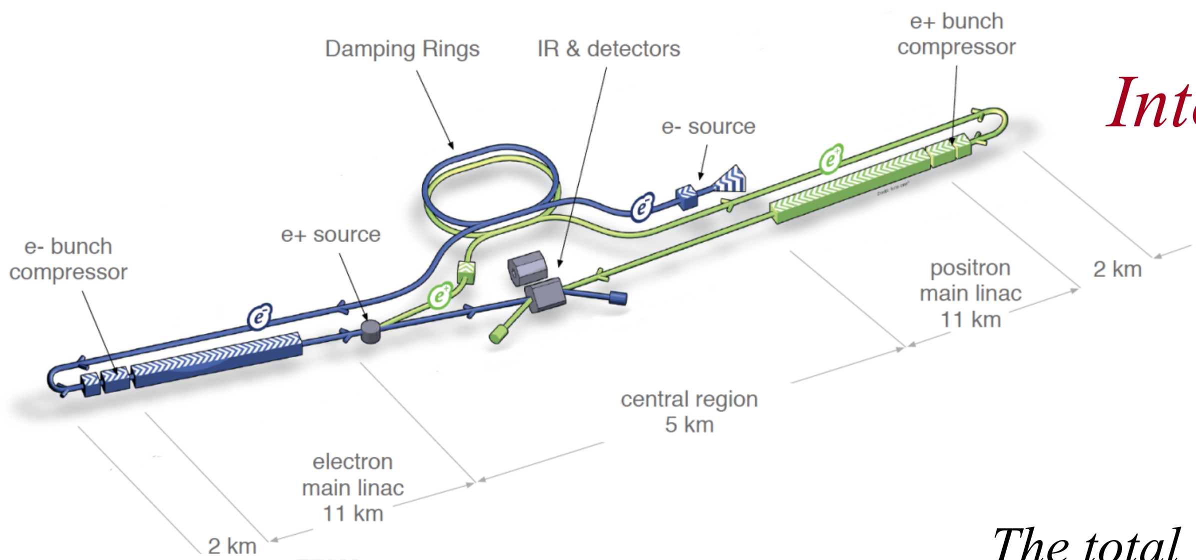


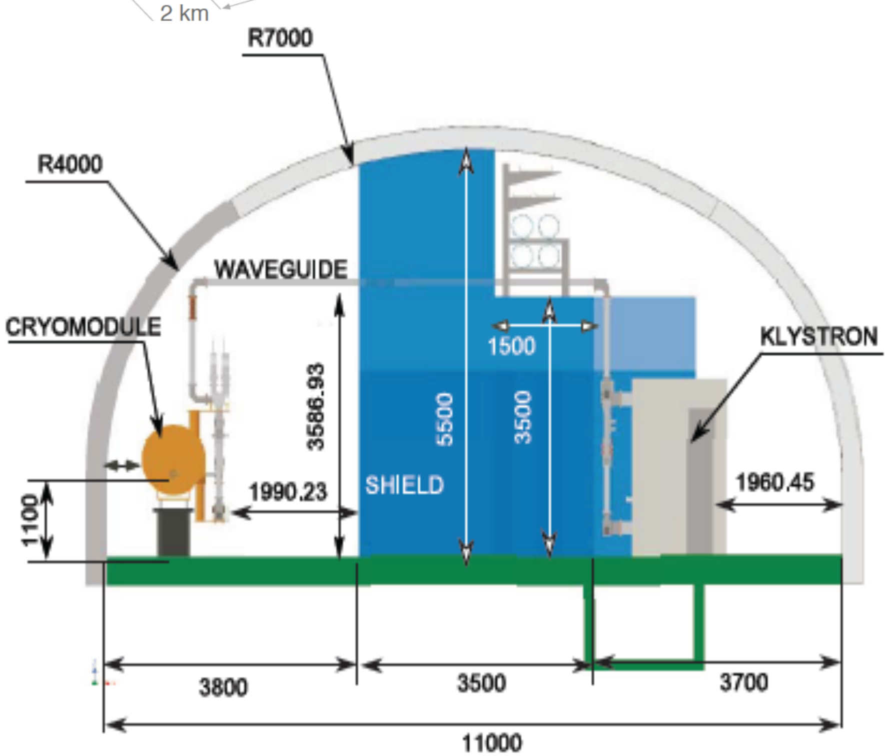
Should one install sufficient shielding to reduce radiation fields to low levels under conditions of maximum possible beam loss even if the chronic losses are very low,

OR

should one shield the low beam loss areas only for expected operational losses and rely on active protection systems to terminate beam operation at higher beam losses?

International Linear Collider





The total length and CMS energy of the ILC will be 31 km and 500 GeV; beam power 18 MW

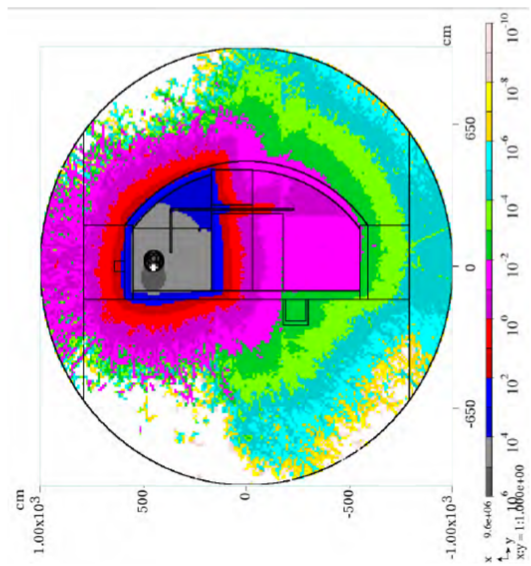
Normal Beam Losses:
Beam gas coulomb ,
Beam gas Brems
Touschek, SR, dark current estimated to be ~0.1 w/m

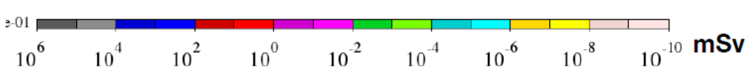
Calculated Dose Rate for a System Failure Case

ILC accelerator/Physics seminar Sep/29/2014 12:30-13:30

ML, RTML - dose rate at system failure

- (assumption) entire 1 pulse train beam is lost at one point. Operation is stopped for a while. This kind of accident would be happened at the rate of less than one time per year.
- Integrated dose for single 500GeV 4.26e13 electron loss
- Failure mode and it's effect are under consideration by each sub group





From Toshiya Sanami (KEK)

Beam loss under normal condition:

~ 0.1 w/m, requires 1 m of concrete to reach 20 μSv/h

Loss of 1 pulse train requires 3.5 m of concrete to reach about the same dose in one hour

How much shielding is needed?

Radiation Control System (RCS)

Keeps radiation hazards away from people

A combination of passive system and active electronic systems that protects personnel outside the shielded enclosure from radiation hazard

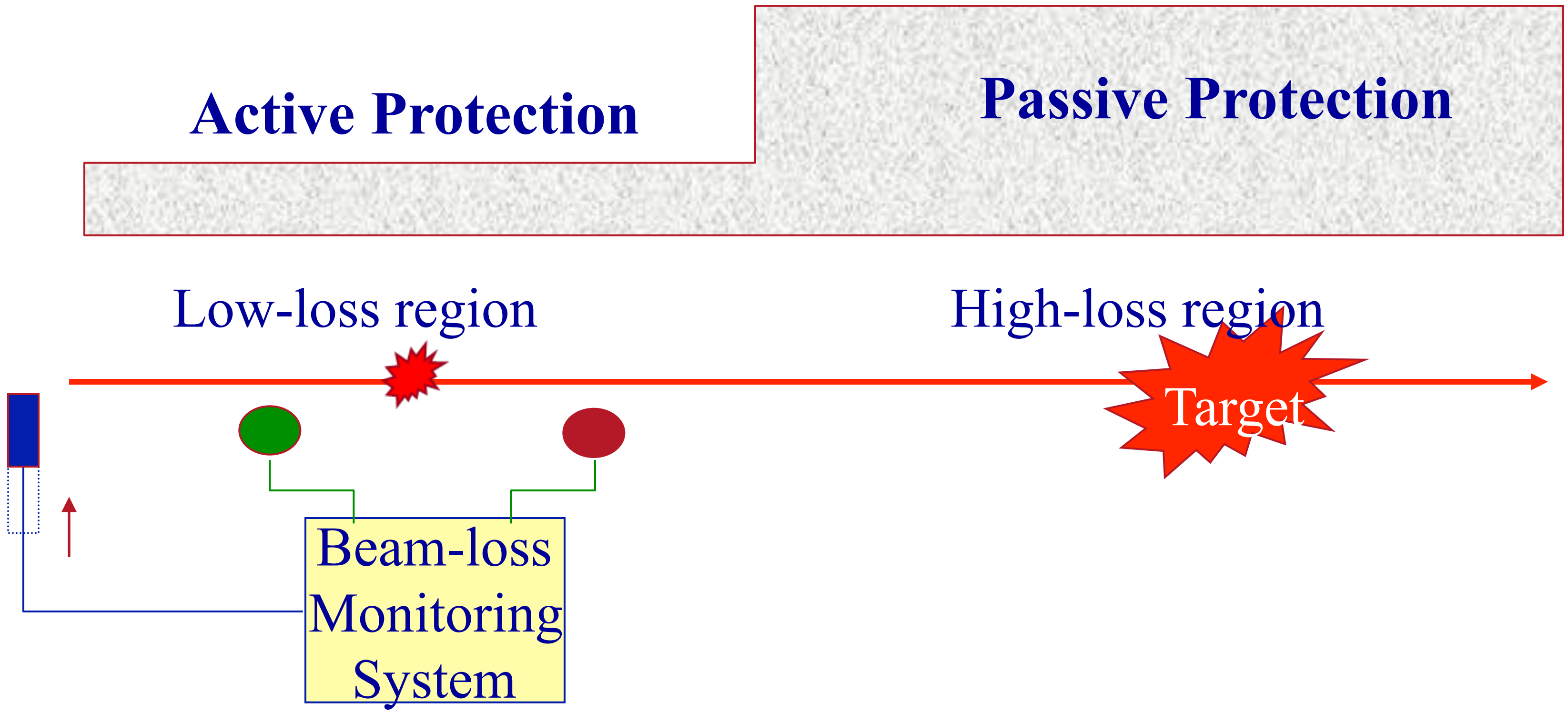
- *Shielding*
- Beam interlocks
- Radiation monitors

Active Radiation Control System (RCS)

SLAC

- RCS active components should be designed to detect unwanted beam operating conditions, and/or higher radiation levels than expected and terminate or limits the initiating conditions
- Protect personnel outside from radiation exposure resulting from both normal and abnormal operations

Passive RCS versus Active RCS



Active Radiation Control Systems

- Monitors/limits for beam energy, beam current, and beam losses
- Credited safety system
- Examples of such system include:
  - A beamline transducer, e.g., current toroid, secondary emission monitor, beam position monitor, repetition rate monitor or meter relay, radiation monitor
  - An electronic processing module that integrates or counts beam current pulses
  - A beam shut-off circuit connected to beam shutters, RF sources or high-voltage supplies

Electron Beam Burn-Through

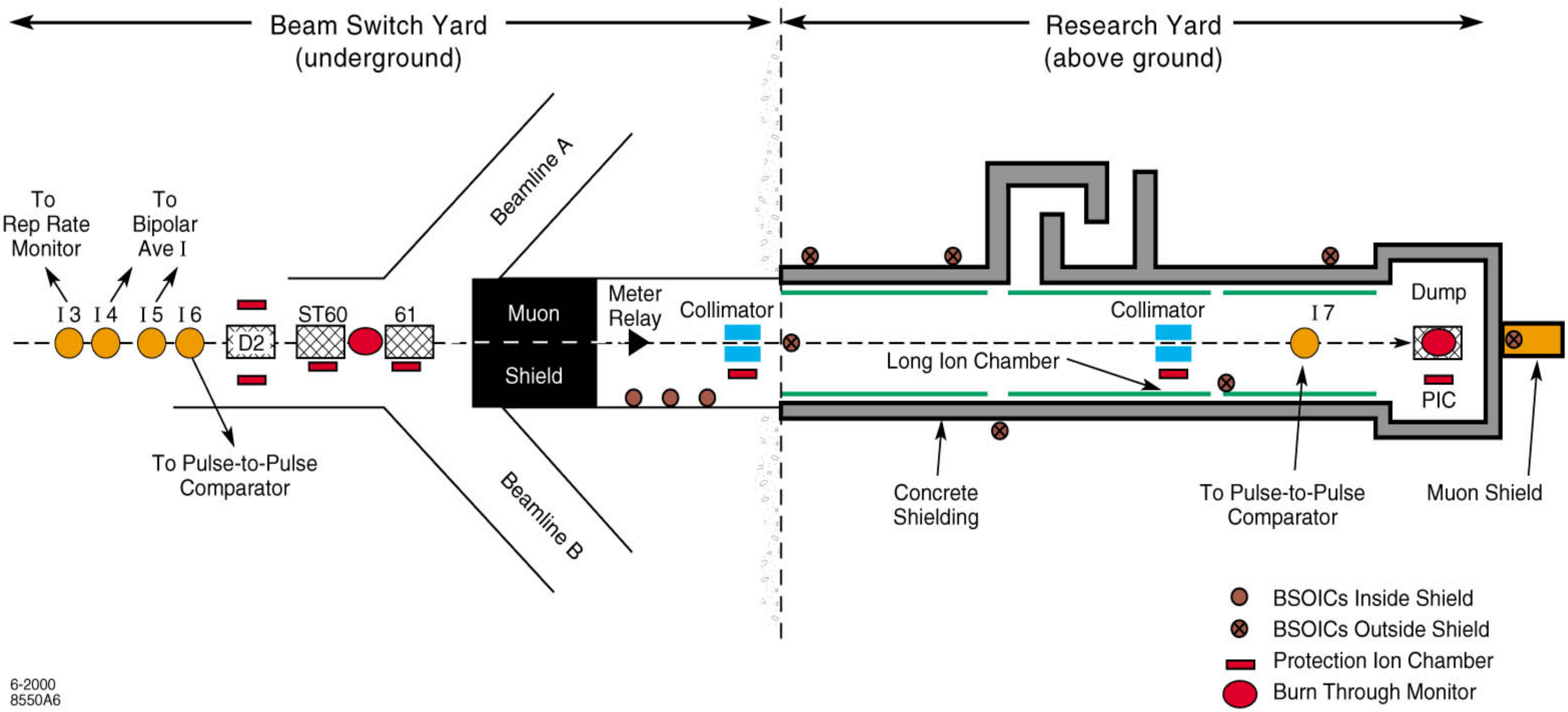
D. Walz et al., SLAC-PUB-1224, 1973

- Copper beam stopper (personnel safety device: 4" in diameter 30" long -53.6 r.l.) that was destroyed by the SLAC electron beam 500 kW, 18 GeV, (11 s for radial blow out, 49 s for burn through)
- Protection of Safety Systems devices:
  - Personnel Protection System or Machine Protection System?

Active RCS Systems

- Protection for mechanical beamline safety devices that have power ratings below the Allowed Beam Power
  - Coolant flow switches
  - Temperature sensors
  - Vacuum pressure sensors
  - Ionization chambers
  - Burn-Through Monitor (BTM), a pressurized chamber that ruptures on over-heating

Radiation Containment System for FFTB



Shielding versus Active RCS

- Normal beam losses need to be addressed by shielding
- Abnormal beam losses or operations need to be controlled by shielding, supplemented by active RCS
  - Dose per unlikely failure event need to be determined: (ANSI N43.1 proposes 10 mSv)

- Balance between passive and active systems
  - Passive systems are preferred

Access Control System versus Active RCS

- ACS failure ⇒ radiation hazard
  - Door or BID interlocks fail ⇒ high radiation
- Active RCS failure + abnormal machine performance ⇒ radiation hazard
  - Detector fails + abnormal beam loss ⇒ high radiation
- Implications: self-diagnosis, redundancy and fail-safe
- Beam shutters are ACS and RCS

Can MPS be used as a radiation safety system for protection of personnel?

Examples of safety failures in particle accelerator facilities

- Radioactive Material release from Hadron Experimental facility at J-PARC, Japan, May 23, 2013
- Beam Mis-steering event during Commissioning of the Brookhaven National laboratory’s NSLS-II Linac, May , 2012
- Contamination at Neutron Science Center at Los Alamos National Laboratory, August 2012
- Reverse polarity of dipole magnet in the Linac to Booster in the Canadian Light Source, October 2009
- Reverse polarity of dipole magnet in Experimental Area (End Station B) at SLAC, prior to 1973

There were no injuries, or known adverse health effects from any of these incidents

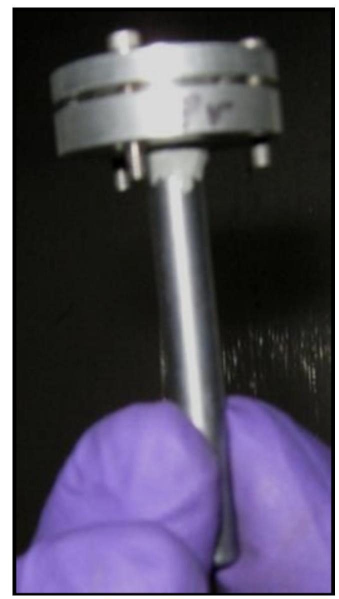
Safety System Failures

- Safety System failures (engineering and administrative) have several common threads:
  - Are avoidable
  - Involve several failures
  - Inadequate conduct of operations, inadequate safety management in organization
- Consequences:
  - Facility mission negatively impacted
  - Negative press coverage, reaction and/or over-reaction of regulating agencies
  - High cost to recover

LANSCE Contamination Event

On August 24th, 2012 contamination was detected on an individual using a Personal Contamination Monitor at the Lujan Center at LANSCE. This Resulted in the activation of the Emergency Operations Center and Declaring a General Emergency.

- Technetium 99 Sample likely source
- Spread off Laboratory:
  - Arizona
  - Numerous homes and businesses
  - Extensive effort to decontaminate off-site
  - Very difficult to manage
  - ~175 laboratory personnel involved
- Weeks to clean up ER-1



http://www.lanl.gov/discover/news-stories-a

LANL responds to radiologi...

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LANL responds to radiological incident

Multiple tests indicate no health risks to public or employees.

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Event Initiation and Emergency Actions

- August 24, 2012, ~ 6 PM, First Indicator
- August 25th, 2012 ~ 4:30 PM, Operational Emergency Declared
  - All levels of NNSA and DOE involved
  - White House notified
  - Off-Site assistance requested (Radiation Protection Program Teams)
- Priorities
  - Protection of public and workers
  - Contain and remediate the source of contamination
  - Determine the source of the contamination

Los Alamos NATIONAL LABORATORY EST.1943

Slide 3

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

NNSA

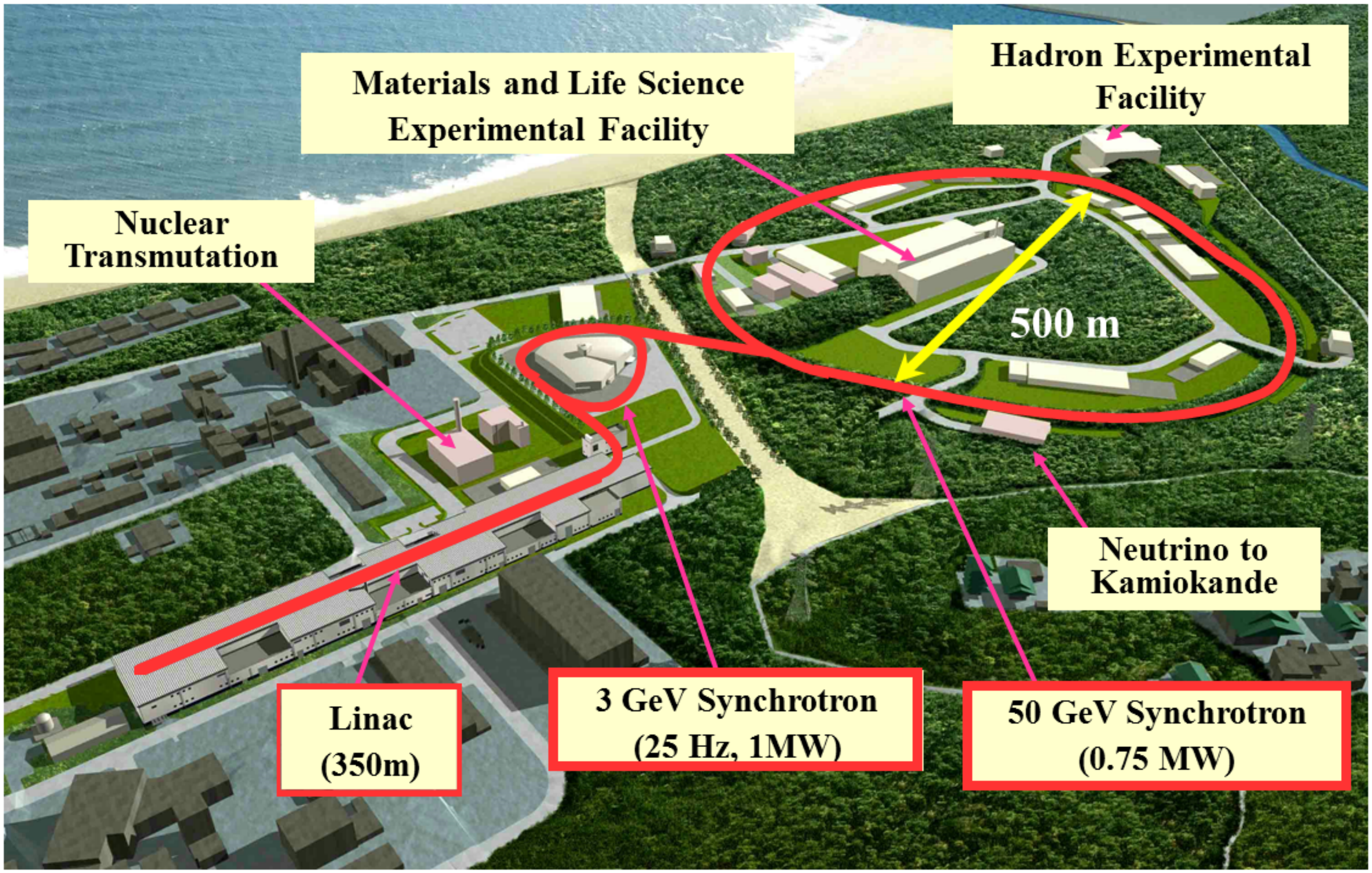
Precise estimates of the extent of personnel contamination and maximum doses are outside the scope of this report. However, based on the amount of contamination, no dose is expected to exceed 1 millirem. Note that persons living in the United States typically receive between 300 and 600 millirem annually from routine, natural and manmade sources (such as cosmic radiation and medical procedures).

The shipping containers and packaging were clearly marked to indicate that they contained radioactive material. However, the canisters themselves were not marked to indicate they contained a hazardous or radioactive material, nor was there a process at the Lujan Center for doing so. Comprehensive chain of custody procedures had not been implemented, and the third canister cannot be accounted for between January and August 2012.

Management processes tolerated deviation from expectations by facility personnel, both in terms of work expectations and with respect to storage and control of materials and equipment. Given these conditions (and similar conditions provided in more detail in the report), an accident of this type was inevitable and not attributable to the actions of any single individual. Rather, the accident was the result of management conditions and routine practices – developed over years – that were incompatible with a non-routine hazard.

This accident also was (and its recurrence is) completely preventable.

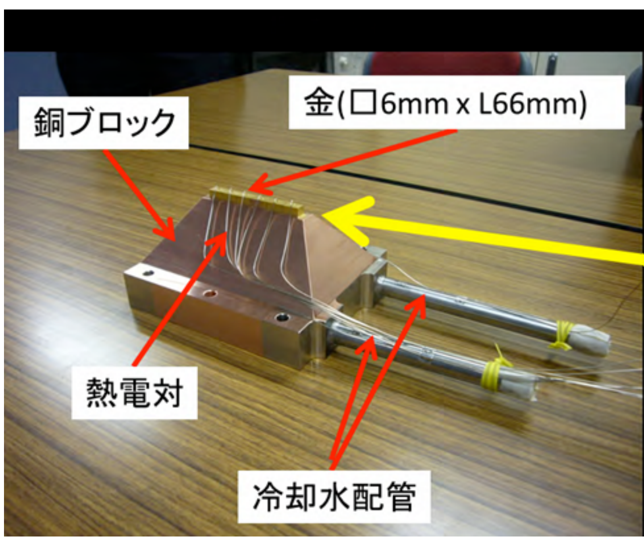
J-PARC Facility

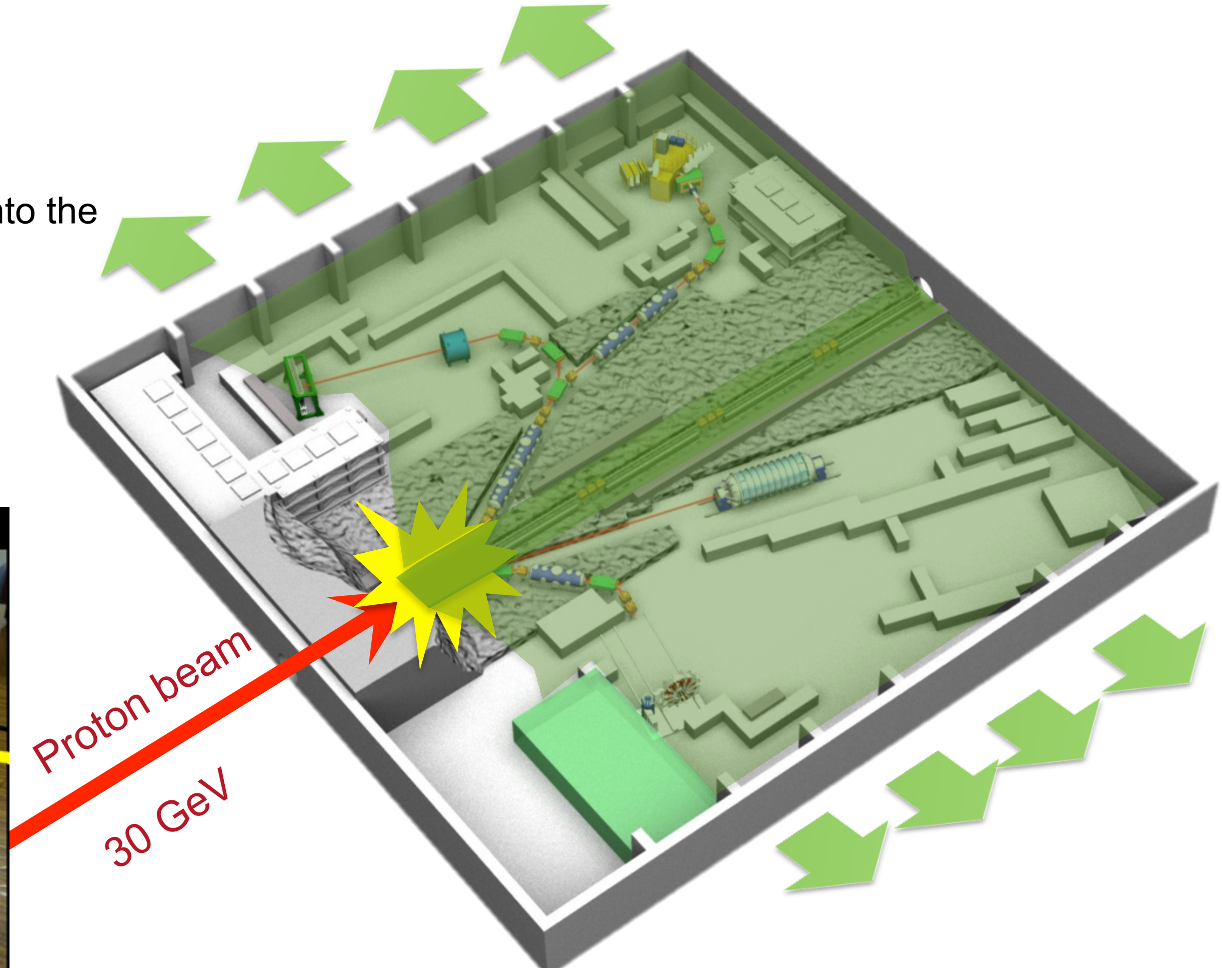


From H. Nakashima

Outline of the J-PARC Accident, May 23, 2013

- Abnormal beam was delivered to the target
- The target was heated up to a very high temperature
- Radioactive material was released from the gold target (about 20 GBq)
- Radioactive material leaked into the experimental hall
  → Workers exposed to radiation
- Radioactive material was released into the environment (outside of the radiation controlled area)

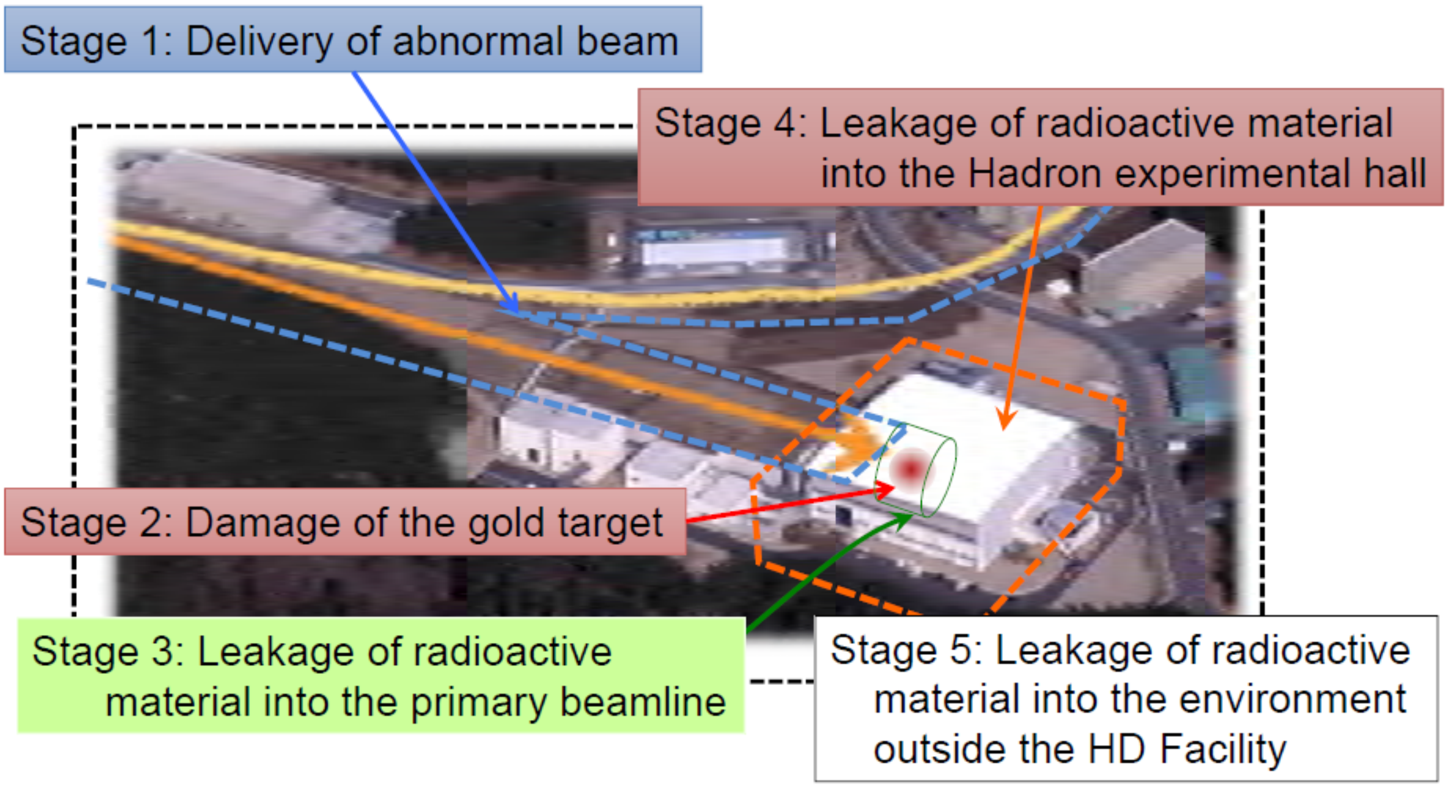




From H. Nakashima

2. Main causes of the radioactive material leakage

The sequence of the accident is dissected into five stages
where the causes therein are analyzed



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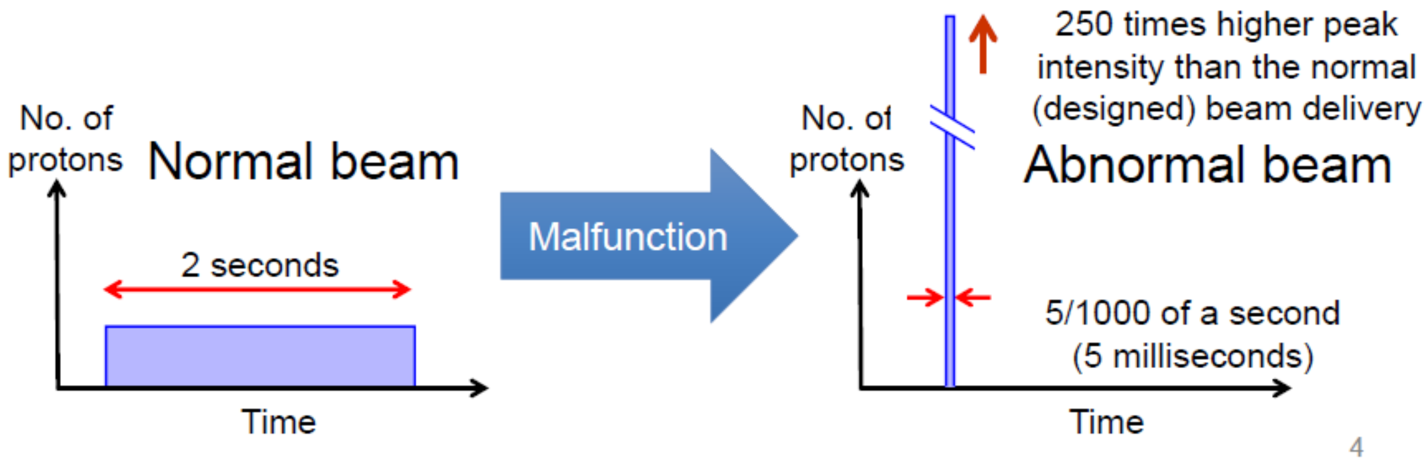
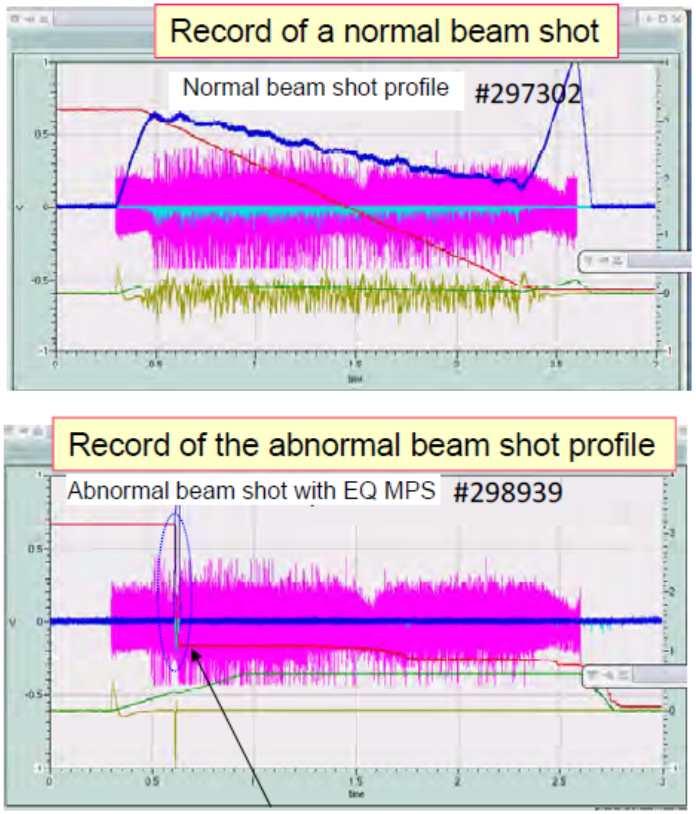
2. Main causes of the radioactive material leakage

Stage 1: Delivery of abnormal beam

- At around 11:55 of May 23, 2013, due to a malfunction of the slow extraction system of the 50 GeV Synchrotron (MR), a proton beam consisting of 2×10^{13} protons was delivered to the gold target within a very short period (5/1000 of a second).
- Normally 3×10^{13} protons are slowly and evenly extracted and delivered to the gold target over a period of 2 seconds.



2. Main causes of the radioactive material leakage
Stage 1: Delivery of abnormal beam



EQ: instantaneous high current output

The monitor display for beam extraction

Cause:
A power supply for driving a magnet, which controls the slow beam extraction, did not properly respond to the control signal during the first fraction of a second in the period of beam spill, and then it abruptly brought a large current to the magnet.

- The accelerator operation was automatically stopped by detecting the malfunction of the power supply and the signals from the beam loss monitors.
- While the operation staff of the accelerator misunderstood that it had been due to a malfunction of the fast extraction kicker. A large fraction of the proton beam in fact was delivered to the target in HD Facility.
- The accelerator staff did not recognize the incident as one that had led to any possibility of partial melting of the gold target.

red line: intensity monitor for the circulating-beam
light blue line: beam spill monitor
green line: preset value for the EQ power supply
blue line: output current of the EQ power supply
pink line: preset value for the RQ power supply
olive-green line: output current of the RQ power supply

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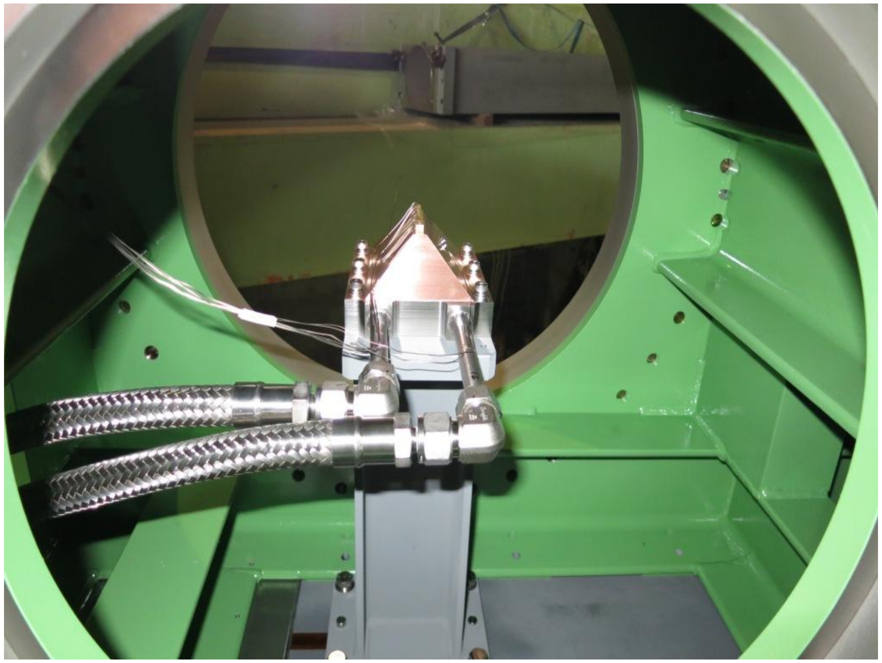
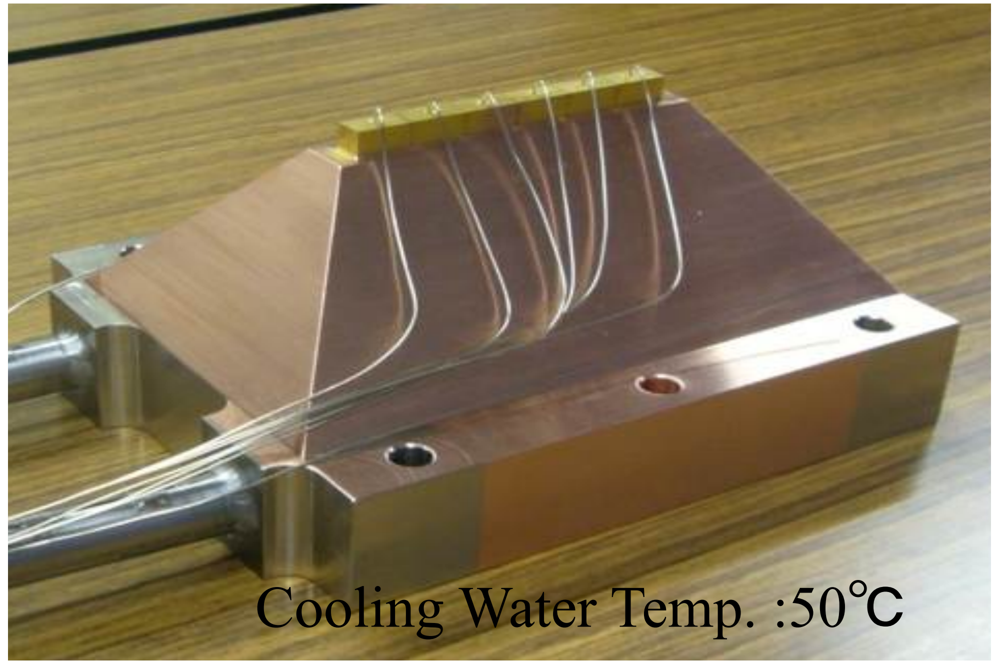
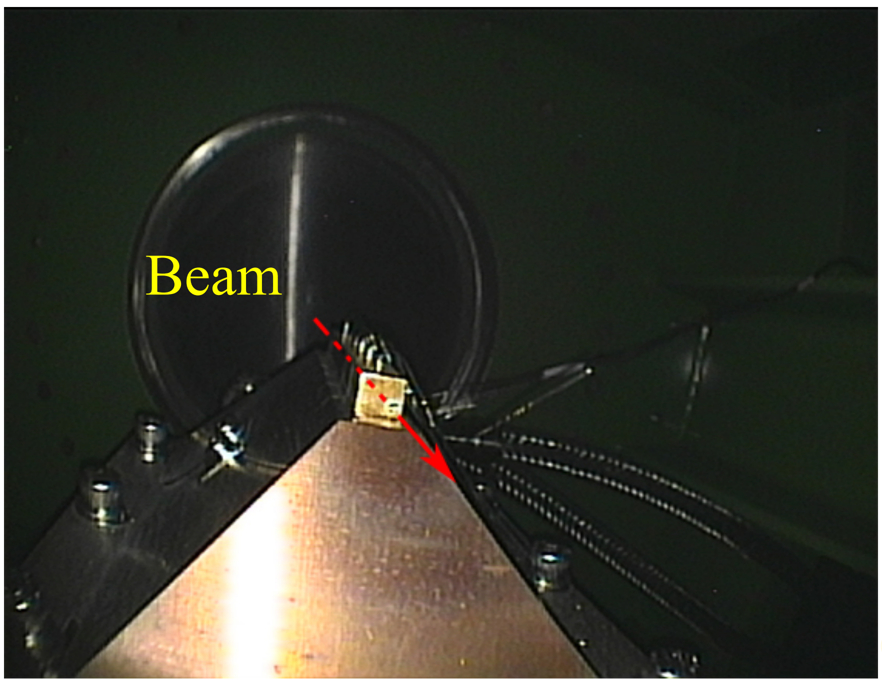
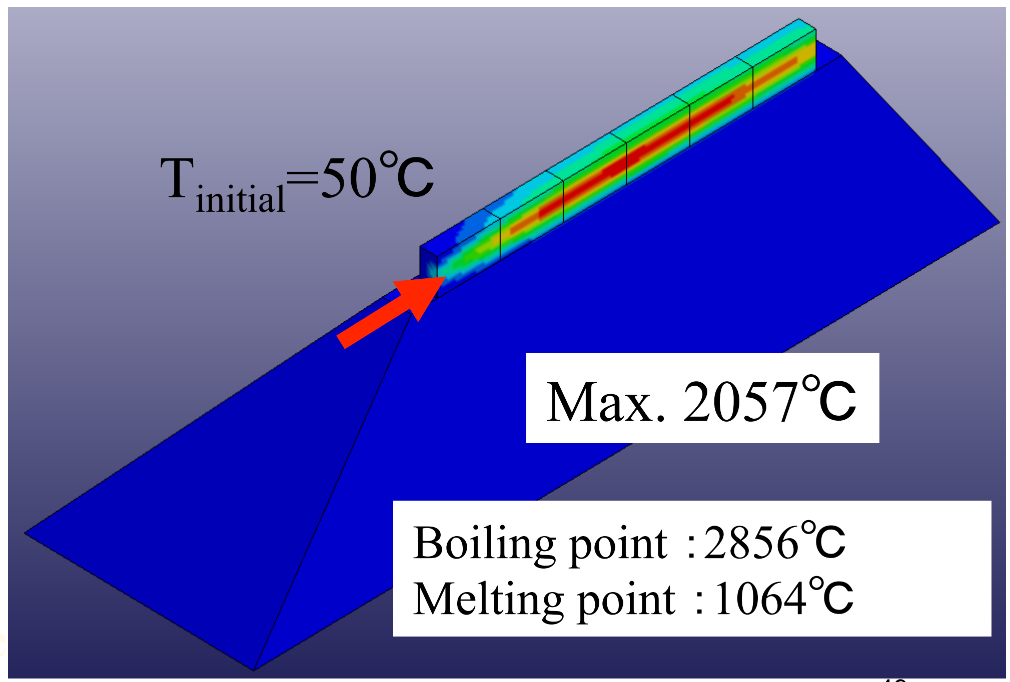
"…circuit board of the relevant the power supply was suffering aging degradation due to insufficient preventive measures against overheat in a three-terminal positive output regulator and it let to malfunction this time."



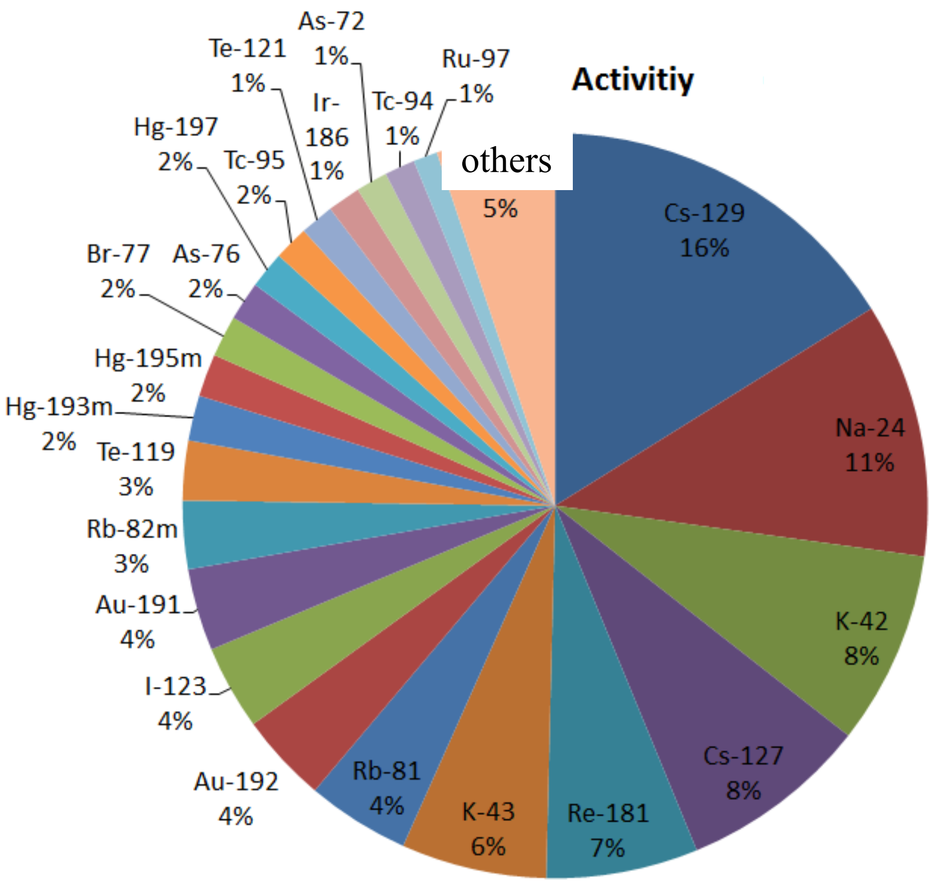

Cooling Water Temp. :50℃


Beam


$T_{initial}$=50℃
Max. 2057℃
Boiling point : 2856℃
Melting point : 1064℃

Measurement of nuclei leaked from Au target

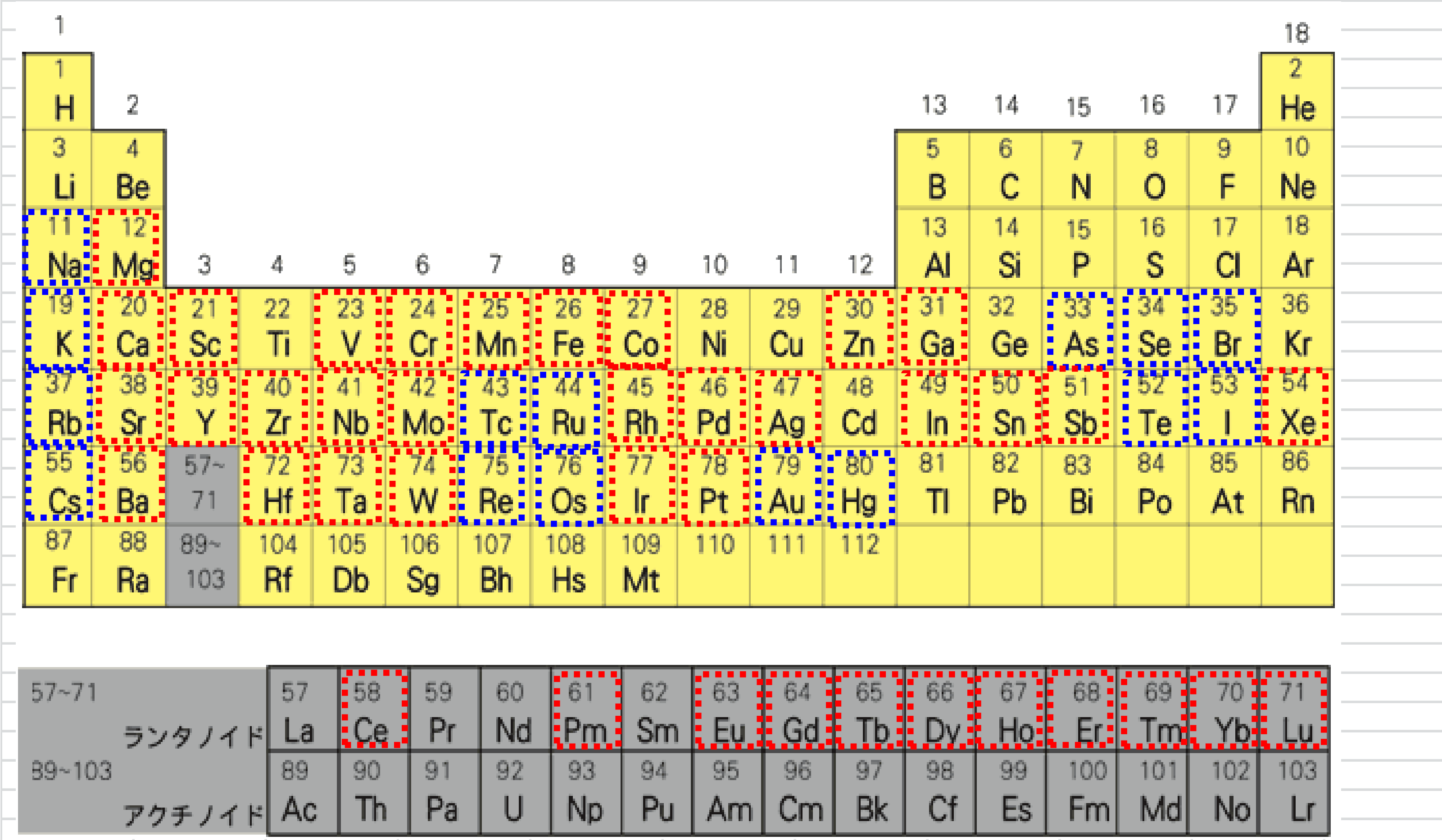
A 500ml air sample was corrected at 17:20, and the amount of nuclei in the sample was measured by a pure Ge detector.



Detection limit : 2.5×10^{-1}Bq/500cc

	Boil. (℃)	Reason
Hg	356.58	Vaporization
As	603	Vaporization
Cs	658	Vaporization
Se	684.9	Vaporization
Ru	688	Vaporization
K	765	Vaporization
Be	2472	Activation of air
Na	883	Vaporization
Ru	4155, RuO_4 (101℃)	Vaporization of Oxide
Tc	4265 , Tc_2O_7 (311℃)	Vaporization of Oxide
Os	5012, OsO_4 (130 ℃)	Vaporization of Oxide
Re	5596, Re_2O_7 (360℃)	Vaporization of Oxide
Au	**2857**	**Vaporization**

Expected Nuclei in Measurement at HD hall



Detected nuclei at the HD hall

From H. Nakashima

Not detected nuclei at the HD hall in measurement, although they are calculated by PHITS.

Radiation Exposure

- Internal and external radiation exposure measurements were performed for anyone who entered the radiation controlled area of the Hadron Experimental Facility after the accident occurred (102 person)
  - Number of persons showing detectable dose：34
    - All are radiation registered workers
    - Individual doses were in the range of 0.1-1.7 mSv
  - Number of persons showing no detectable dose：66
  - Whole body counter measurements were carried out on two users from overseas in their home countries
  - Maximum integrated radiation dose estimated to be 0.17 μSv (17 μrem) at the site boundary

Science 7 June 2013:
Vol. 340 no. 6137 p. 1155
DOI: 10.1126/science.340.6137.1155

‹ Prev | Table of Contents | Next ›
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NEWS & ANALYSIS

RADIATION SAFETY

Accelerator Leak Halts Japanese Physics Experiments

Dennis Normile*

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Nuclear physics lab continued experiment even after radioactive leak

May 25, 2013

THE ASAHI SHIMBUN

Scientists at a nuclear physics laboratory in Tokai, Ibaraki Prefecture, ignored the ringing of an alarm that radioactive substances were leaking and continued with the experiment that triggered the problem for more than four hours, the Japan Atomic Energy Agency said May 25.

The government and the public were kept in the dark for about 30 hours after the accident occurred. At least four scientists, all male, received internal doses of up to 1.6 millisieverts, about the same level that constitutes the annual background dose for anybody living in Japan.

The leak occurred at the Hadron Experimental Facility on the grounds of the Japan Proton Accelerator Research Complex (J-PARC), which is operated jointly by the JAEA and the High Energy Accelerator Research Organization.

About 20 scientists were in the laboratory at the time. The experiment involved bombarding gold with proton beams to generate elementary particles.

The alarm sounded at 11:55 a.m. on May 23.

Officials said 55 individuals entered the facility and were in close

The Japan Proton Accelerator Research Complex (J-PARC) in Tokai, Ibaraki Prefecture, on May 25 and the Hadron Experimental Facility, lower right (Wataru Sekita)

August 12, 2013

3rd Accelerator Facility Accident Report to Nuclear Regulation Authority

Incorporated Administrative Agency - Japan Atomic Energy Agency
Inter-University Research Institute - High Energy Accelerator Research Organization

Subject : The radioactive material leak at the Hadron Experimental Facility of the Japan Proton Accelerator Research Complex (J-PARC)

In addition to describing the facts, etc., investigated and disclosed after the 2nd report on June 18, the 3rd report has incorporated the preventive measures against recurrence from both the aspects of hardware and software, which reflect the contents subject to the review of the accident by the External Expert Panel.

Official summary of the report in English

Report of Findings

by the External Expert Panel to Review the Radioactive Material Leak Accident

at the Hadron Experimental Facility of J-PARC

August 22, 2013

[

Table 1: Correspondence between hardware-related arising issues and preventive measures against recurrence

Problems	Arising issues	Measures
Leakage of radioactive material	Malfunction of electromagnets	• Reinforcement of interlock system (prevention of overcurrent, etc.) • Faster interlocking system
	Insufficient hermetic sealing	• Making the target container airtight • Reinforcing airtightness of the primary beamline area
	Inadequate ventilation equipment	Venting the air in the HD hall through filters while monitoring concentration of radioactive material in the air
Delay in reporting to relevant authorities	—	—
Radioactive exposure of workers	Inadequate radioactive alarm system	Improving the monitoring system to observe radiation level in J-PARC facilities

Table 2: Correspondence between subject matters concerning the safety management system and preventive measures against recurrence

Problems	Arising issues	Measures
Leakage of radioactive material	Inadequate safety review system	Reinforcement of the radiation safety review system
	Ambiguous criteria for judgment	Review of the framework to respond to an anomaly (introduction of the "alert status") Improvement of operating manuals
	Ambiguous description of procedures for restarting beam operation	Improvement of operating manuals
Delay in reporting to relevant authorities	Insufficient information collection	Review of the framework to respond to an anomaly (introduction of the "alert status")
	Insufficient criteria for making judgment	Review of the framework to respond to an anomaly (introduction of the "alert status") Improvement of operating manuals
	Misunderstanding of laws and ordinances	Review of the framework to respond to an anomaly (introduction of the "alert status") Appointment of a Deputy Director to oversee safety
	Inadequate command system	Review of the framework to respond to an anomaly (introduction of the "alert status") Appointment of a Deputy Director to oversee safety
Radiation exposure of workers	Ambiguous criteria for evacuation	Review of the framework to respond to an anomaly (introduction of the "alert status") Improvement of operating manuals
	Poor system for information sharing	Review of the framework to respond to an anomaly (introduction of the "alert status")
	Poor system for safety education	Enhancement of employee education and user education

I

SLAC-PUB-1223
(A)
March 1973

TESTS AND DESCRIPTION OF BEAM CONTAINMENT DEVICES AND INSTRUMENTATION — A NEW DIMENSION IN SAFETY PROBLEMS*

D. Walz, D. Busick, T. Constant, K. Crook, D. Fryberger,
G. Gilbert, J. Jasberg, L. Keller, J. Murray, E. Seppi, and R. Vetterlein

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Summary

The destructive capability of the beam power of some accelerators was dramatically demonstrated in a series of tests at SLAC using an 18 GeV e^- beam at average powers ranging from 165 to 880 kW. The purpose of the experiments was to examine a series of devices which simulated beam stoppers, protection collimators and burnthrough monitors as presently applied at SLAC. Specific attention was given to the recording of burnthrough times, temperature behavior, and to the analysis of failure modes. A summary of the test data is presented. The design of an extensive electronic system to prevent damage to mechanical devices and to detect onset of destruction is discussed. Various sensors are connected to integrating and peak reading circuits to form power, beam verification and errant beam monitors. Burnthrough monitors shut down the accelerator

A real example of such a potentially serious situation has fortunately been known to happen only once at SLAC. During the initial health physics checkout a magnet with reverse polarity allowed the primary e^+ beam of 30 W to escape its proper transport enclosure and interact with the concrete wall instead of the beam dump. High-intensity radiation (360 R/hr) was discovered outside of a 1.8 meter thick concrete enclosure. Scaled to 900 kW, the photon dose rate would have been 3×10^3 R/s.

Thus, any review of the probable operational safety of a beam line poses questions about failure modes and burnthrough times. Burnthrough time in this paper is defined as the time interval from the beginning of beam exposure to the time when the beam emerges substantially unattenuated from the downbeam face of the power absorber, i.e., when the beam has destructively created a passage. Questions are

-Policy required initial radiation survey which discovered the problem
- -Survey meter went off-scale at 5 Gy/h
- -Turning beam off was via radio communication
- -Poor command of English language delayed beam off

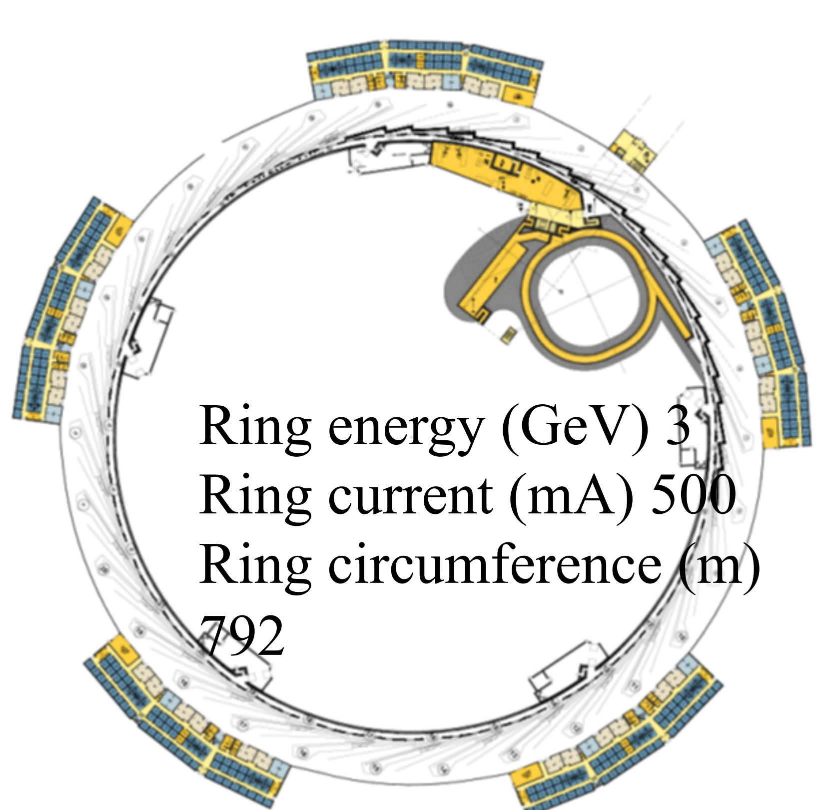
-SLAC Director asked for development and implementation of Beam Containment System (active RCS)

August 30, 2012

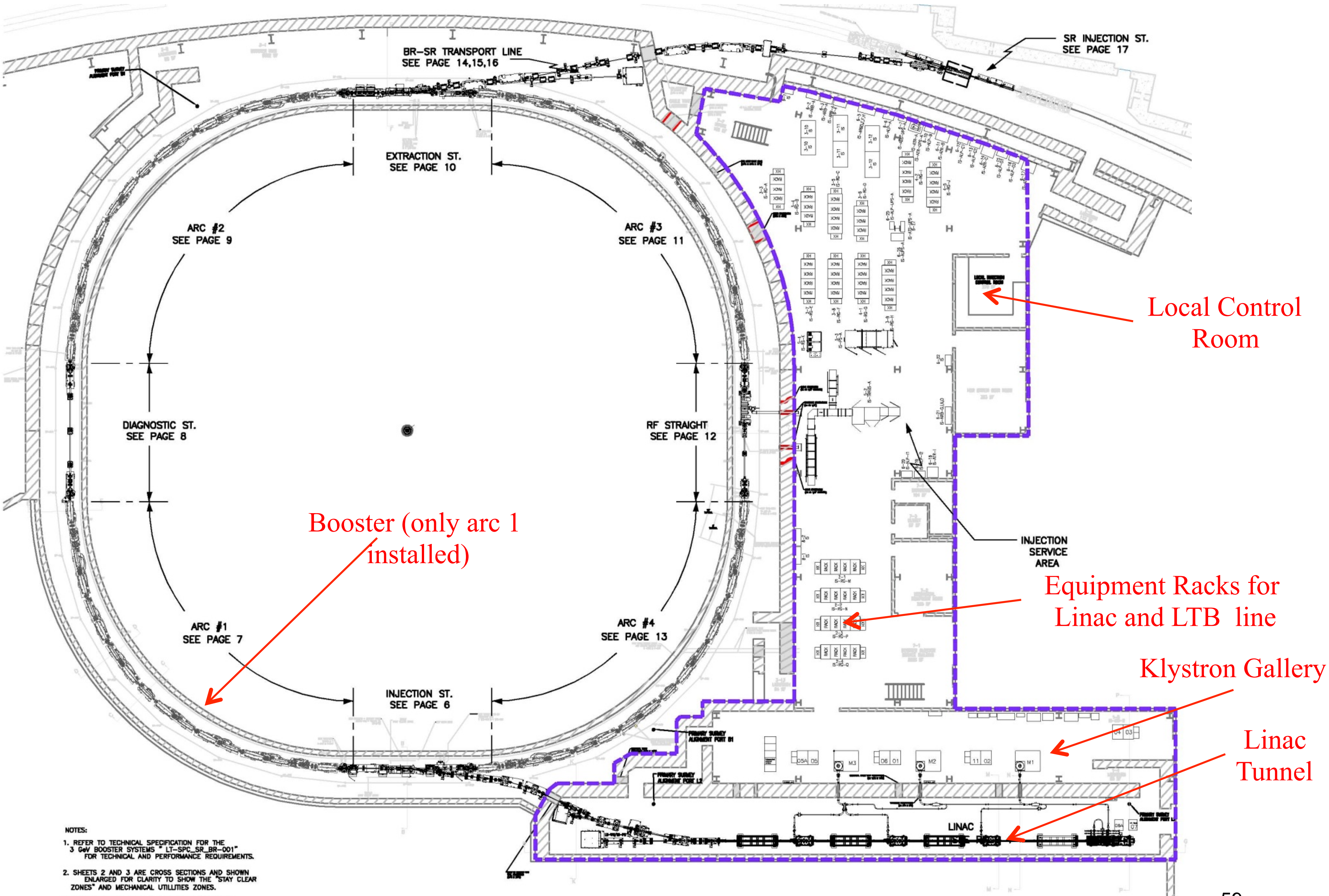
Report to the Associate Laboratory Director
Photon Sciences Directorate

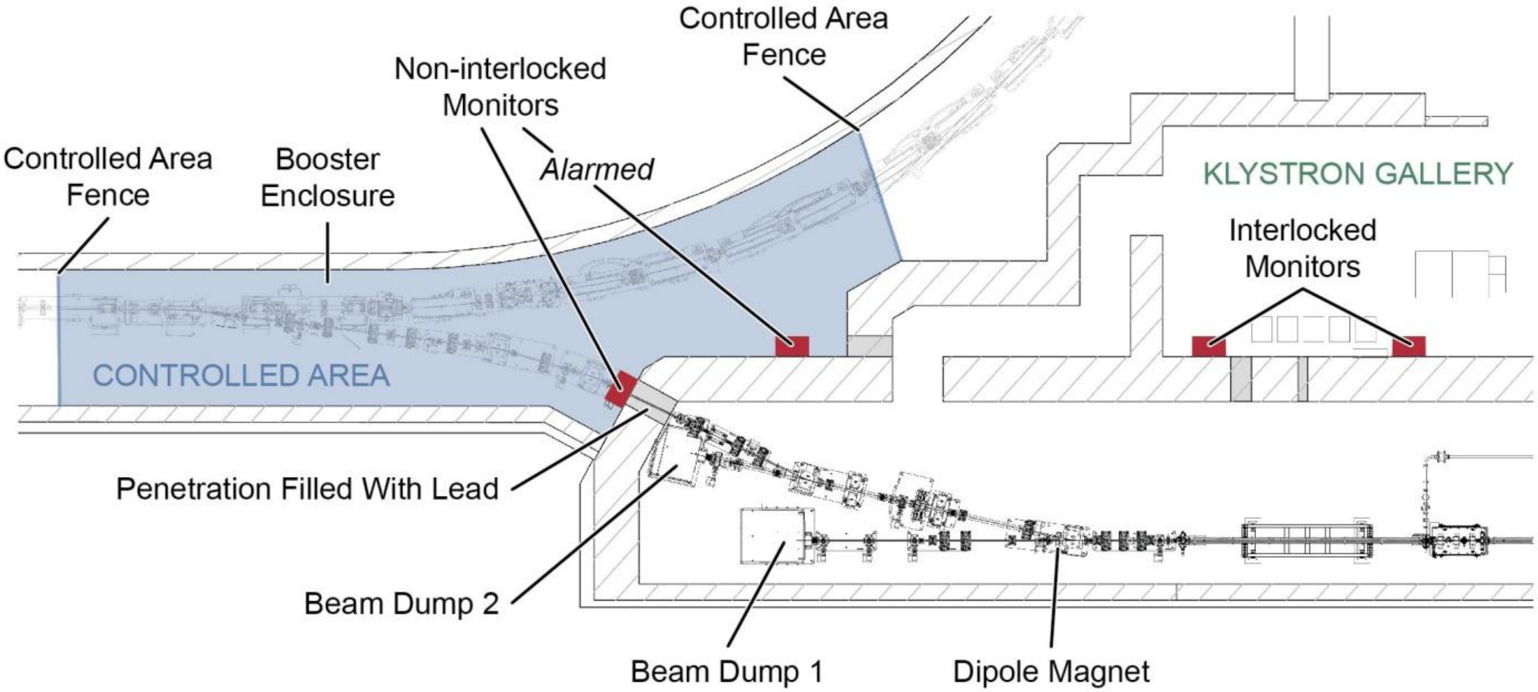
Independent Investigation
of a
Beam Mis-steering Event
during
Commissioning of the NSLS-II Linac
on
May 29, 2012

BROOKHAVEN
NATIONAL LABORATORY

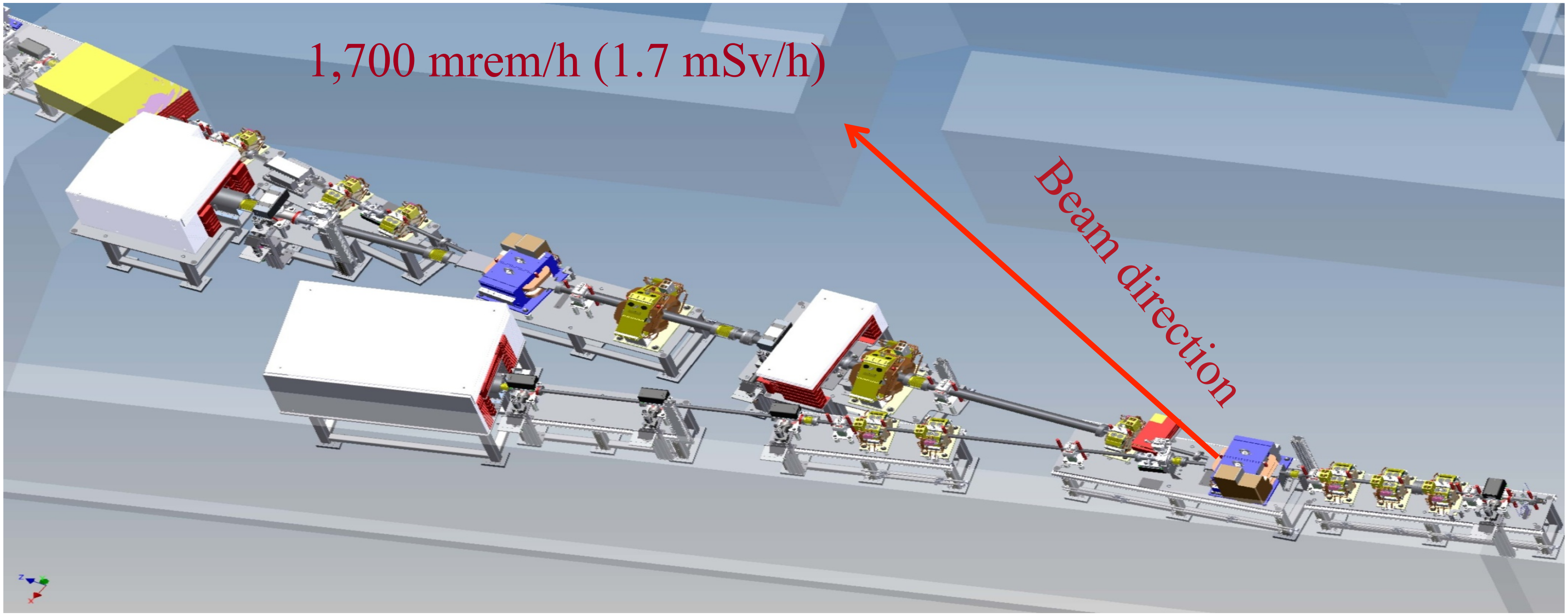


Injection Building





- During Linac injector commissioning, operator tuning machine with 100 MeV beam energy at 15 nC/s, while steering the beam to beam dump 2, the dipole ramped up to its maximum current
- This combination caused the beam to bend 4 times more than designed
- Beam misses downstream shield wall and created radiation levels in tunnel which caused local alarms


1,700 mrem/h (1.7 mSv/h)
Beam direction

Investigation Report

- Planning assumed that tuning would be conducted at 200 MeV
- Operators chose to begin the tuning at 100 MeV
- Operator accidently entered an out-of range current into the control system increasing the current to dipole LB-B1
- Radiation monitors in the region provided visual and audible warnings of the increased radiation fields
- The states of the non-interlocked monitors were not echoed on a dedicated display in the control room
  - Operators would have had to have called up alarm pages on the control room screens
  - It was subsequently determined that the data from the radiation monitors was not being correctly interpreted by the control system

Investigation Report

- Operators tried to diagnose the alarm by cycling the magnet to full power several times, thereby creating additional alarms within the Controlled Area
- Review of logs showed that on May 11, May 16, May 24, May 25, 2012: elevated radiation levels had occurred
- Shielding analysis did not consider use of 100 MeV beam
- The failure analysis considered that nominal beam energy would be 200 MeV and failure of 1 klystron would drop the beam energy to no less than 170 MeV
  - The peak radiation level in the booster enclosure was reduced from to 0.6 mrem/h (6 microSv/h) by the modified shadow shield

Hazard: Ionizing radiation		Target: Construction workers in booster	
What were the barriers?	**How did the barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect the event?**
			inadequately to the radiation alarms during commissioning
Roles and responsibilities for the radiation monitoring system (as part of systems important to safety) (CF-7)	Failed	Ability to implement alarm response procedure not reviewed by software Quality Assurance (QA) process	Allowed an opportunity to create high radiation levels in booster enclosure without Operator knowledge; radiation alarm systems in Control Room did not work to inform the Operators
Hardware readiness (CF-3)	Failed	ARR team did not verify Control Room hardware readiness	Allowed an opportunity to create high radiation level in the booster enclosure
ARR review of configuration management	Failed	ARR team did not adequately review PSD configuration management process	Did not identify various failed barriers that contributed to this event
Configuration/Change Management			
Shielding design action tracking (CF-1)	Failed	Operations safety working group did not track a recommendation to re-analyze shielding for the actual beam energy evolutions in order to verify whether assumptions made in 2010 about the capabilities of the Linac matched the Linac installed in 2011 (see Minutes of Meeting on March 9, 2010, Design basis documentation)	Shielding not analyzed for actual beam conditions; did not shield bending magnet under all practicable operating or commissioning conditions
Change Control (CF-1)	Failed	The difference between the specified Linac and the installed Linac did not trigger formal change control processes in configuration management; e.g., failure of one klystron would result in 100 MeV beam, not 170 MeV beam, as specified in the LCSAD	Shielding not analyzed for actual beam conditions; did not shield bending magnet under all practicable operating or commissioning conditions; design, safety documentation staff, radiation safety,

Direct cause:

•Operators exceeded 42 amps in magnet current to bending magnet 1 for 100 MeV beam

Root Causes:

1.PSD did not effectively implement change management processes (e.g., not tracking changes to shielding assumptions)

2. PSD did not effectively implement the Conduct of Operations

3. PSD did not effectively implement the ARR process

Contributing Causes

- PSD did not have a documented strategy to review shielding and track long-term actions
- Safety analysis not comprehensive to include 100 MeV beam; this would have been captured by turnover between the SAOS and the local shielding review team
- PSD's ARR process was inadequate in that it did not verify implementation of procedures, safety review process, Control Room equipment, or chain of command.
- Duties of the Control Room Supervisor were not assumed by a specific individual
- PSD's implementation of the Conduct of Operations Manual was found to be inadequate
- The requirement for *a* detailed radiation survey, which was not performed by RCTs for 100 MeV beam, was poorly defined by procedure LT-C-ESH-LC-RAD-001
- QA Program insufficient
- Operator training ineffective
- Operations procedures not followed or implemented properly

Safety System Failures

- Safety System failures (engineering and administrative) have several common threads:
  - Are avoidable
  - Involve several failures
  - Inadequate conduct of operations, inadequate safety management in organization
- Consequences:
  - Facility mission negatively impacted
  - Negative press coverage, reaction and/or over-reaction of regulating agencies
  - High cost to recover

Summary

- Particle accelerator facilities need Radiation Safety Systems to protect personnel from prompt radiation
- ACS, shielding and active RCS are all needed:
  - consistency and balance among the systems
- Program, policies are needed to:
  - Analyze hazards and identify controls
  - Commission, maintain and operate RSS in a rigorous manner
  - Define clear role and responsibilities
- RSS life-cycle management including independent and thorough review of the RSS systems and program, are essential

Acknowledgment:

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Work, materials and figures from many of them is used in preparation of this lecture.

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ES&H

END

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Appendix 2

Report from the Working Group

Working Group for the External Expert Panel
on the Radioactive Material Leak Accident
at the Hadron Experimental Facility of J-PARC

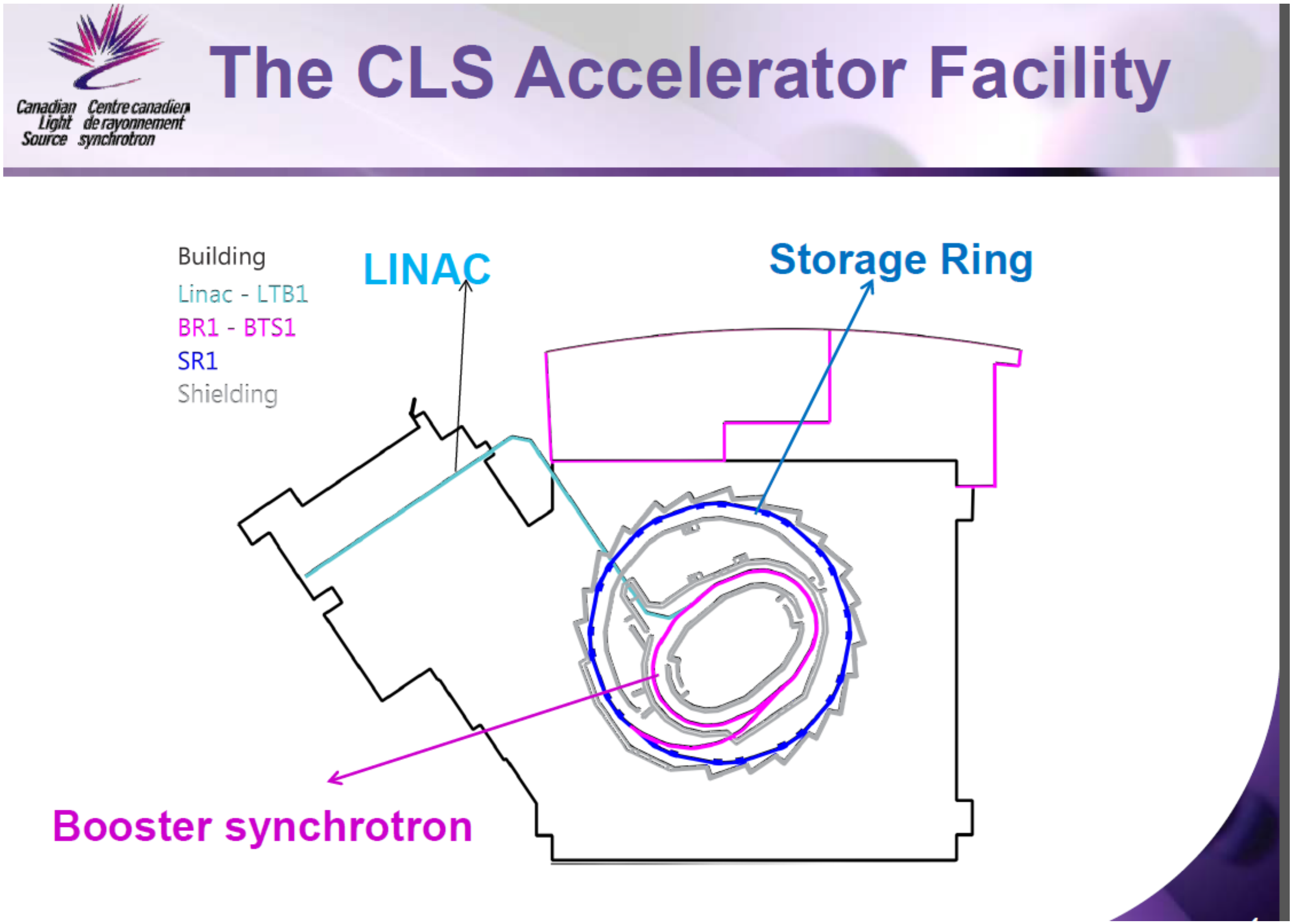
1. Progress report
2. Main causes of the radioactive material leakage
3. Problems in the safety management system

The Second External Expert Panel Meeting to Review the Radioactive Material Leak Accident at the Hadron Experimental Facility of the J-PARC at KKR Hotel Tokyo on July 5, 2013

1

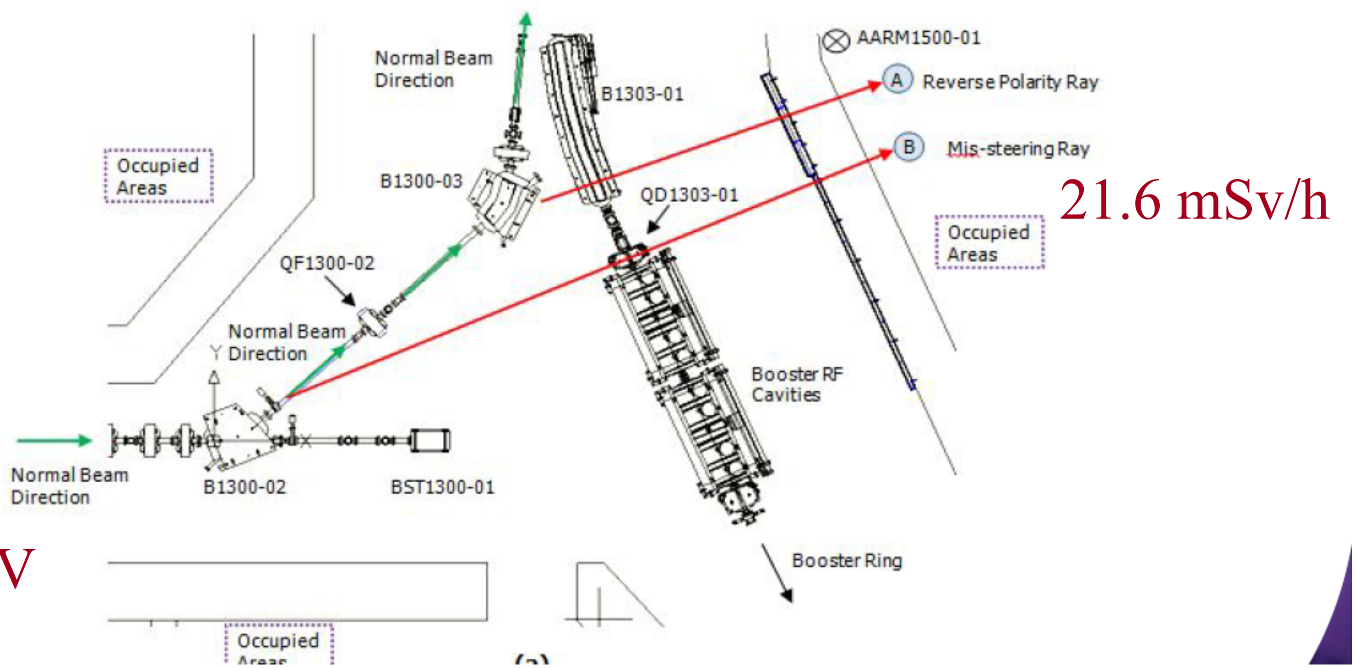
J-PARC Center Report- November 11, 2013

After the accident, the J-PARC Center has investigated the cause of the malfunction of the EQ magnets in cooperation with the manufacture of the EQ power supply. As a result of the investigation, it was identified that a transient failure occurred in part of the transmission system of the power supply, not correctly transferring current command input as follows. The failure was resulted from voltage drop in a circuit board of constant voltage power supply that supplies a voltage of 5V to the interface circuit board that converts an external input signal. The EQ power supply had operated without a failure since 2009. However, a circuit board of the relevant power supply was suffering aging degradation due to insufficient preventive measures against overheat in a three-terminal positive output regulator and it let to the malfunction this time. To avoid having recurrence of aging degradation, we will change the configuration of the circuit board of the power supply.



From M. Benmerrouche

Linac to Booster Transfer Line between Dipoles B1300-02 and B1300-03



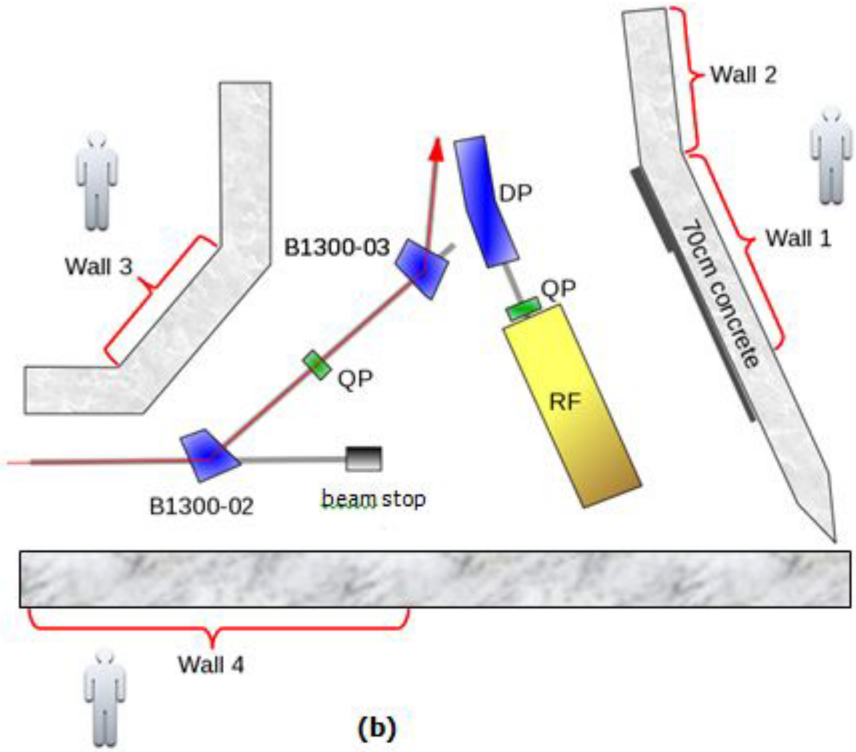
21.6 mSv/h

250 MeV

2.1 W

5 to 15 minutes

From M. Benmerrouche



The dosimeters of personnel involved as well as an area monitor dosimeter were collected and submitted for processing. The whole body gamma and neutron dose results for the dosimeters were found to be below the detection limits of the dosimeters.