Status of Radiation Safety System at Taiwan Photon Source

Joseph C. Liu
Radiation and Operation Safety Division
National Synchrotron Radiation Research Center, Taiwan
NSRRC layout

Taiwan Photon Source (TPS)
- 3 GeV, 518.4 m, 500 mA
- Natural emittance: 1.6 nm-rad
- Straight sections: 7 m (x 18); 12 m (x 6)

Taiwan Light Source (TLS)
- 1.5 GeV, 120m, 400 mA

Administration and Operation Center
Academic Activity Center
**Major parameters of TPS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>3 GeV</td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td>500 mA at 3 GeV (Top-up injection)</td>
</tr>
<tr>
<td><strong>SR circumference</strong></td>
<td>518.4 m ($h = 864 = 2^5 \cdot 3^3$, dia. = 165.0 m)</td>
</tr>
<tr>
<td><strong>BR circumference</strong></td>
<td>496.8 m ($h = 828 = 2^2 \cdot 3^2 \cdot 23$, dia. = 158.1 m)</td>
</tr>
<tr>
<td><strong>Lattice</strong></td>
<td>24-cell DBA</td>
</tr>
<tr>
<td><strong>Straight sections</strong></td>
<td>12 m x 6 ($\sigma_v = 12 \mu m, \sigma_h = 160 \mu m$)</td>
</tr>
<tr>
<td></td>
<td>7 m x 18 ($\sigma_v = 5 \mu m, \sigma_h = 120 \mu m$)</td>
</tr>
<tr>
<td><strong>Bending magnets</strong></td>
<td>48</td>
</tr>
<tr>
<td><strong>Emittance</strong></td>
<td>1.6 nm·rad at 3 GeV (Distributed dispersion)</td>
</tr>
<tr>
<td><strong>Coupling</strong></td>
<td>1%</td>
</tr>
<tr>
<td><strong>RF frequency</strong></td>
<td>500 MHz</td>
</tr>
<tr>
<td><strong>RF gap voltage</strong></td>
<td>2.8~3.5 MV (3 SRF cavities)</td>
</tr>
<tr>
<td><strong>RF power</strong></td>
<td>750 kW (3 SRF cavities)</td>
</tr>
</tbody>
</table>

![Diagram of TPS components: quadrupole, dipole, sextupole]
**Radiation Safety System of TPS**

- **PAST**
  - External review of preliminary Safety Analysis Report (SAR)
  - Revised SAR submitted to Taiwan AEC and approved

- **NOW**
  - Accelerator shielding is completed
  - Shielding design for 7 phase I beamlines is under-way
  - Performance verification of radiation detector
  - Commissioning of LINAC and SRF

- **FUTURE**
  - Installation of access control system
  - Deployment of detector and monitoring network
  - Radiation safety control of commissioning
**TPS SAR peer review and approval**

- Preliminary SAR was drafted and reviewed in 2009
- Methodology, tools and results were reviewed.
- Final SAR submitted to Taiwan Atomic Energy Council in 2010.
- Installation permission of high intensity radiological facility was granted in 2010.
# Dose limit: TPS vs TLS & others

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ALS</th>
<th>SSRL</th>
<th>NSLS-II</th>
<th>APS</th>
<th>TLS</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring Circumference (m)</td>
<td>197</td>
<td>234</td>
<td>792</td>
<td>1104</td>
<td>120</td>
<td>518</td>
</tr>
<tr>
<td>Stored Beam Energy (GeV)</td>
<td>1.9</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Stored Current, I (mA)</td>
<td>400</td>
<td>500</td>
<td>500</td>
<td>100</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>Stored Energy (J)</td>
<td>500</td>
<td>1200</td>
<td>4060</td>
<td>2578</td>
<td>240</td>
<td>2590</td>
</tr>
<tr>
<td>Stored Beam Power, Ps (MW)</td>
<td>760</td>
<td>1500</td>
<td>1500</td>
<td>700</td>
<td>600</td>
<td>1500</td>
</tr>
<tr>
<td>Design Lifetime, (\tau) (h)</td>
<td>8</td>
<td>10</td>
<td>3</td>
<td>54</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Typical Straight Length (m)</td>
<td>6</td>
<td>6</td>
<td>6.6</td>
<td>15</td>
<td>6</td>
<td>7-12</td>
</tr>
<tr>
<td>GB Power from Straight ((\mu)W)</td>
<td>19</td>
<td>38</td>
<td>42</td>
<td>44</td>
<td>16</td>
<td>47-80</td>
</tr>
<tr>
<td>Ring Floor Shielding Limit (mSv y(^{-1}))</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Beamline Shielding Limit (mSv y(^{-1}))</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Site Boundary Dose Limit (mSv y(^{-1}))</td>
<td>0.1</td>
<td>0.05</td>
<td>0.05</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Ref: Radiat Prot Dosimetry. 2009 Nov;137(1-2):18-34
Progress of TPS construction

2010 TLS only

2012

2013 TLS+TPS
**Shielding & dose simulation**

**TPS Operation**: Extraction/Transfer/Ramping/Injection Efficiency

- **LINAC** 2.25W
- **LTB** (90%)
- **Booster** (90%)
- **BTS** (90%)
- **Storage Ring** (I=400mA, $\tau=7$Hr)

Reference Beam Loss → Operation Envelope → Safety Envelope

**Dose Profile over a Cross-Section of TPS Tunnel (Total Ambient Dose (pSv/s))**
Accelerator shielding
TPS Phase-I Beamline

μ Protein Crystallography

Duel IDs in one Straight, Double mini-βy lattice

Temporal Coherent XRD

10^9
coherent length: 5 ~ 22 mm

E resolving power
35000
0.6 mm x 0.23 mm

μ soft X-ray

IU22 x 3
IU22 (1+1) x 2
EPU48 (1+1) x 1
EPU46 x 1

100 nm x 100nm
3 mrad x 3 mrad

Coherent Scattering
SAXS

30 nm at 15 keV
coherent flux: > 1x10^10 ph/s
dynamics from ms to μs

Soft RIXS

total hv/Δhv > 40000 @ 900 eV
**Beamline shielding**

- **Bremsstrahlung**: collimator, stopper, local shielding.  
  Monte-Carlo code: FLUKA
- **Synchrotron**: hutch, shielding enclosure, exclusion zone.  
  Analytical code: STAC8

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**Dose rate limit: 0.5 µSv/h**  
Where users are accessible.

**Synchrotron Radiation**: Low energy, high flux  
**Bremsstrahlung**: High energy, low photon flux  
1. Gas bremsstrahlung  
2. Bremsstrahlung streaming from beam loss
Dose assessment for GB scattering
30cm PB Collimator ⇒ 30cm W Stopper

Gamma dose rate ($\mu$Sv/h)

Neutron dose rate ($\mu$Sv/h)
Dose assessment for GB scattering

10cm PE Enclosure around Stopper

Gamma dose rate
0.068 0.093 0.102

Dose assessment for GB scatteringscattering

10cm PE Enclosure around Stopper

Neutron dose rate (µSv/h)
0.409 0.073 0.006
Dose evaluation for synchrotron

<table>
<thead>
<tr>
<th>Component</th>
<th>Power loss, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond filter</td>
<td>37.7</td>
</tr>
<tr>
<td>Be window</td>
<td>2</td>
</tr>
<tr>
<td>Slits (intercept beam)</td>
<td>47.6</td>
</tr>
<tr>
<td>VBPM (intercept beam)</td>
<td>47.6</td>
</tr>
<tr>
<td>HBPM (intercept beam)</td>
<td>47.6</td>
</tr>
<tr>
<td>Screen (intercept beam)</td>
<td>47.6</td>
</tr>
<tr>
<td>DCM</td>
<td>47.6</td>
</tr>
<tr>
<td>VFM</td>
<td>&lt;&lt; 1</td>
</tr>
<tr>
<td>HFM</td>
<td>&lt;&lt; 1</td>
</tr>
</tbody>
</table>

Incoming power 87.3 W thru FE-slits (worst case)

µ Protein Crystallography

Scattering angle vs. inelastic surface (degree)
TPS Radiation Safety System & interlock

- Personnel Protection System
  - Access Control System
  - Top Up Safety Interlock
  - Radiation Monitoring Interlock
  - Operation Envelope Limiter
  - BL Radiation Safety Interlock
  - Vacuum Interlock
  - Cooling Interlock
  - Mis-steering of Electron Beam
  - Subsystem Protection

- Machine Protection System
  - LINAC ACS
  - Booster/Ring ACS
  - Accelerator Monitoring
  - Beamline Monitoring
  - SRF, IU, etc.
Access control system

- Ring divided into 4 sections
- Search sequence
- Emergency shut down mechanism
- High electric voltage protection
- Oxygen deficiency evaluation for cryogenic leakage
## Radiation safety for Top-up operation

<table>
<thead>
<tr>
<th>Facility</th>
<th>Ray tracing simulation</th>
<th>Minimum current interlock</th>
<th>Dipole setting interlock</th>
<th>Bending magnet in front-end</th>
<th>Interlocked rad. monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>TLS</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>ESRF</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>PETRA III</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSRL</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>SPring-8</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td></td>
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<tr>
<td>PLS</td>
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<td>o</td>
<td>o</td>
<td></td>
<td></td>
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<tr>
<td>ELETTRA</td>
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<tr>
<td>ALS</td>
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<td>o</td>
<td></td>
<td>o</td>
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<tr>
<td>CLS</td>
<td>o</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Diamond</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOLEIL</td>
<td>o</td>
<td></td>
<td>o</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALBA</td>
<td>o</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSLS-II</td>
<td>o</td>
<td></td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>PF</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APS</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: Measures explicitly indicated by each facility are shown.*
Radiation monitoring & interlock

- Annual dose limit 1mSv ÷ 2000 working hours = 0.5 µSv/h
- Accumulating 4 hours, integrated dose (\(\gamma+n\)) \leq 2 \mu Sv
- Inhibited device:
  - For accelerator: LINAC e-gun & RF
  - For beamline: heavy metal shutter
Control scheme and network for radiation monitoring system

- Gamma & Neutron Detector
- Radiation & Operation Safety Division
- Interlock Control Automatically
- Ethernet
- Control Display Communication
- Control room
- Accelerator Operation Group
- RO SD Safety Officer
- Instrumentation & Control Group
- Message Notification
- Display
- Communication
- Control
Environmental monitoring
New radiation detectors

- Thermo FHT-191 N ionization chamber
- FHT 762 Wendi-2 Neutron detector (He-3)
- FHT 6020 Display and Alarm Unit for interlock and data logging

<table>
<thead>
<tr>
<th>FHT 191 N</th>
<th>Ionization chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Ranges</td>
<td>Gamma dose rate measurement from 10nSv/h up to 10Sv/h</td>
</tr>
<tr>
<td>Energy Range</td>
<td>35 keV to 7 MeV</td>
</tr>
<tr>
<td>Data Memory</td>
<td>256 periods of selectable length (history)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FHT 762 Wendi-2</th>
<th>Wide-Energy Neutron Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Ranges</td>
<td>1µSv to 100mSv/h Cf-252</td>
</tr>
<tr>
<td>Energy Range</td>
<td>25meV to 5 GeV according to ICRP 74 (1996)</td>
</tr>
</tbody>
</table>
| Sensitivity | Sensitivity: 0.84 cps/(µSv/h) Cf-252  
Gamma sensitivity: 1 to 5µSv/h at 100 mSv/h, 662keV |
Functional test & comparison

- Various radiation environments
  - 150 MeV LINAC
  - 1.5 GeV TLS
  - Beamline hutch
Inside BL15 optics hutch

Stored Current

60 refill injections / 60 mins

Time structure of Top-up refill injection

Dose

<table>
<thead>
<tr>
<th>Signal Name</th>
<th>Max</th>
<th>Min</th>
<th>Dif</th>
<th>Avg</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>gamma (micro-Sv/h)</td>
<td>12.42</td>
<td>1.30</td>
<td>11.12</td>
<td>1.87</td>
<td></td>
</tr>
</tbody>
</table>
**LINAC commissioning**

- Preview of TPS rad. safety practice
- Licensing, shielding, monitoring, ACS, survey, simulation and safety control.
- Beam power & workload
- Op. Envelope: 150MeV, 3Hz, 1~3nC
### LINAC radiation survey

#### Diagram:
- **Diagram of LINAC radiation survey**

#### Table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch train length (us)</td>
<td>0.2 to 1 (MBM); (SBM, FWHM ≤ 1 ns)</td>
</tr>
<tr>
<td>Charge in bunch train (nC)</td>
<td>≥ 5 (MBM)</td>
</tr>
<tr>
<td>Energy (MeV)</td>
<td>≥ 150</td>
</tr>
<tr>
<td>Pulse to pulse energy variation (%)</td>
<td>≤ 0.25 (rms)</td>
</tr>
<tr>
<td>Relative energy spread (%)</td>
<td>≤ 0.5 (rms)</td>
</tr>
<tr>
<td>Normalised emittance (1σ) (nm mrad)</td>
<td>≤ 50 (both planes)</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>1 to 5, adjustable</td>
</tr>
<tr>
<td>Pulse to pulse time jitter (ps)</td>
<td>≤ 100</td>
</tr>
</tbody>
</table>

#### Dose Rate in µSv/h:
- **Earth Line**
  - 1.1
  - 1.4
  - 2.3
  - 5.5
  - 9
  - 210
  - 670
  - 20
  - 10
- **Downstream Wall of LINAC**
  - 0.3
  - 0.8
  - 2.3
  - 4.8
  - 15
  - 850
  - 3000
  - 30
  - 25

**May 11, 2011**
- 2° to conc. wall
- 4nC, 150MeV, 5Hz
Conditioning of SRF and survey
2013/01/14 SRF (110kW, 1.6MV)

- Dose ~ 550µSv/h downstream of SRF inside the bunker.
- Dose ~1.1µSv/h at the joint of shielding wall.
**2013/01/15 SRF (300kW, 2.4MV)**

- Dose can easily reach several tenths of thousands at high power.
- Maximum dose 50~68 mSv/h.
- Notable dose at working area

![Graph showing dose levels inside and outside the shielding wall with values 0.5 µSv/h and 1 µSv/h marked.](image-url)
Radiation safety of TPS

- Regulatory requirement:
  - ✓ Exempt of environmental assessment
  - ✓ Review of TPS SAR
  - ✓ Permission of LINAC commission
    - Permission of TPS commission
    - Approval of TPS operation

- Operation coordination:
  - Safety audit on civil construction
  - Interface discussion for interlock
  - Radiation safety control on commissioning
  - Industrial hygiene of installation

- Responsible system:
  - Dose evaluation and safety assessment
  - Shielding design for accelerator and beamline
  - Monitoring network and interlock
  - Access control system
  - Radiation safety interlock
  - Toxic waste disposal facility
Operation Envelope

TPS Operation: Extraction/Transfer/Ramping/Injection Efficiency

LINAC 2.25W → LTB (90%) → Booster (90%) → BTS (90%) → Storage Ring (I=400mA, τ=7Hr)

Reference Beam Loss → Operation Envelope → Safety Envelope

Effect of stored current & beam lifetime

Max Annual Dose for 2000 hours near Shielding Walls [mSv/y]

<table>
<thead>
<tr>
<th>Tau (T)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.09</td>
<td>0.18</td>
<td>0.28</td>
<td>0.37</td>
<td>0.46</td>
</tr>
<tr>
<td>18</td>
<td>0.10</td>
<td>0.19</td>
<td>0.29</td>
<td>0.39</td>
<td>0.48</td>
</tr>
<tr>
<td>16</td>
<td>0.10</td>
<td>0.21</td>
<td>0.31</td>
<td>0.41</td>
<td>0.52</td>
</tr>
<tr>
<td>14</td>
<td>0.11</td>
<td>0.22</td>
<td>0.33</td>
<td>0.45</td>
<td>0.56</td>
</tr>
<tr>
<td>12</td>
<td>0.12</td>
<td>0.24</td>
<td>0.37</td>
<td>0.49</td>
<td>0.61</td>
</tr>
<tr>
<td>10</td>
<td>0.14</td>
<td>0.28</td>
<td>0.41</td>
<td>0.55</td>
<td>0.69</td>
</tr>
<tr>
<td>8</td>
<td>0.16</td>
<td>0.32</td>
<td>0.48</td>
<td>0.64</td>
<td>0.80</td>
</tr>
<tr>
<td>7</td>
<td>0.18</td>
<td>0.35</td>
<td>0.53</td>
<td><strong>0.71</strong></td>
<td>0.88</td>
</tr>
<tr>
<td>6</td>
<td>0.20</td>
<td>0.40</td>
<td>0.60</td>
<td>0.79</td>
<td>0.99</td>
</tr>
<tr>
<td>5</td>
<td>0.23</td>
<td>0.46</td>
<td>0.69</td>
<td>0.92</td>
<td><strong>1.15</strong></td>
</tr>
<tr>
<td>4</td>
<td>0.28</td>
<td>0.55</td>
<td>0.83</td>
<td><strong>1.10</strong></td>
<td><strong>1.38</strong></td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.70</td>
<td><strong>1.05</strong></td>
<td>1.41</td>
<td>1.76</td>
</tr>
<tr>
<td>2</td>
<td><strong>0.50</strong></td>
<td><strong>1.01</strong></td>
<td><strong>1.51</strong></td>
<td><strong>2.02</strong></td>
<td><strong>2.52</strong></td>
</tr>
</tbody>
</table>

[hour]