포항 방사광 가속기의 방사선안전 특성 및 현안

Radiation Safety of PAL Synchrotron Facilities and Current Issues

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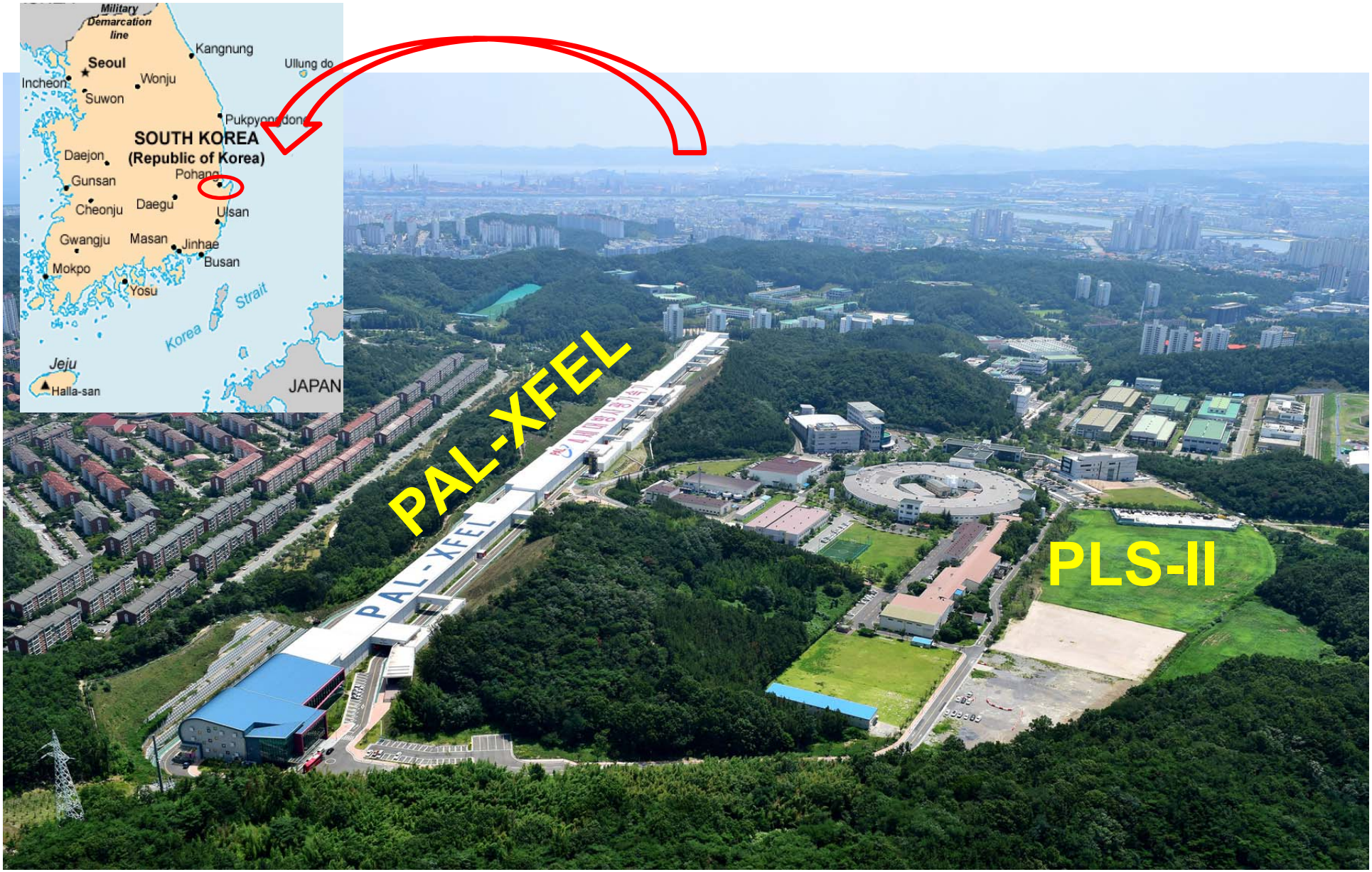
Outline

- ***Introduction – Two Big Brothers and Three Tiny Sisters***
- ***Radiations from Synchrotron Facilities, Synchrotron Radiation, and X-ray Free Electron Laser***
- ***Risk-based Safety Control***
- ***Change at PAL Safety Policy***
  - ***Motivation – Korean Nuclear Safety Act***
  - ***Change of PAL Safety Control on SR User***
  - ***Base Facts – Operation Record***
  - ***Current Status of Negotiating with Authority***
- ***Community (Radsynch) and Intercomparison***
- ***New Community (ARSF)***

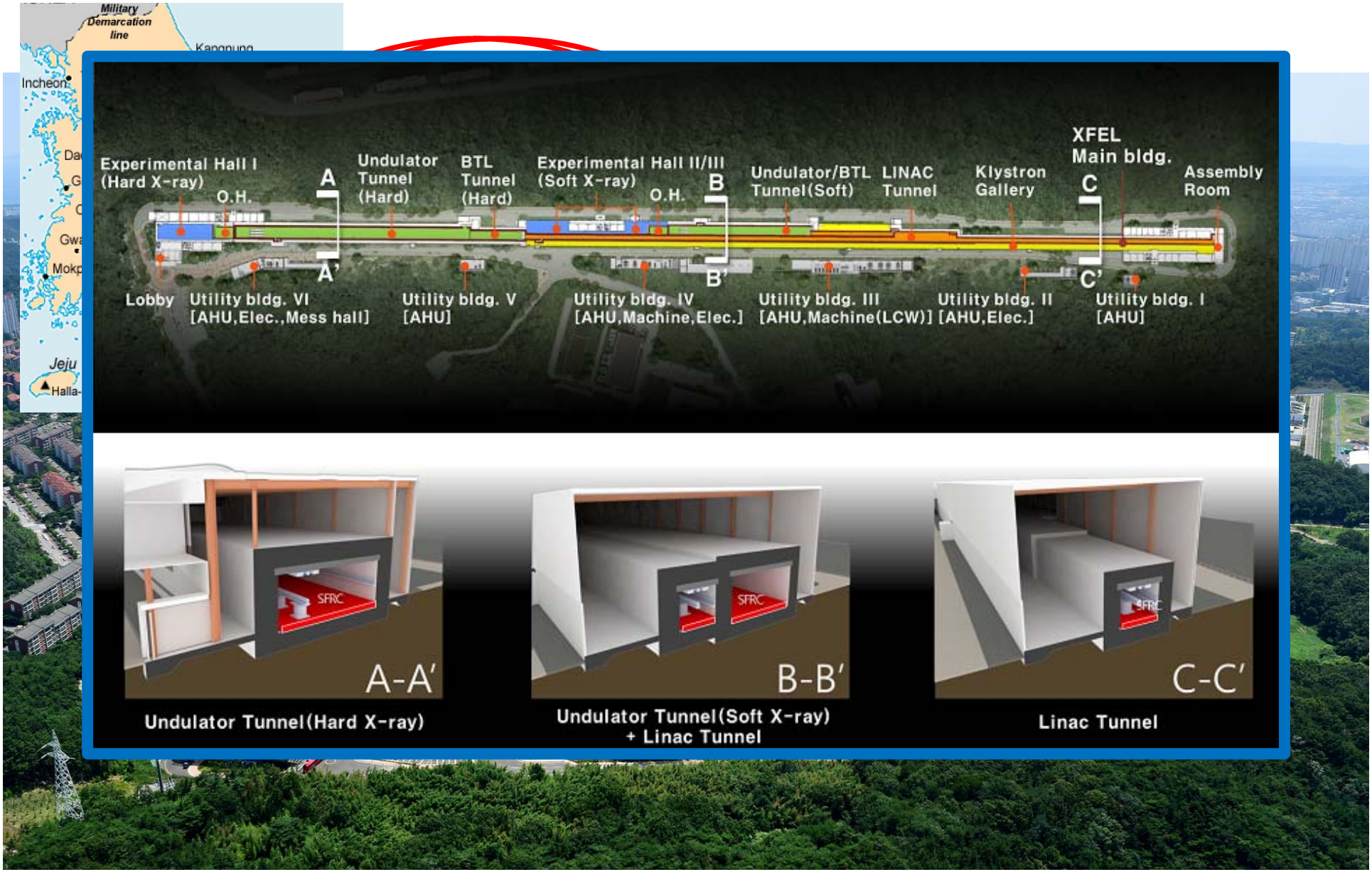
Two Big Brothers



PAL Chronology

Ancient Era	I. PLS		
	▪ Project started	Apr. 1	1988
	▪ Ground-breaking	Apr. 1	1991
	▪ 2-GeV Linac commissioning	June 30	1994
	▪ Storage ring commissioning	Dec. 24	1994
	▪ User's service started	Sept. 1	1995
	▪ 1st PLS Upgrade Complete	Nov. 1	2002
	✓ Energy ramping to 2.5 GeV	Sept. 1	2000
	✓ 2.5-GeV injection	Nov. 1	2002
Yesterday	II. 2nd Major Upgrade of the PLS (PLS-II)		
	▪ 3.0 GeV PLS-II Upgrade begin	Jan.	2009
	▪ 3.0 GeV PLS-II Upgrade Complete	Dec.	2011
	▪ Achievement of Goal (400 mA, Top-up)	July	2015
	III. PAL XFEL (10GeV Linac & SASE Based 0.1 nm X-ray FEL)		
	▪ Project Started		2011
	▪ Building Construction Completed	Jan	2015
	▪ Commissioning Started	Apr. 14	2016
	▪ First Lasing Achieved (0.5 nm)	Jun. 21	2016
	▪ 0,1 nm Lasing Achieved	Mar. 16	2017

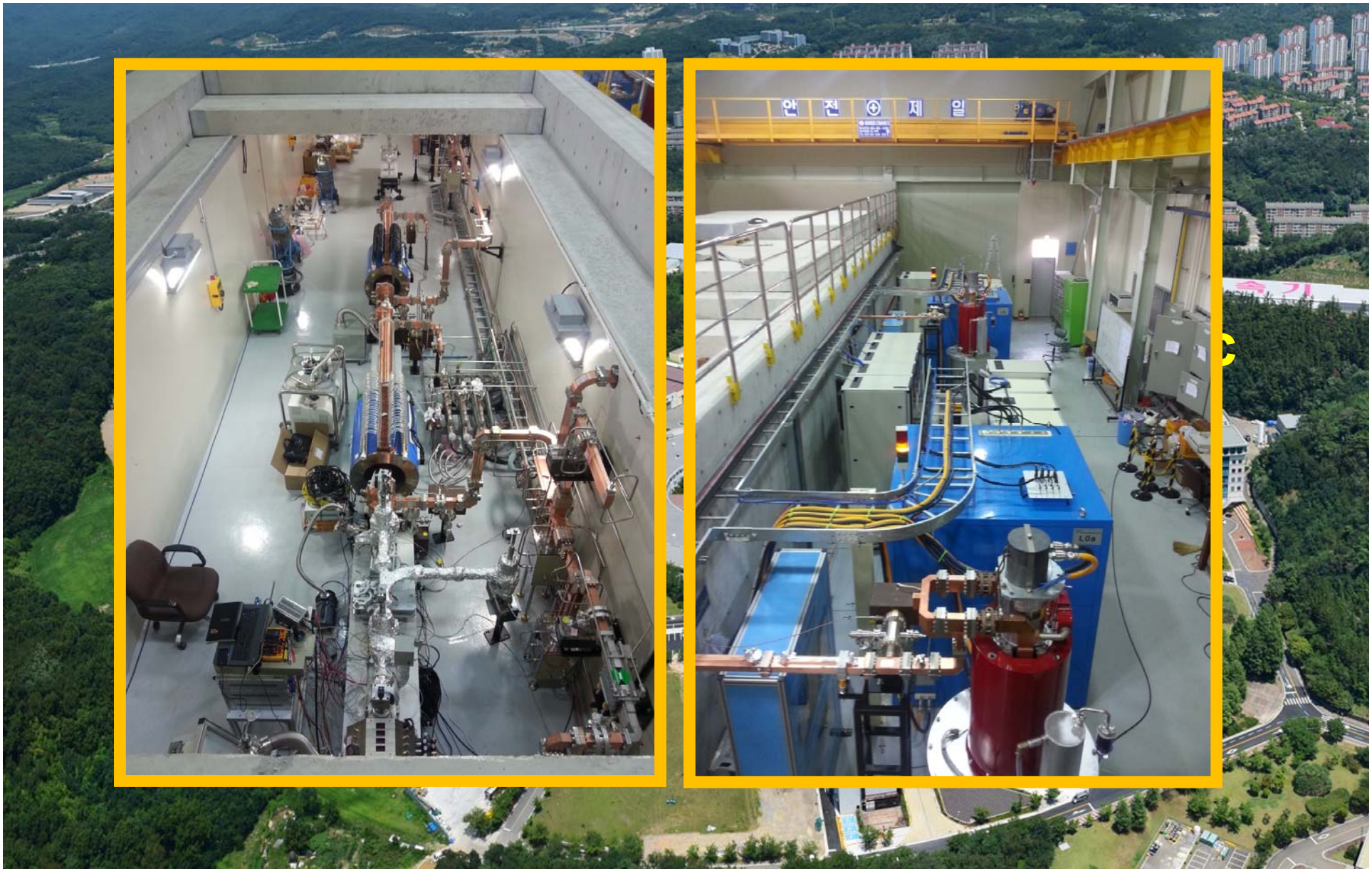
PAL-XFEL (10 GeV, 240W, 0.1 nm HX, SX)



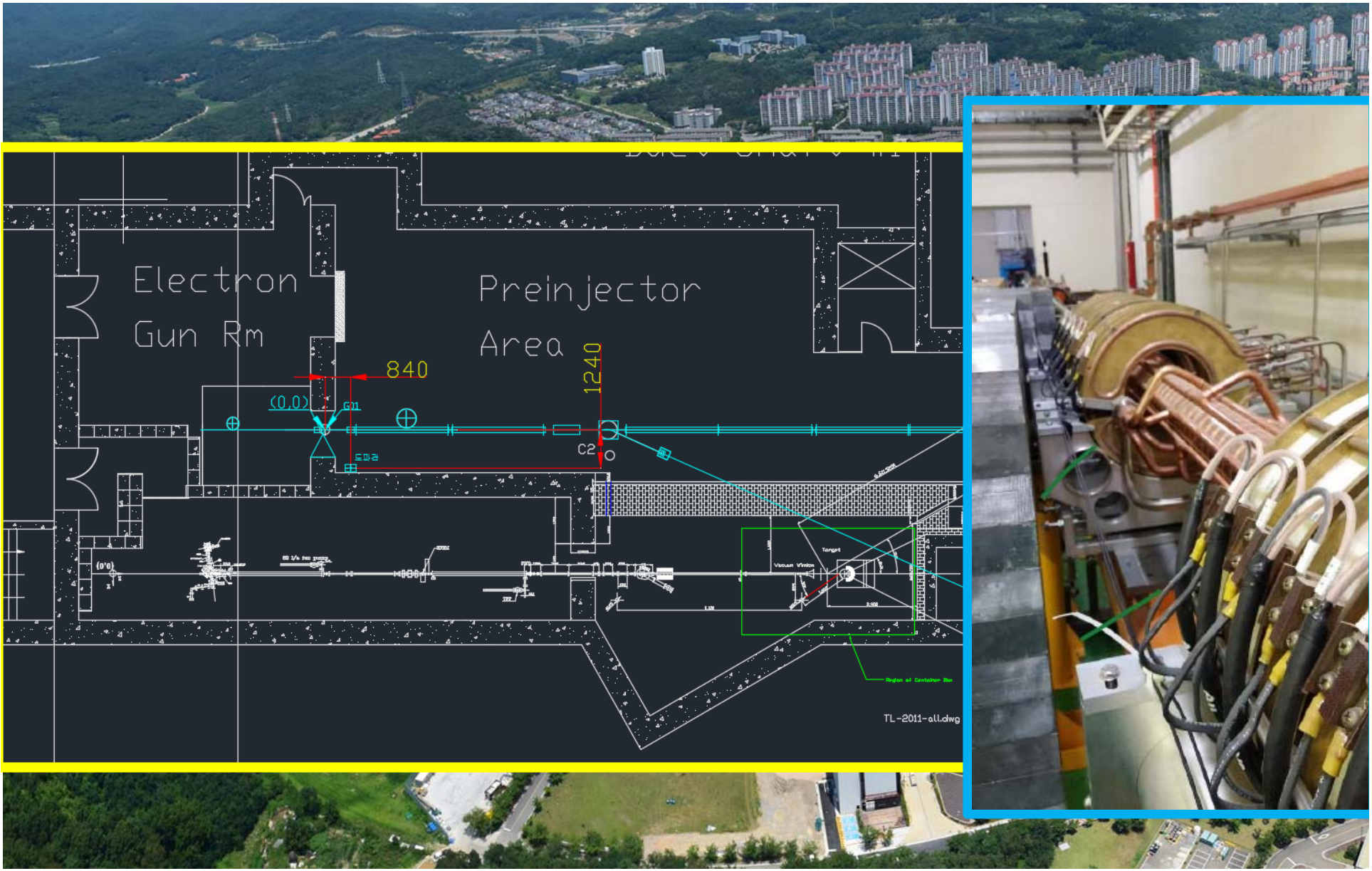
PLS-II (3 GeV, 400 mA, Top-up, 20 IDs)

Three Tiny Sisters

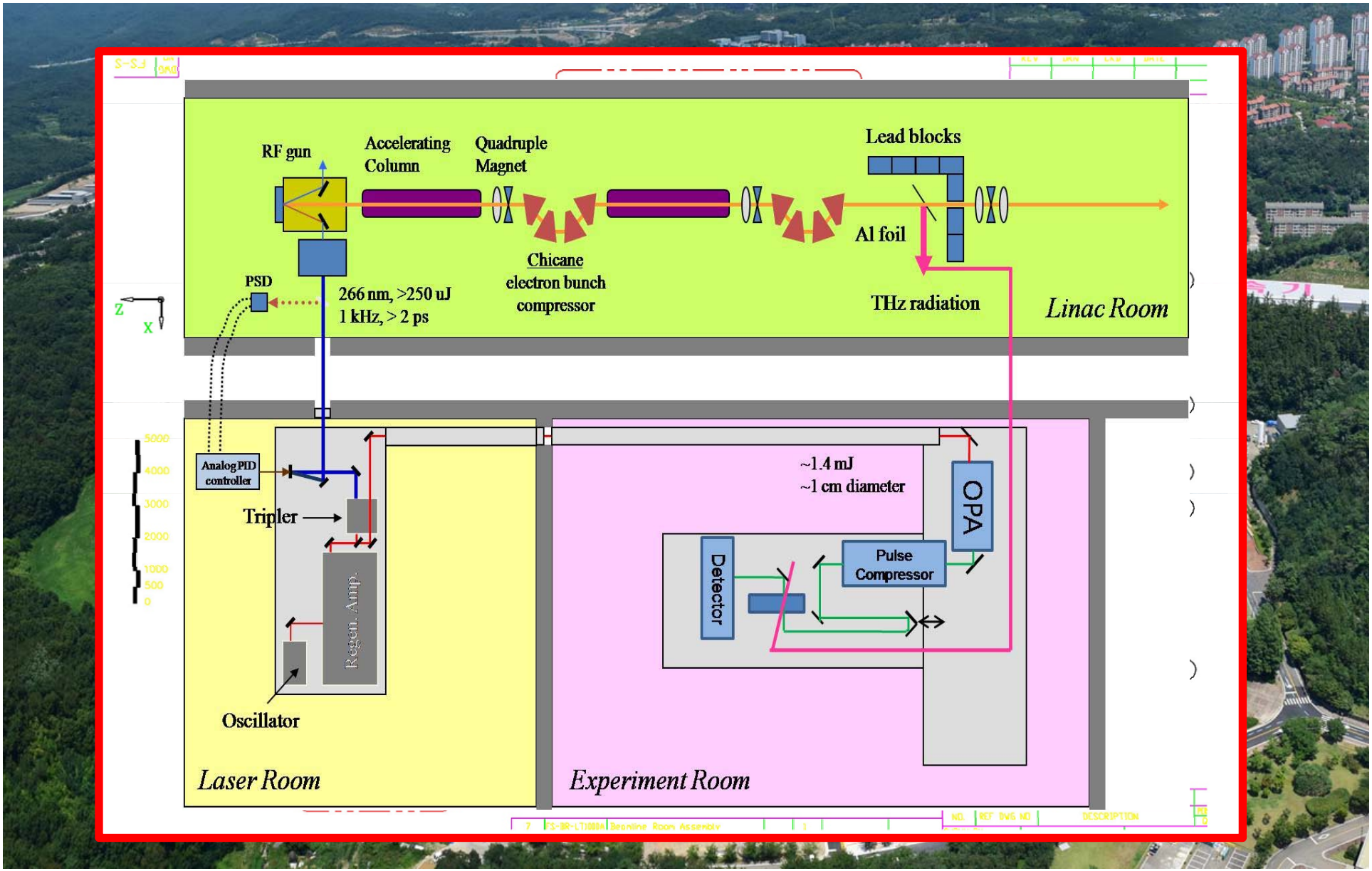
Injector Test Facility (140 MeV)



Test Linac (80 MeV, 1 kW)



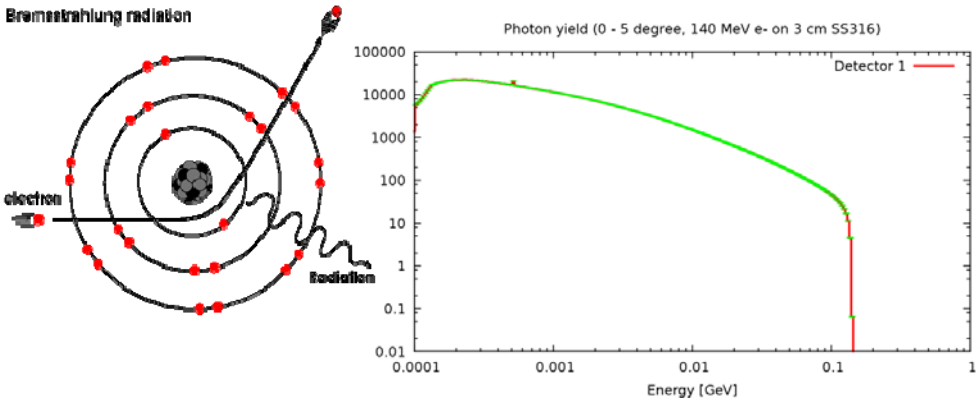
fs-THz Beam (60 MeV, 10Hz, 0.1~3 THz)



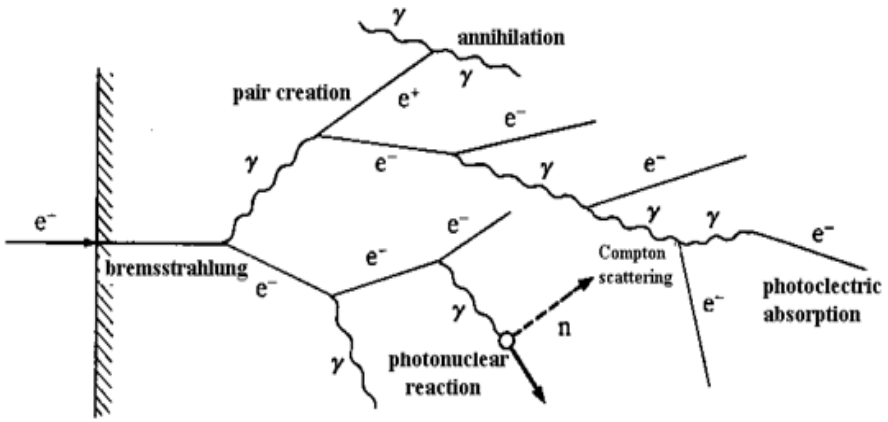
Radiation, Synchrotron Radiation, And X-ray Free Electron Laser

Radiations from Synchrotron Rad. Facility

- ***Bremsstrahlung Photon & Photoneutrons***

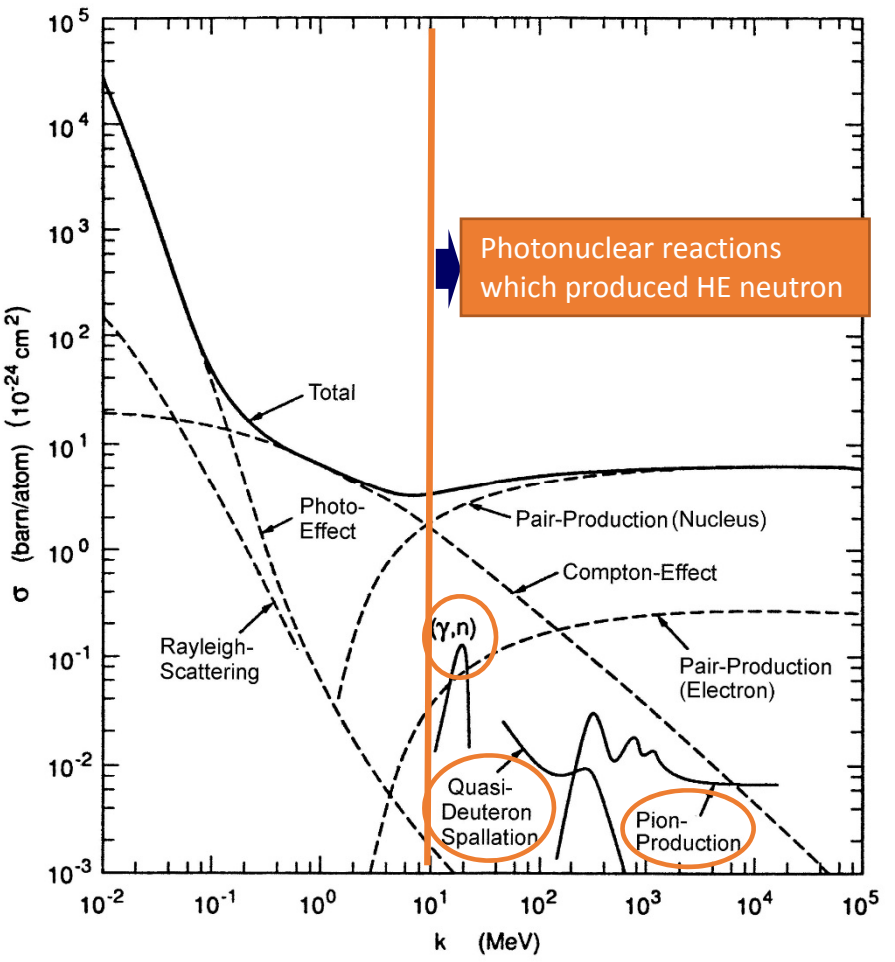


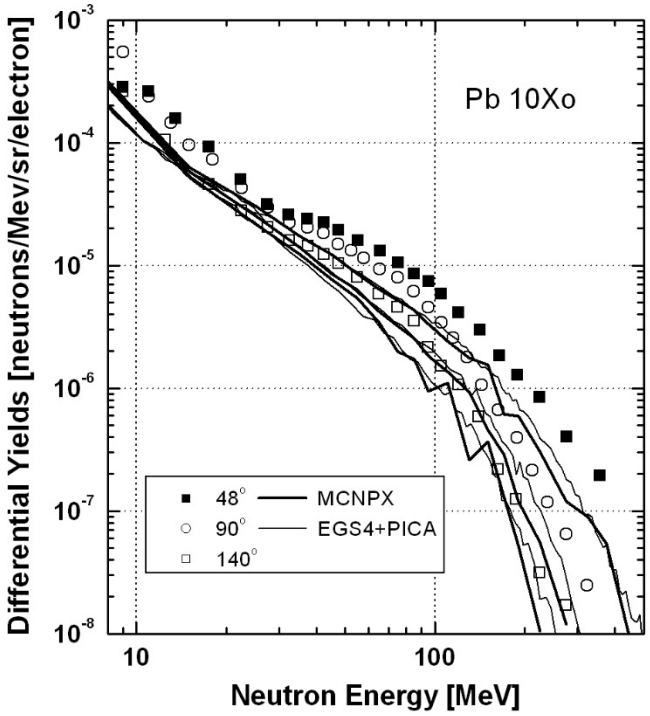
Bremsstrahlung by 140 MeV electron



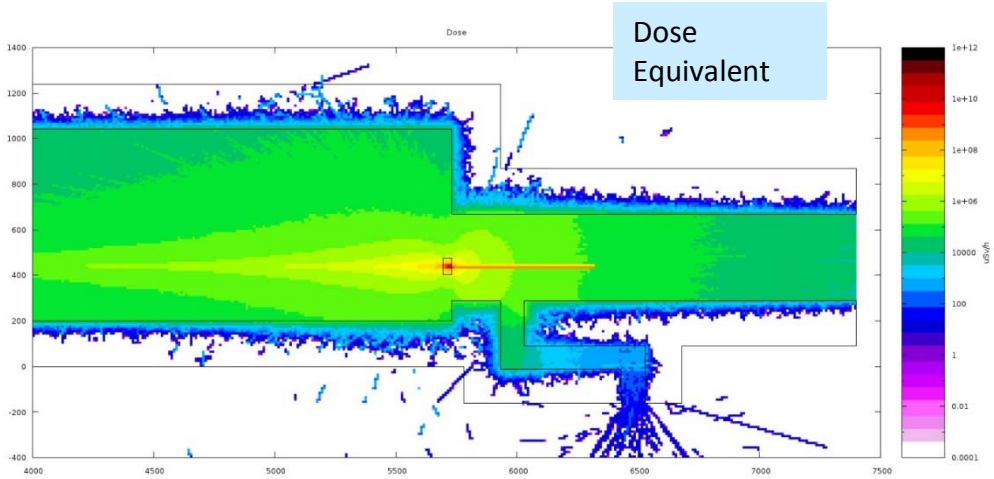
High Energy Electron induced Electromagnetic Cascade

Reaction Cross-section of photons





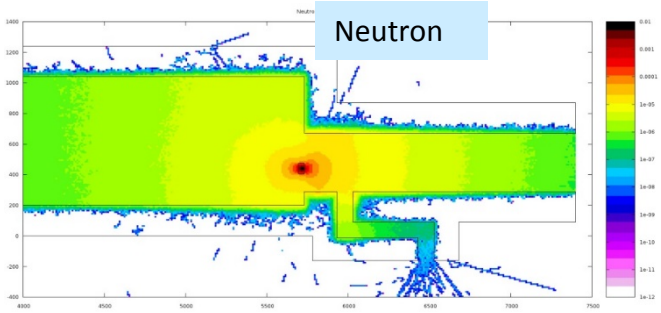
❑ FLUKA result : MAZE #5

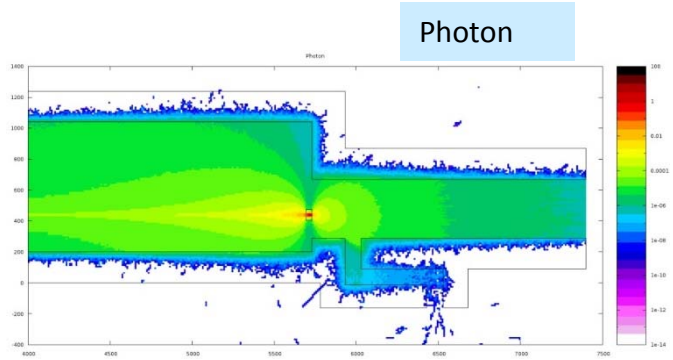


- Thick target : Φ72 x 36 cm Iron
- No. of Electrons : 2.7E+14/hour
- 1E+6 Histories
- Distance between target surface & maze hole : 2 m

Neutron Yields by
2.5 GeV electrons

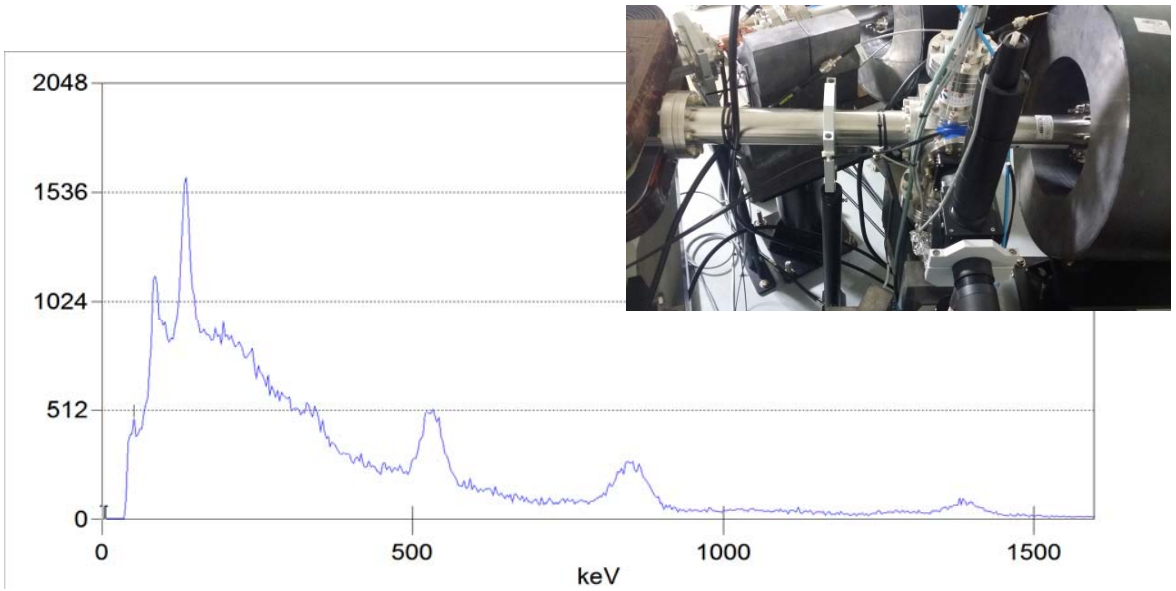
$Y_n(e) = 1/100\ Y_n(p)$



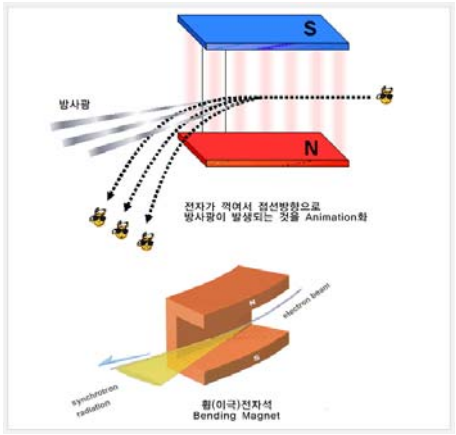


Radiations from Synchrotron Rad. Facility

- ***Induced Activity & Synchrotron Radiation …. Muon***



Gamma spectrum near ITF beam dump

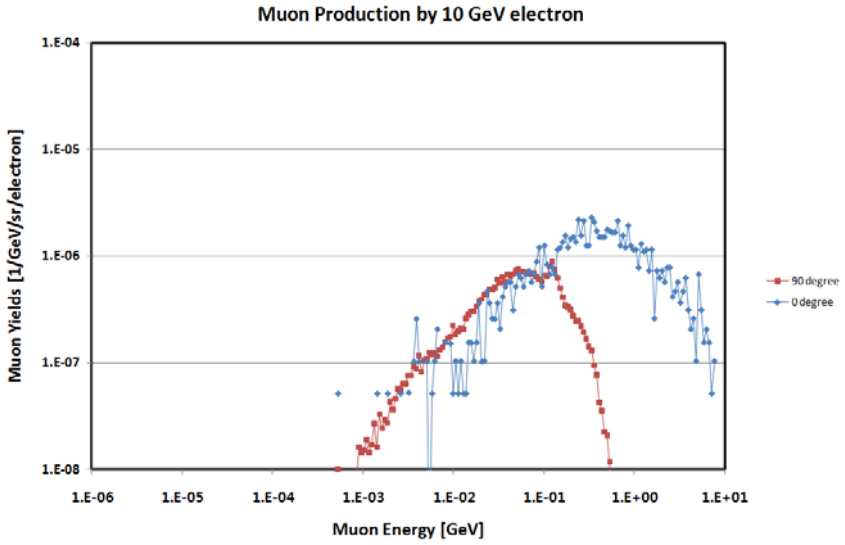


방사광 발생 (가속기연구소 홈페이지)

< Major Radioactive Isotopes >

Cu-64 ($T_{1/2}$: 12.7 hours) : 511 keV, 1346 keV γ

Mn-56 ($T_{1/2}$: 2.57 hours) : 846 keV γ



Radiation, Synchrotron Radiation, XFEL

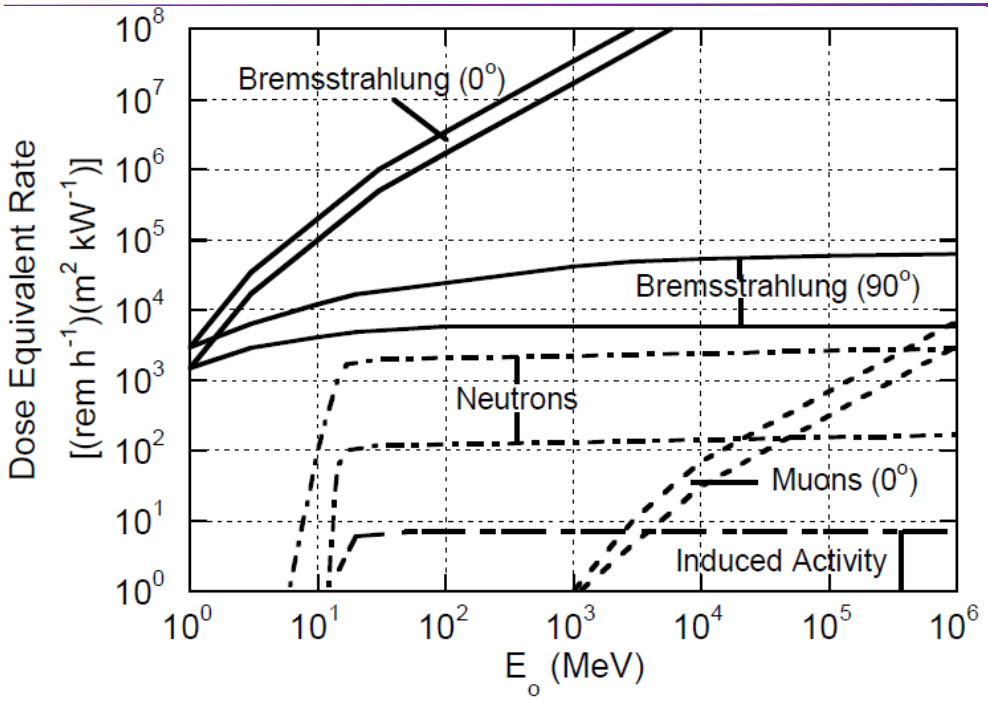
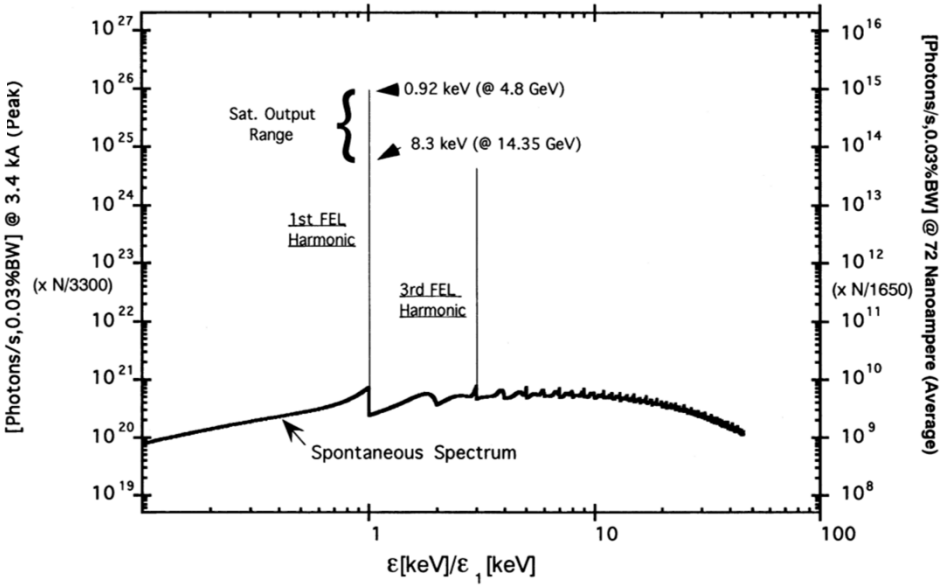


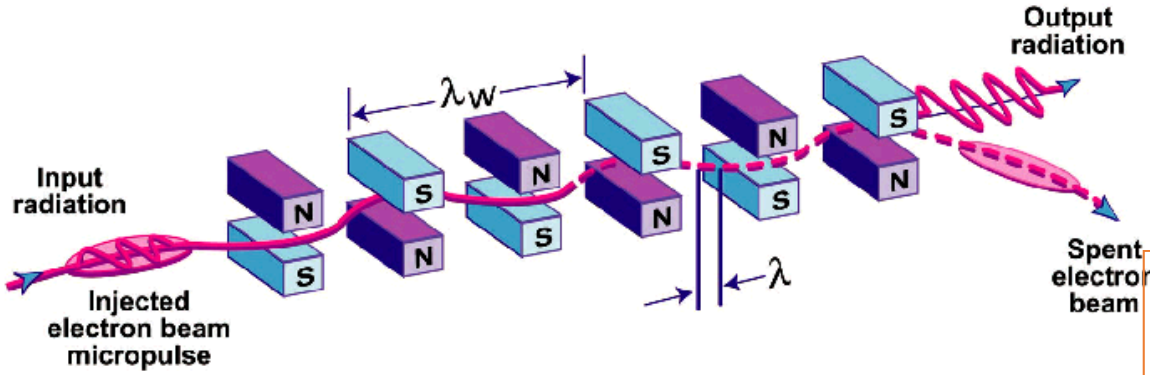
Fig. 3.8 Dose equivalent rates per unit primary electron beam power at one meter produced by various types of "secondary" radiations from a high-Z target as a function of primary beam energy, if no shielding were present (qualitative). The width of the bands suggests the degree of variation found, depending on such factors as target material and thickness. The angles at which the various processes are most important are indicated. Dose due to neutrons and induced activity have essentially no angular dependence. [Adapted from (Sw79a).]

W.P. Swanson (1979)

Synchrotron Radiation &
X-ray Free Electron Laser
(LCLS)

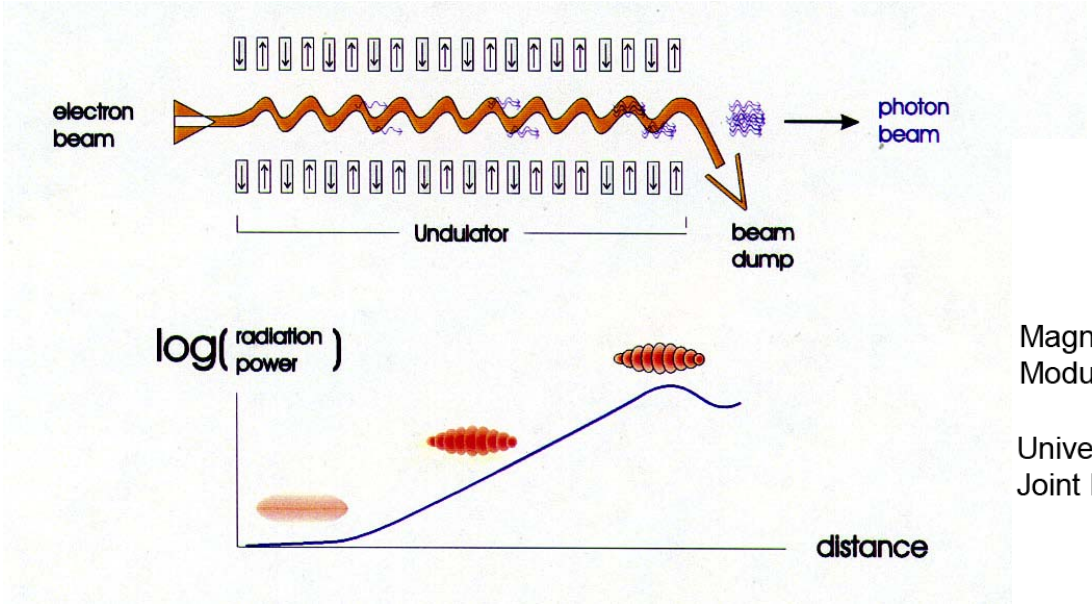


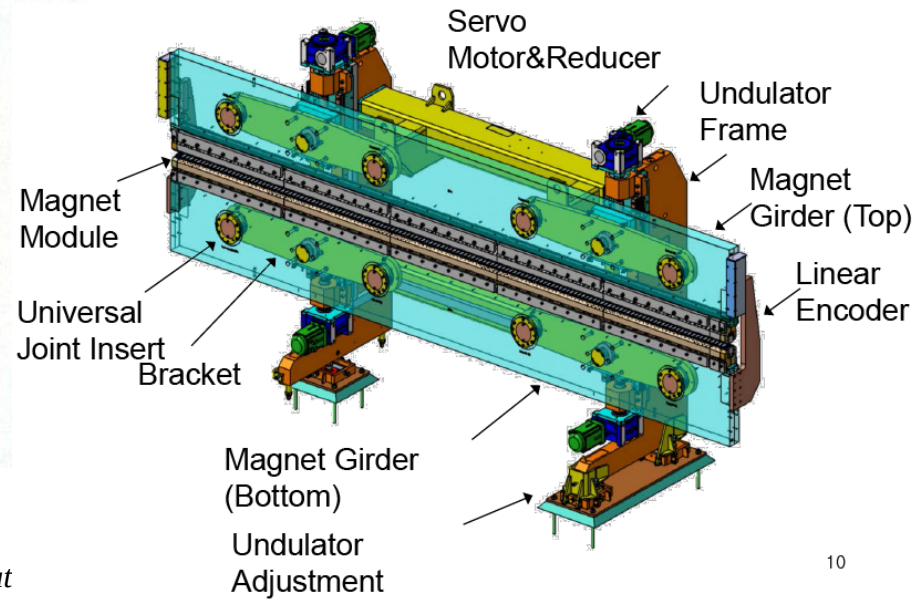
Single Pass FEL



$$\lambda_r = \frac{\lambda_w}{2\gamma^2}\left(1+\frac{k^2}{2}\right)$$

- Large tunable range.
- Capable of high-power
- Expensive
- Complex
- Stability and reliability





Risk-based Safety Control

TABLE 2.3—*Potential for radiation exposure from particle accelerator component systems.*

	Particles Accelerated					
	Electron Energy (MeV)			Proton, Heavy Ion Energy (MeV)		
	10–100	100–1,000	>1,000	<10	10–100	>100
Ion source	low	mod.	mod.	low	low	mod.
Accelerator	mod.	mod.	high	low	mod.	high
Beam delivery	high	high	high	mod.	mod.	high
Target/user	high	high	high	mod.	high	high
Beam stop	mod.	high	high	mod.	high	high

- NCRP144

Low Power, High Energy Electron Accelerator - PALXFEL

Activity Estimation on Interested Materials

❑ Activation calculation on interested materials (FLUKA)

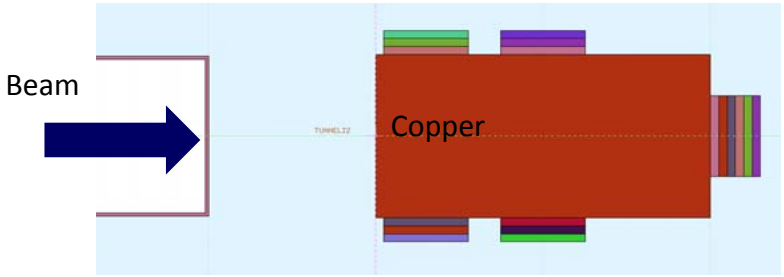
- Assumed Beam Condition

✓ **Beam : 430 MeV/n or 430 MeV, 400kW**

✓ **Irradiation: 10 days, Cooling: 1 day**

Material		Comparison with self-disposal level (per1kW)			
		Electron acc.	Proton acc.	Heavy ion acc.	
				^{12}C	^{238}U
Concrete (ANSI-ANS)		1	21	145	338
Metal (ST304L)		1	101	984	3,033
Insulator	Kapton	1	7,838	120,375	641,250
	Teflon	1	6,075	64,417	200,833
	PVC	1	64	1,397	6,667
Paint (Epoxy)		1	186	2,366	12,994

→ **10 ~ 100,000 times difference between materials.**



Radiation Safety Control Policy of PAL and Recent Change!

Radiation Safety Policy of PAL

☐ Radiation Control Policy based on Korean Regulation

- Annual dose limit for radiation worker: 20 mSv/year
- Annual dose limit for publics: 1 mSv/year
- 6 mSv/yr for frequent visitors, 10 μSv during 1 hour for temporary visitors

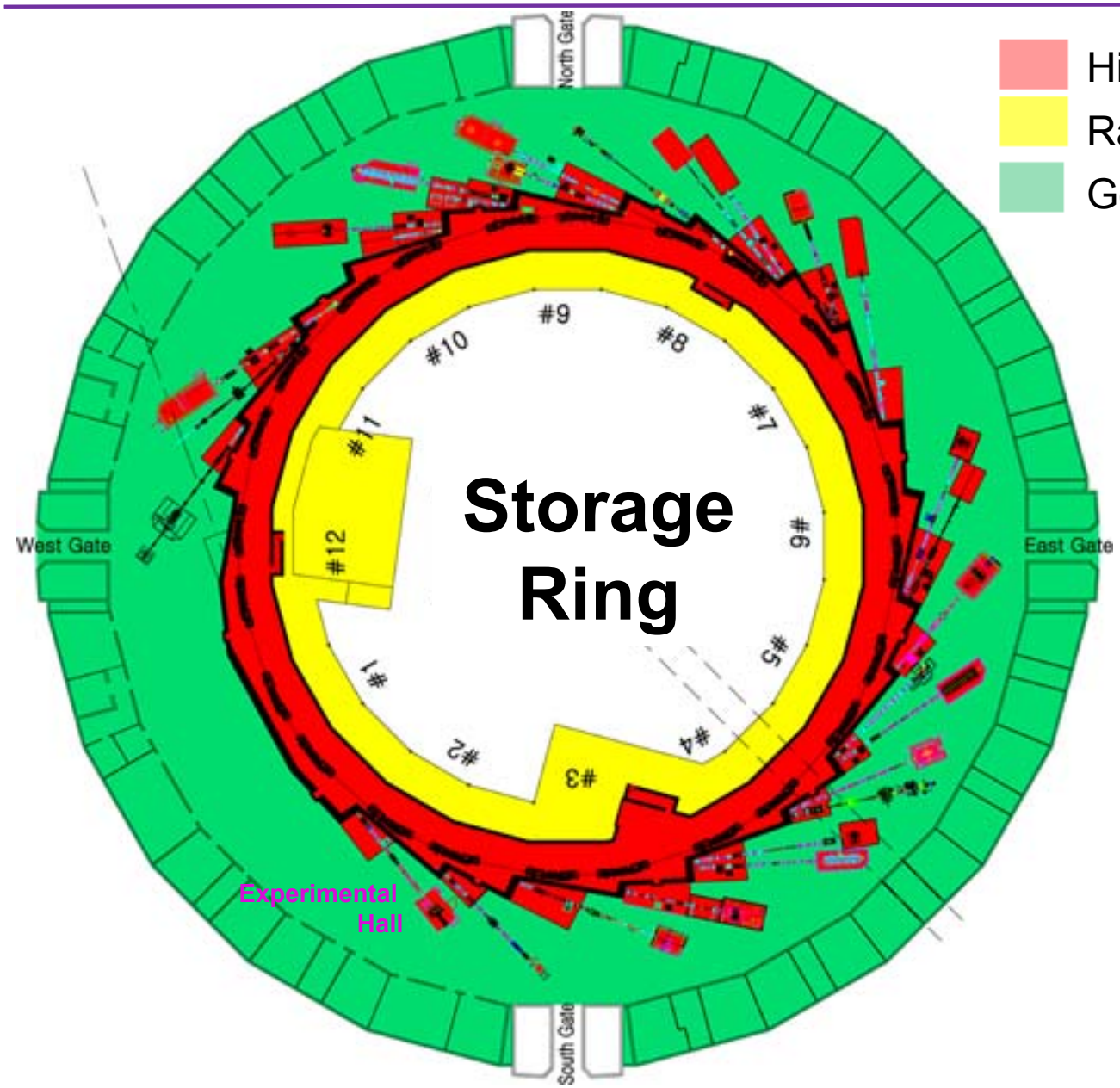
☐ Shielding Criteria based on ALARA

- **10 mSv/year on Surface (2000 h ⇒ 5 μSv/hour)**
- **1 mSv during 1 hour for accidental event**
- **Area requirements (e.g. 0.4 mSv/week)**

☐ Area Classification

- Restricted Area: 0.25 mSv/y < Dose < 1 mSv/y
- Generally-Controlled Area: 1 mSv/y < Dose < 20 mSv/y
  (A dosimeter is required)
- Radiologically-Controlled Area: 20 mSv/y < Dose < 1 mSv/h
- High Radiation Area: 1 mSv/h < Dose
  (No Access)

Area Classification when Beam On



High Radiation Area

Radiologically Controlled Area

Generally Controlled Area

No of Synchrotron Radiation User of PAL
~5000 per year

SR user was classified as
Frequent Visitor

Motivations: Change of Nuclear Safety Act

Classification of Person in Korean Nuclear Safety Act

- **Radiation Worker (100 mSv/5yr)**
- **General Public (1 mSv/yr)**
- **Frequent Visitor (6 mSv/yr)**

Persons who access to RC area for works such as cleaning and maintenance, but except of radiation worker

Motivations: Change of Nuclear Safety Act

- Several Accidents at NDT companies
- No rigor of regulation for persons who visit at RC area

To Enhance Nuclear Act and Implementation

- Safety training system for radiation worker was enhanced and changed to parallel mode (NDT & non-NDT)
- Strict application of Frequent Visitor category with new THREE requirements

New Requirements for Frequent Visitor

- Medical Check is obligation, which was only to Radiation Worker
- To v
  rec
- Exte

New PAL Policy :
SR User is classified as the general public

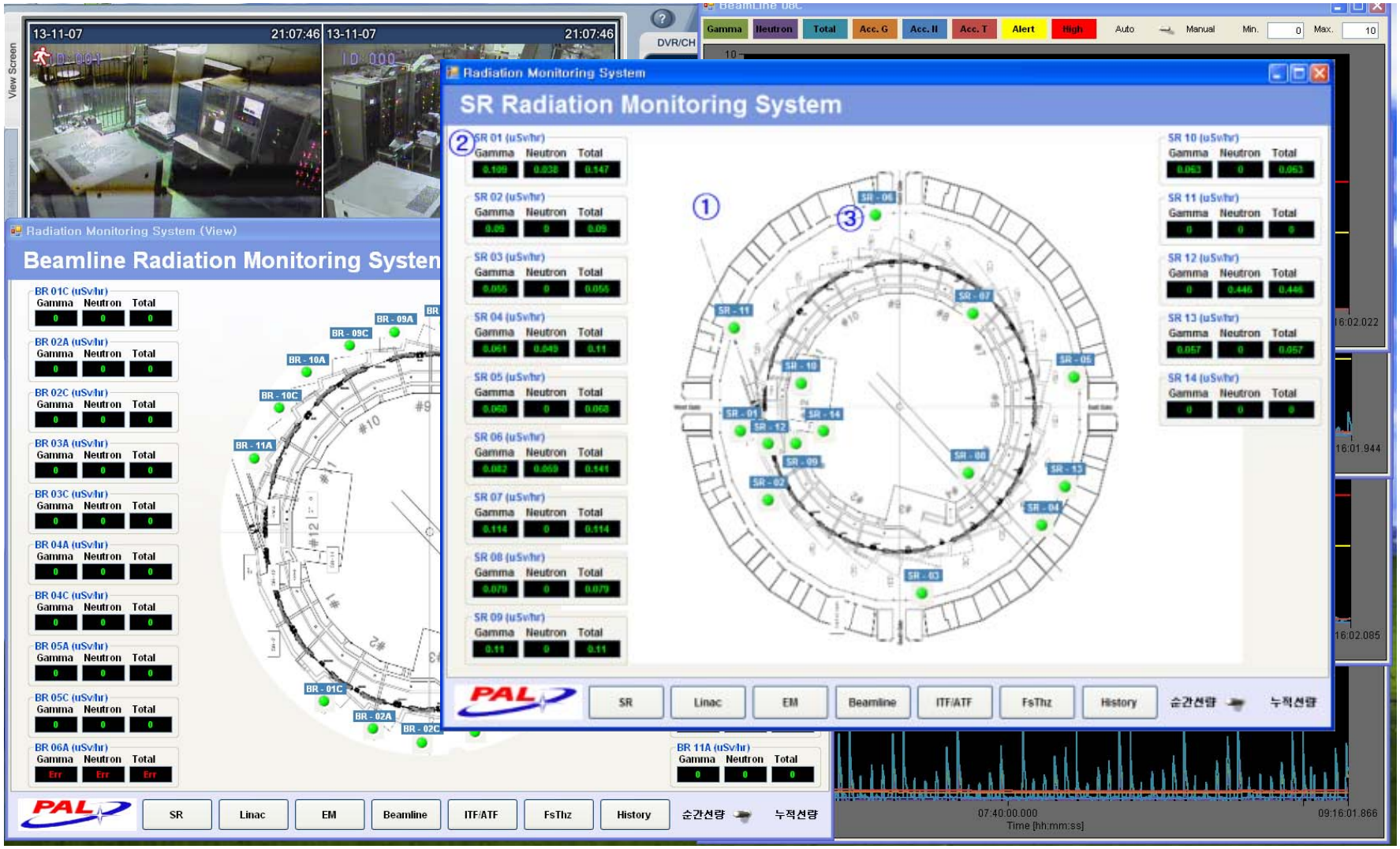
How to apply it to SR users?

Check Base Facts

- Experimental Hall at PAL is not RC area, but Generally-Controlled Area
- Radiation Level at Exp. Hall and Exposure Record of SR Users are sufficiently low.

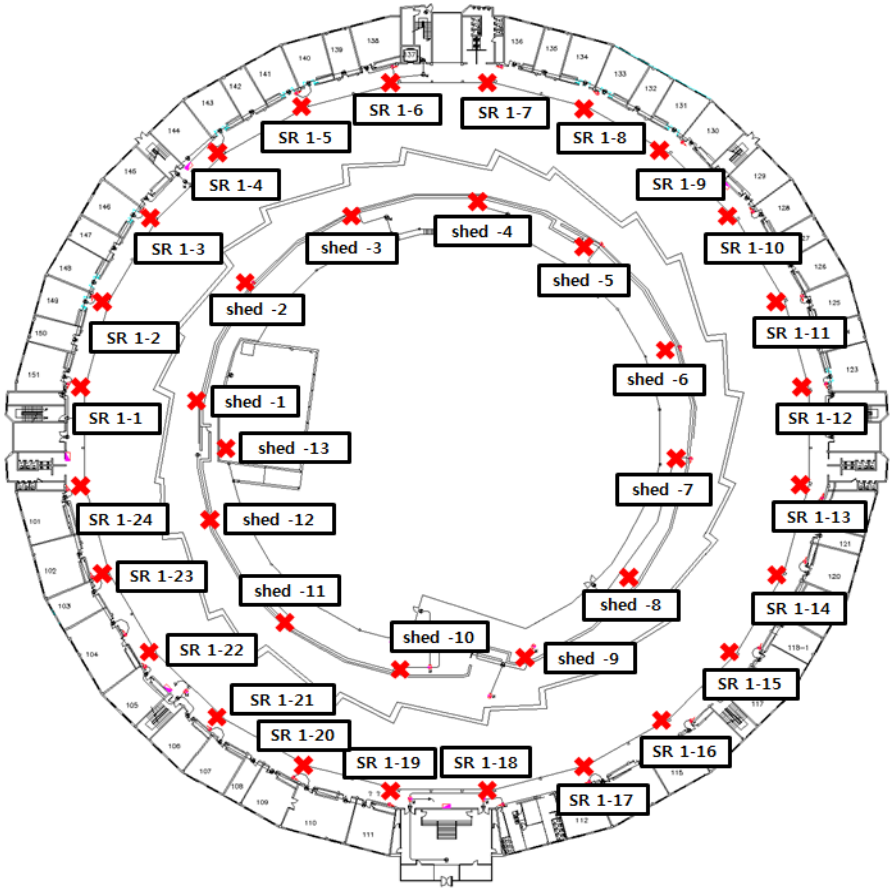
Radiation Monitoring Record

- **Area Monitoring System (SR + Beamline)**

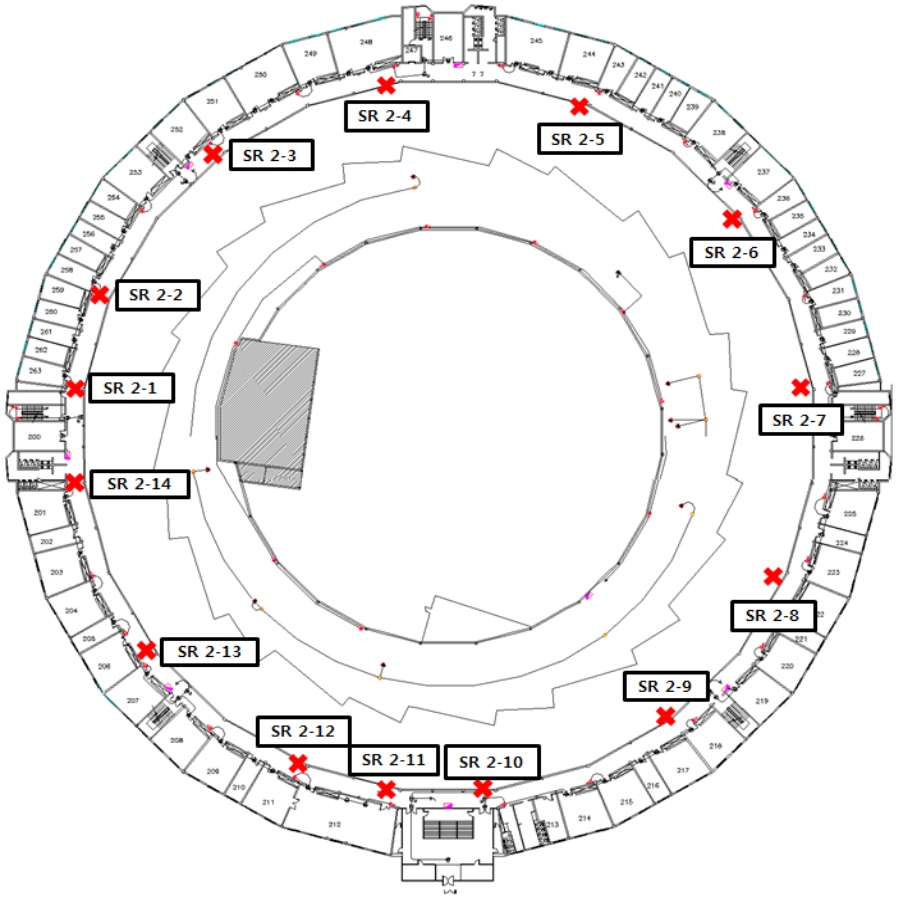


Radiation Monitoring: OSNL Arrangement

- Area Monitoring using Passive Dosimeter (OSNL)
- To check integrated dose (gamma + neutron) at every quarter



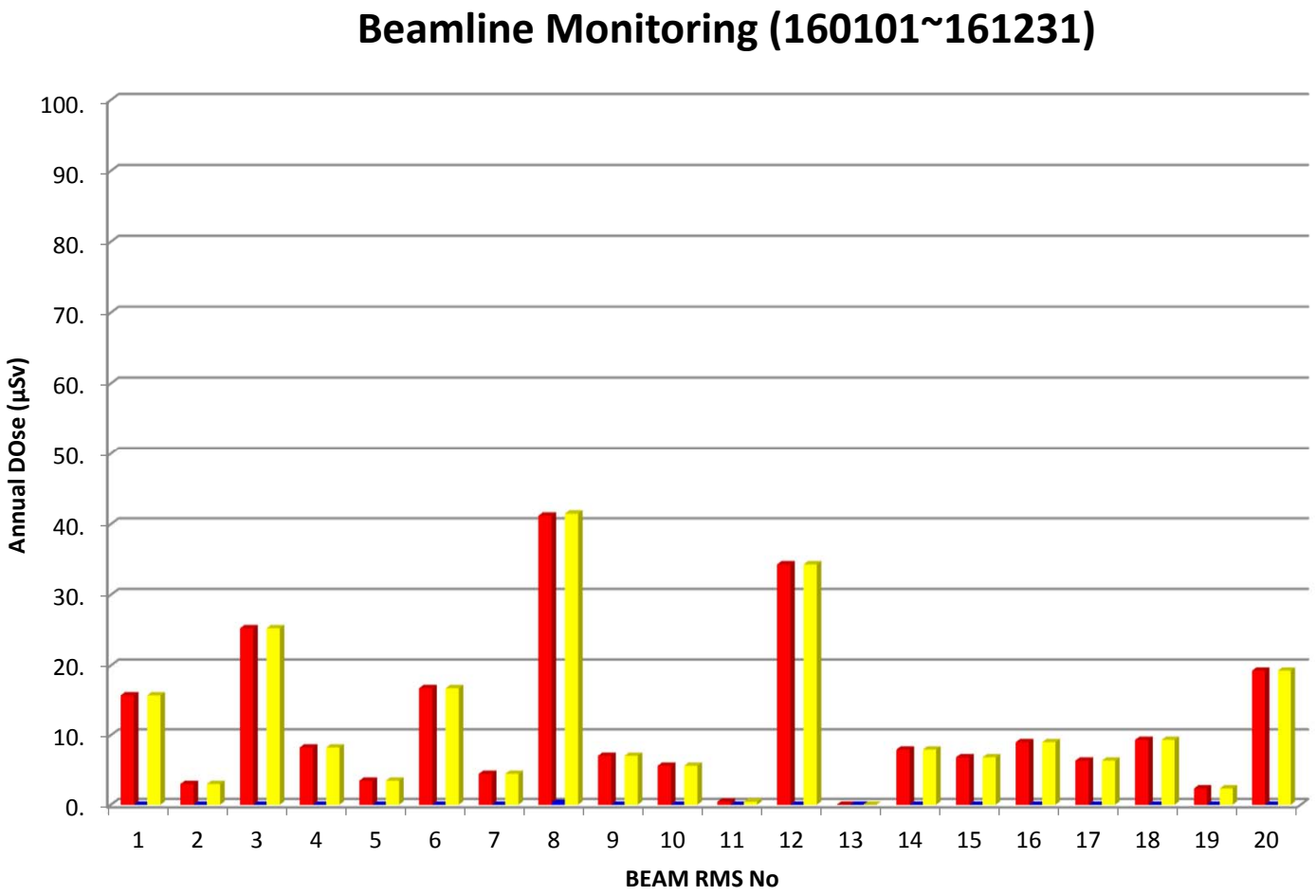
1st floor



2nd floor

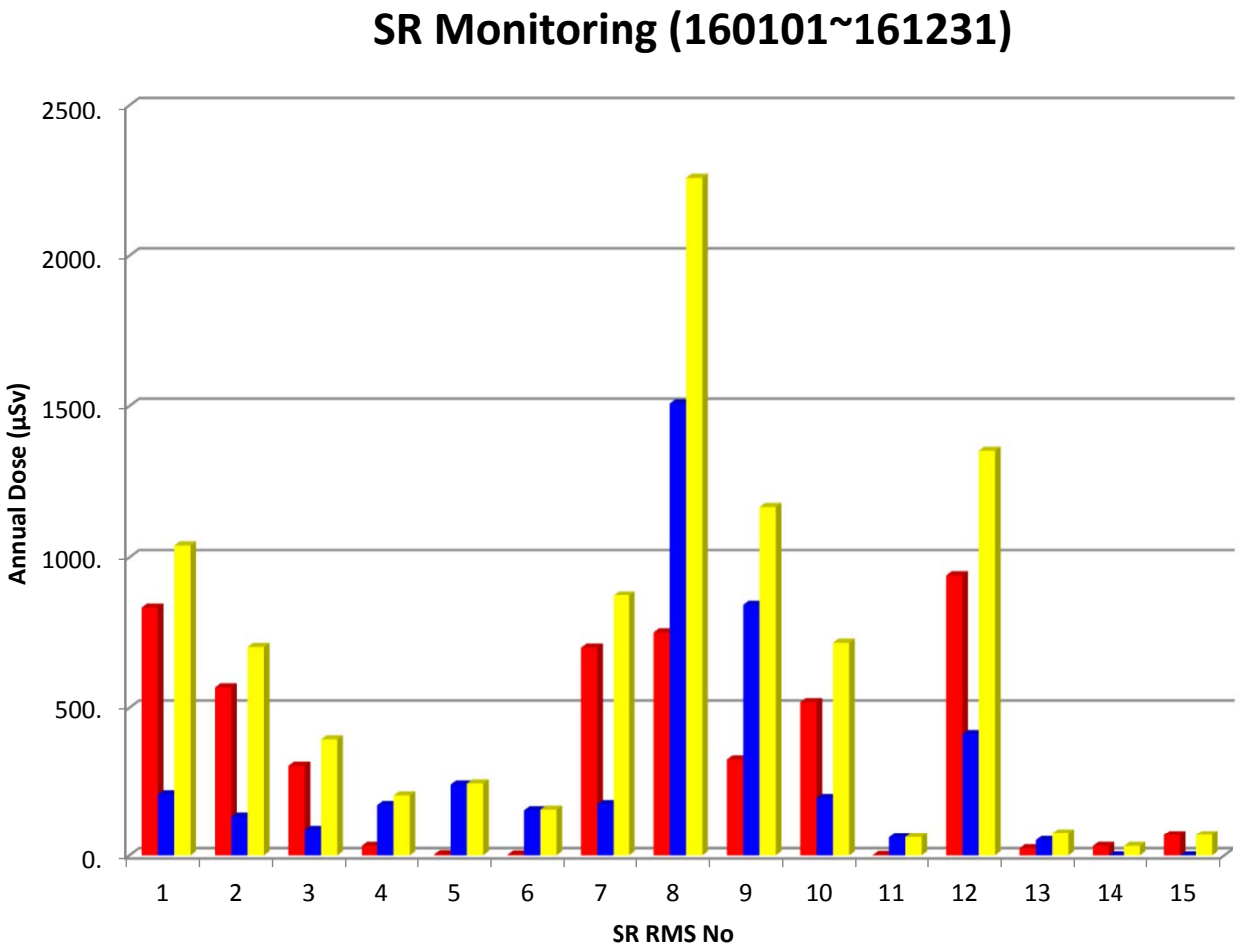
Annual Dose at Beamline Monitors

With Background Dose



Annual Dose in Storage Ring Building

With Background Dose



No 1, 2 – Injection Area
No 7, 8, 9, 10, 12 - Infield

Fact Check : Exposure Record of SR User

Using OSLD (with ^{6}Li)

in 2015

	< 0.1 mSv	> 0.1 mSv
Feb	364	
Mar	675	1 (0.11)
Apr	532	
May	436	
Jun	668	
Jul	609	
Aug	12	
Sep	160	
Oct	770	
Nov	709	1 (0.12)
Dec	344	
Total No of Dosimters	5279	1

in 2016

	< 0.1 mSv	>0.1 mSv
Feb	399	
Mar	747	
Apr	713	
May	684	
Jun	645	
Jul	616	
Aug	1	
Sep	258	
Oct	604	
Nov	679	1(0.31)
Dec	543	
Total No of Dosimters	5889	1

0.1 mSv : Report limit

Confirming PAL Policy, but Another Issue

- SR Users work at low dose area, experimental hall, for their exp. period and their exposure dose records are much lower than the dose limits of general publics

→ SR User = General Publics
with dosimeter and short training

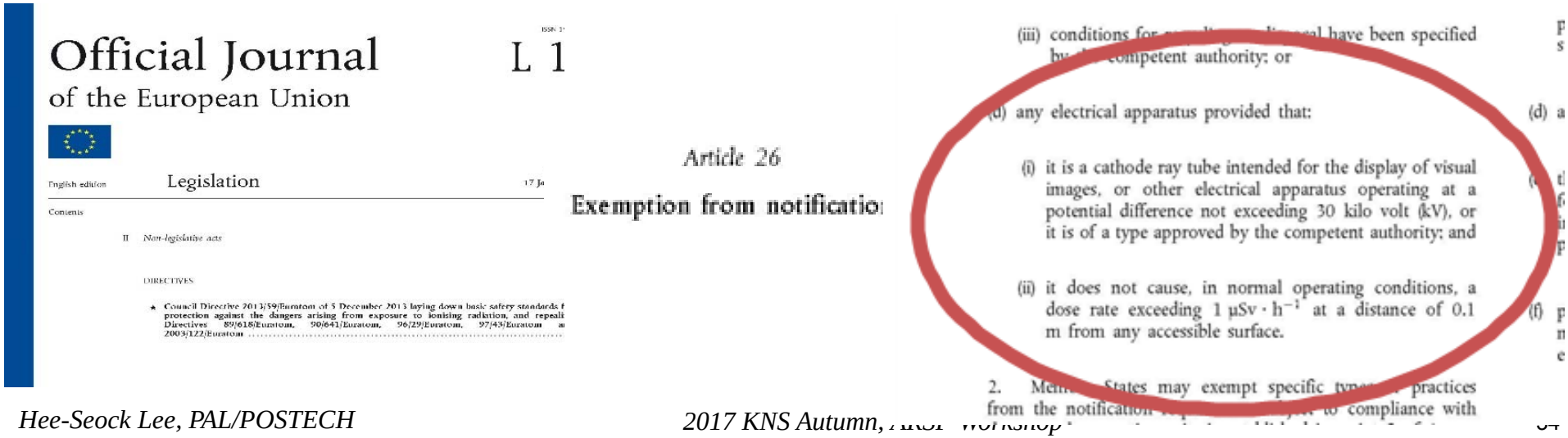
- But SR Users handle the safety/hutch shutter to allow SR into exp. hutch.

→ Activity to use radiation and related things (Authority issue)

→ SR User is a radiation worker.

Exemption Conditions (NSSC Notices)

- Radiation below 5 keV is not controlled by nuclear safety act.
- For licensed X-ray device with well-shielded housing, if maximum applied HV is lower than 50 kV and a dose rate does not exceed 1 uSv/h at 10 cm from any surface, it is not controlled by nuclear safety act.



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L 1

English edition — Legislation

Contents

II Non-legislative acts

DIRECTIVES

★ Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards f protection against the dangers arising from exposure to ionising radiation, and repeali Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom a 2003/122/Euratom

Article 26

Exemption from notificatio

(iii) conditions for ... have been specified by ... competent authority; or

(d) any electrical apparatus provided that:

(i) it is a cathode ray tube intended for the display of visual images, or other electrical apparatus operating at a potential difference not exceeding 30 kilo volt (kV), or it is of a type approved by the competent authority; and

(ii) it does not cause, in normal operating conditions, a dose rate exceeding 1 $\mu Sv \cdot h^{-1}$ at a distance of 0.1 m from any accessible surface.

2. Member States may exempt specific types of practices from the notification ... to compliance with

Community, Intercomparison, And General Equality

Community(Radsynch) - Intercomparison

- ***SATIF (Int. Workshop on Shielding Aspects of Accelerator, Targets, and Irradiation Facilities)*** ➔ ***In 2018, KOMAC-PAL***
- ***ARIA (Int. Workshop on Accelerator Radiation Induced Activation)***

➔ ***In 2019, RISP***

Questionnaire for consensus

Radsynch2017 Questionnaire

Proposed by Hee-Seock Lee, added by *Joseph Liu*

1. Basic Information

Name of Facility	
Location & Country	
Electron Beam Energy	
Stored Beam Current	
Operation Mode	☐ *Top-up* ☐ *decay* ☐ *other* : _____
Number of Beamlines	(ea) for Used Photon Energy < 5 keV (ea) for Used Photon Energy > 5 keV

2. Dose limit

Facility annual dose limit	Staff : ___mSv,User: ___mSv,Contractor: ___mSv, Note:
Regulatory annual dose limit	Staff : ___mSv,User: ___mSv,Contractor: ___mSv, Note:
Detector interlock limit for accelerator	Note: At ☐ shielding surface, ☐ experimental floor, ☐ other : _____
Detector interlock limit for beamline	Note: At ☐ hutch surface, ☐ user end station, ☐ other : _____

3. Introduce area (zone) classification in your facility

4. Is the experimental hall of your facility classified to the "radiation control area"?
   ☐ No ☐ Yes
   If yes, what is the reason?
   If no, which area category is applied to there?

5. Which area categories are applied to the experimental hutch and optical hutch of your facility?

	Beam On (Shutter Opened)	Beam Off (Shutter Closed)
Optical Hutch		
Experimental Hutch		

- What is the reason of such classification?

6. The SR user classified as
   ☐ Radiation worker (if multi-level of RW is, please mark)
   ☐ General public
   ☐ The other ( )
   What is the base policy for classification of the SR user?

7. Requirements for the SR user
   - (annual) Medical Check ☐ No ☐ Yes
   - what kind of training is done for user? ()
   - Does the SR user wear the personnel dosimeter at the experimental hall?
     ☐ No ☐ Yes, Always ☐ Yes, on special occasions ( )

8. Do you need extra operation permit from governmental authority to install or use new SR beamline?

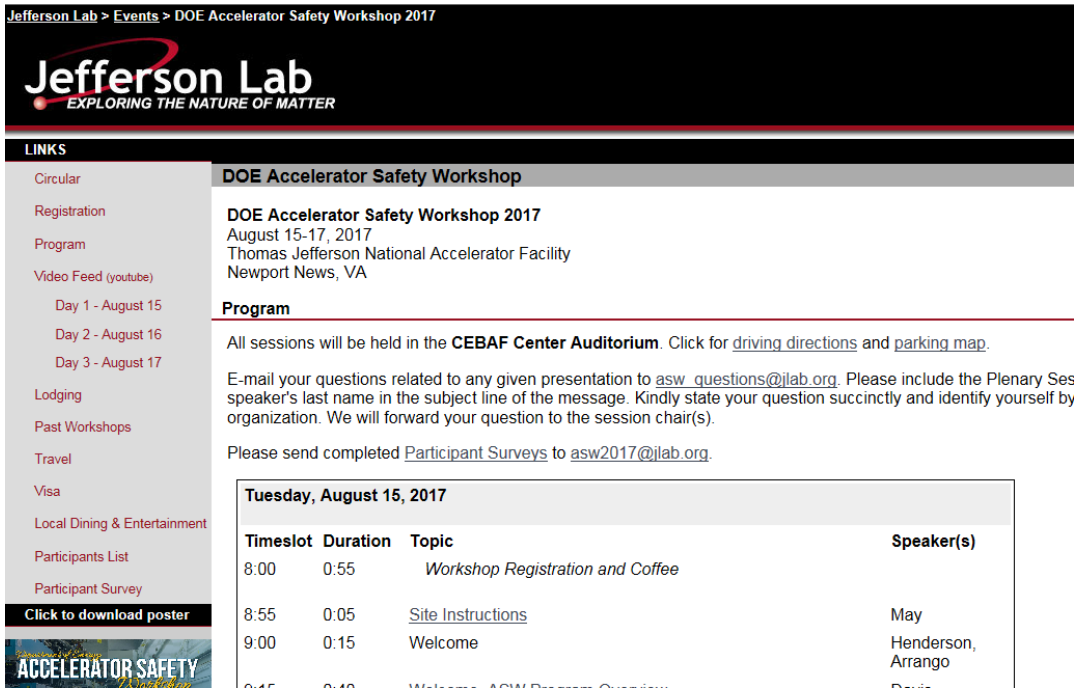
Totally 15 countries, 21 institutes, and 27 SR facilities

9. Contributors

	Facility	Name
1	MAX IV lab.	Magnus Hörling
2	Elettra	Katia Casarin
3	ALBA	Arnaud Devienne
4	SOLARIS	Justyna Wiklacz
5	BESSY-II	Yvonne Bergmann
6	ANKA	Michael Hagelstein
7	European XFEL	Eric Boyd
8	PETRA III	Albrecht Leuschner
9	SOLEIL	Jean-Baptiste PRUVOST
10	iRSD (formerly LURE)	Jean-Michel Horodynski
11	SSRL LCLS	Sayed Rokni Johannes Bauer
12	CLS	Brian Bewer
13	TLS / TPS	Joseph C. Liu
14	PLS-II / PAL-XFEL	Hee-Seock Lee, Nam Suk Jung
15	Spring-8 / NewSUBARU	Yoshihiro Asano
16	KEK-PF / KEK-PFAR	Hiroshi Iwase
17	SLRI	Methee Sopehn
18	SSLS	Yang Ping
19	Indus-2	Prasanta Kumar Sahani
20	ESRF	Paul Berkvens
21	APS	Bradley Micklich
22	Australian Synchrotron	Hock Ch'ng

New Community (ARSF)

- ***대형 가속기 방사선안전 협의회***
  (Accelerator Radiation Safety Forum, ARSF)



DOE Accelerator Safety Workshop

Conclusions

- ***Fundamentally the regulation strength should be based on the danger level, RISK.***

- ***ARSF will contribute the safety culture and regulation for large accelerator society.***

Thank You for Your Attentions