Revised Version of SSCAT:
Simplified Shielding Calculation System for High Energy Proton Accelerator Facilities

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The simplified shielding calculation (SSCAT) system is a calculation system for radiation shielding design of high energy proton accelerator facilities, based on Moyer’s and Tesch’s formulae for bulk shielding and Stapleton’s formula for neutron skyshine. SSCAT was originally developed for conceptual shielding design calculations of the J-PARC (Japan Proton Accelerator Research Complex) facilities, and was recently revised in order to cope with safety analysis for the licensing of the J-PARC facilities and shielding design for other proton accelerator facility. This report describes the recent status of SSCAT.

Keywords: Proton Accelerator Facilities, Conceptual Shielding Design, Bulk Shielding, Moyer Model, Tesch’s Formula, Skyshine, Stapleton’s Formula, Simplified Shielding Calculation System

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SSCAT は、Moyer モデルと Tesch の式によるバルク遮へい簡易計算式及び Stapleton の式による中性子スカイシャイン簡易計算式に基づく、高エネルギー陽子加速器施設用簡易遮へい計算システムである。このシステムは、当初、大強度陽子加速器施設（J-PARC）の概略遮へい設計に適用する目的で開発された。近年、J-PARC の使用許可申請にかかる安全評価及び他の陽子加速器施設への適用を目的として改良が行われた。本報告書では、この SSACT の改良について報告する。
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1. Introduction

The J-PARC (Japan Proton Accelerator Research Complex) \(^1, 2, 3\) has constructed and being operated under collaboration between Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK). The missions of this project are studies on the latest basic science and the advancing of nuclear technology using the proton beam generated by the high-energy proton accelerators of the world’s highest instantaneous intensity. The J-PARC consists of three accelerator facilities and three major experimental facilities: 400-MeV LINAC, 3-GeV rapid-cycling synchrotron (RCS), 50-GeV synchrotron, Materials and Life Science Experimental Facility (MLF), Hadron Experimental Facility, and Neutrino Experimental Facility. And further, Accelerator-Driven Transmutation Experimental Facility is planned for the future mission.

From the viewpoint of radiation shielding, the characteristics of J-PARC are summarized as follows: high beam power (up to 1 MW), high beam energy (up to 50 GeV), and a large-scale of accelerator facilities (about 3.2 km in length). Because of these characteristics, some very difficult radiation problems such as a widely distributed radiation source and a thick shield should be overcome. On the other hand, shielding calculation methods with high accuracy were required to save the construction cost. In order to establish a reasonable shielding design, both simplified and detailed design methods were used for the shielding design of the J-PARC project.\(^4, 5\)

The most serious problem concerning the shielding design for most accelerator facilities is that a primary beam-loss condition cannot always be determined accurately, with a few exceptions, such as beam dumps and targets. Thus, considering the large uncertainty in source term estimation, we basically employ semi-empirical formulae and/or simplified methods for most of the accelerator shielding designs. The thickness of shield had to be decided by the radiation shielding criteria, satisfying the laws and ordinances at the boundaries of the radiation controlled area and site, and considering the environmental effect.

Since there are so many beam–loss position to be shielded in each accelerator facility and each contribution to the dose at site boundary must be summed up with those from other facilities, an easy-to-use system is required to decide the proper thickness of shield. Thus, this simplified shielding calculation (SSCAT) system was made with Microsoft Excel.\(^6\) And then the system has been revised so as to cope with change of shielding design as the J-PARC project advances. There are two major alterations. The one is a soil density, which was changed into 1.5 g/cm\(^3\) from 1.3 g/cm\(^3\). The other is an annual operation time of the experimental facilities. For example, the annual operation time for the Hadron Experimental Facility was changed into 4000 h/y from 5000 h/y.

In this report, we described how to use of this system as well as used formulae and calculation conditions such as parameters, reference values, and assumption about proton beam loss, and showed the some example sheets of this system.
2. Simplified shielding calculation system

Since some portion of the SSCAT are specialized to the calculation of J-PARC facilities, some modifications will be necessary to be applied to the design of other facilities. In this section, we describe formulae and parameters adopted in SSCAT and the detail of the system configuration.

2.1. Bulk shielding

2.1.1. Limitations

Simplified calculation formulae have limitations. Conditions suitable for calculation by simplified formulae are as follows:

(a) The distance between a source and the nearest shielding material is more than 1 m,
(b) The position of the calculation points is not extremely forward or backward of beam direction.

According to these conditions, it is clear that beam dump, for example, has an unsuited structure for calculation by simplified formulae. It is necessary to confirm that the structure is satisfied with calculation conditions when using the simplified formulae.

2.1.2. Calculation formulae

There are some formulae for bulk shielding calculation depending on the proton energy or the type of source. Therefore, it is necessary to use the formulae properly for conditions.

(1) Formula applied to line source for the proton energy below 1 GeV.

Tesch’s formula for the line source\(^7\) was applied to the calculation for the line source for the proton energy below 1 GeV. Figures 1 and 2 show the parameters of \(H_{\text{casc}}\) and attenuation coefficient \(\lambda\), respectively.

\[
H = \frac{dJ}{dL} \cdot 2H_{\text{casc}} \cdot \frac{1}{r} \cdot \exp\left(-\frac{d}{0.89\lambda(E_p)}\right) \quad \text{(Sv/s)}
\]  

(1),

where,

\[
\begin{align*}
\frac{dJ}{dL} &: \text{Intensity of the line source (proton/m/s)}, \\
H_{\text{casc}} &: \text{Dose equivalent per proton due to neutrons with energies higher than 8 MeV at a distance of 1m (Sv m}^2/\text{proton)}, \\
r &: \text{Distance from source to calculation point (m)}, \\
d &: \text{Thickness of shielding material (g/cm}^2\) \quad (= \text{density (g/cm}^2\) \times \text{Thickness of shielding (cm)}), \\
\lambda (E_p) &: \text{Dose equivalent attenuation lengths, 90-degree to the proton beam (g/cm}^2\). 
\end{align*}
\]
(2) Formula applied to point source for the proton energy below 1 GeV

Tesch’s formula for point source\(^7\) was applied to the calculation of the point source for the proton energy below 1 GeV.

\[
H = H_{\text{casc}} \cdot J \cdot \exp\left(-d / \lambda(E_p) \right) \cdot \frac{1}{r^2} \quad (\text{Sv/s}) 
\]  

(2),

where,

- \(H_{\text{casc}}\): Dose equivalent per proton due to neutrons with energies higher than 8 MeV at a distance of 1 m (Sv m\(^2\)/proton),
- \(J\): Intensity of the point source (number of incident protons) (proton/s),
- \(d\): Thickness of shielding material (g/cm\(^2\)),
- \(\lambda(E_p)\): Dose equivalent attenuation lengths for concrete, 90-degree to the proton beam (g/cm\(^2\)),
- \(r\): Distance from source to calculation point (m).

(3) Formula applied to the point source for the proton energy above 1 GeV

Moyer’s formula for the point source\(^8\) was applied to the calculation of the source for the proton energy above 1 GeV. Two points to consider for using this formula are as follows:

(a) The applicable angle from the beam axis to the calculation point is between 60 and 120 degrees,
(b) Target size is small enough to regard as a point.

This system calculates for the case of only 90 degrees from the beam direction although Moyer model can calculate any angle within limitation for angle. The parameters used in this system, \(\lambda\) and \(H_0\), were applied from the measurement by Ban et al.\(^{13}\), as shown in Table 1.

\[
H = J \cdot H_1(E_p) \cdot r^{-2} \cdot \exp\left(-(d / \lambda(\pi/2, E_p))\right) \quad (\text{Sv/s}) 
\]

(3),

\[
H_1(E_p) = H_0(E_p) \cdot \exp\left(-\frac{\pi}{2} b\right) \quad (\text{Sv·m}^2/\text{proton})
\]

(4),

Where,

- \(J\): Intensity of the point source (number of incident protons) (proton/s),
- \(H_1(E_p)\): Constant depends on proton energy and shielding materials (measurements) (Sv·m\(^2\)/proton),
- \(E_p\): Proton energy (GeV),
- \(\lambda(\pi/2, E_p)\): Dose equivalent attenuation lengths for concrete, at 90 degrees to the proton beam (g/cm\(^2\)) (Parameters from measurements),
- \(r\): Distance from a source point to calculation points (m),
- \(d\): Thickness of shielding material (g/cm\(^2\)),
- \(H_0(E_p)\): Extrapolating dose equivalent when shielding thickness is 0 cm (measurements) (Sv·m\(^2\)/proton),
2.2. Skyshine

Stapleton’s formula was applied to the skyshine calculation for all proton energy. The applicable distance for this formula between the source and calculation point is from 11 m to 1005 m. Table 2 shows parameter $g$, which are equivalent dose per unit fluence for typical accelerator leakage neutron spectra of various upper energies. Figure 3 shows the parameter $\lambda(E_c)$, which is the effective neutron absorption length in air as a function of the upper neutron energy cut-off assuming a $1/E$ and a typical accelerator leakage spectrum. Both of the parameters listed in Table 2 and shown in Fig. 3 are used for our calculation.

$$H(r) = a \cdot \exp\left(-\frac{r}{\lambda(E_c)}\right) \cdot \frac{(b + r)^2}{Q} \cdot Q$$

(5)

$$Q = \frac{d^2}{g} \cdot H(d, t) \cdot \Omega$$

(6)

$$\Omega = 2\pi(1 - \cos \theta)$$

(7)

where,

$a$ : coefficient ($= 2 \times 10^{-15} \text{m}^2\cdot\text{Sv}$)

$b$ : coefficient ($= 40 \text{ m}$)

$r$ : Horizontal distance from source to the calculation point (m)

$\lambda(E_c)$ : Effective neutron absorption length in air as a function of the upper neutron energy cut-off

$E_c$ : Cut-off energy

$Q$ : Neutron yield from the ground level (for the case of underground tunnels) or the roof (for the case of buildings) (neutron/h)

$d$ : Distance from source to the ground level or the roof (m)

$g$ : Equivalent dose per unit fluence ($\text{fSv}\cdot\text{m}^2$), $f = 1.0 \times 10^{-15}$

$H(d, t)$ : Equivalent dose rate on the ground level (Sv/h)

$t$ : Thickness of roof shield (m)

$\Omega$ : Solid angle subtended by the of source at the roof ($\theta = 26.6(\text{degree})$: polar angle)

2.3. System configuration

The system consists of (1) input sheets and (2) calculation sheets. Table 3 shows contents of each sheet with attentions when entering the data and Fig. 4 shows their relationship.
2.3.1. Input sheet

There are three kinds of input sheets. Since the calculation sheets of each facility refer to the parameters defined on the input sheets, the calculation sheets show the latest results automatically using new input values when the parameters on the input sheets are changed.

(A) Calculation conditions (input1 sheet)

Parameters according to shielding structure such as wall thickness that should be examined are listed in this sheet. Figure 5 illustrates the parameters needed to calculate the bulk shield. “A depth of beam line” (BL-depth) means the distance from the center of beam line to the outside of bulk shields in ceiling direction. The "outside of bulk shields" means the soil surface for underground building, and does the outside of roof for ground facilities. “Space without shield” means the length of the space without shield between the source and the inside of wall. Figure 6 shows the example of this sheet. You should note about “unit”, for example, thickness of shields must be set in “centimeter”, the BL-depth and the space without shield must be set in “meter”.

(B) Parameters of physical property (input2 sheet)

Parameters such as material densities, operation time, parameters dependent on proton energy are listed in this sheet. Table 4 shows the parameters depending on the proton energy. Proper interpolation of the parameters will be necessary for unlisted proton energy. Figure 7 shows the example of this sheet.

(C) Distance settings

The distance from a source to a calculation point for skyshine has to be inputted in this sheet. Figure 8 shows the example of this sheet.

2.3.2. Calculation sheet

These sheets make calculation by referring to the entered values in the input sheets and then give the results. These are categorized as follows; calculation of dose rates for the outer surface of primary shield such as concrete, dose rates for the outer surface of whole shields, and dose rates for skyshine. The dose rates for skyshine from all facilities are summarized on one sheet, and others show calculation results of dose rate for each facility. The calculation sheets cannot be changed directly because of setting of the sheet protection. The sheet protection is set to protect the settings such as reference to another cell, calculation formulae, and so on. Change the information when cancel the sheet protection.

(A) Bulk shielding for each facility

Results of dose rates at surface of bulk shield and ground level are listed in the sheet with the parameters such as density, thickness of shielding material, proton energy, and formulae-specific parameters. Some of parameters in this sheet are referred from the values in the input1 and the input2 sheets. The results are shown in the sheet with reference value of dose rates. In addition, dose rates for
soil activation are compared with the reference values. Compared results are shown visually as “○” (within the reference values) or “×” (over the reference values). Figure 9 shows an example of this sheet.

(B) Skyshine

The calculation sheet for skyshine shows both the calculation conditions and results. The sheet shows the parameters used the calculation as follows; distance from sources at each facility to calculation points, distance from beam line to ground level, thickness of shielding materials, dose rates of soil surface, yearly operation time, and specific parameters used in the formula. These values are referred from the input sheet or the calculation sheets for each facility.

The sheet shows the calculation results as follows; skyshine dose rate for each source, for each facility, each estimation point on site boundary. There are seven estimation points on site boundary for J-PARC. At all estimation points, the dose rates must be lower than the reference values. Figure 10 shows an example of this sheet.

(C) Detailed skyshine dose rate calculation for 50 GeV synchrotron

Although the form of beam line of 50 GeV synchrotron is like a triangle, the skyshine dose rates for 50 GeV synchrotron were calculated as an approximate circle. Because the calculation as an approximate circle gave the higher results than the calculation as a triangle, to change assumption of source shape is good for designing. Figure 11 shows an example of this sheet.
3. **Calculation conditions for J-PARC**

The conditions of J-PARC design calculation are as follows. Table 4 shows the used parameters that depend on proton energy.

3.1. **Density of shielding materials**

The shielding materials used in the calculations are ordinary concrete, soil, and steel. Their default values of mass density used in calculation are 2.2, 1.5, and 7.7 g/cm³ respectively, otherwise the real density based on measurement at the construction site is used.

3.2. **Operation time**

The yearly operation time is scheduled as Table 5.

3.3. **Calculation for bulk shield**

3.3.1. **Sources**

We assumed three kinds of beam losses, full beam loss, point loss, and line loss as a source of calculation of bulk shield. The full beam loss indicates discarding all beams for beam adjustment, measurement, and disposal. The point loss indicates a beam loss occurred locally at the place where the beam size expands temporarily, the beam duct size is narrowed structurally, or the accelerating structure is changed. The line loss indicates a continuous beam loss along with the beam line, mainly occurred by collision with the residual gas.

The calculations for bulk shield for the case of a point loss without local shield and line loss can be applied in the system. The calculation for the cases of the point loss with local shield and the full beam loss were directly calculated or adjusted by Monte Carlo code because their structures are too complicate to apply to the simplified formulae.

3.3.2. **Design criteria of dose rates**

We set the design criteria for dose rates at the outer surface of primary shields, the outer surface of the whole shields such as ground level, and the site boundary. The purpose is to keep safety for radiation workers and the public living around the site boundary.

The design criterion for dose rate at the outside of facility was set to 0.25 μSv/h. This value is the half of that required by the laws and ordinances.

3.3.3. **The dose rates for soil activation**

Almost of beam lines are buried underground. The radioactive nuclides induced in the accelerator structure or concrete of the accelerator room are relatively immobile. However, the radio nuclides produced in the soil or groundwater are free to move.

The radioactive nuclides produced in the groundwater might pass into the general groundwater
system and therefore potentially into the public water supplies extracted from the area. In addition, the possibility that activity induced in the ground may be reached into the groundwater system must also be considered.

Therefore, the internal dose by drinking the contaminated groundwater was estimated, and then the dose rates at the outer surface of the primary shield were calculated back to confirm the safety. The dose rates at the outer surface of primary shield were determined as follows;

\[
\begin{align*}
\text{against to the full beam loss and point loss:} & \quad 1.1 \times 10^4 (\mu\text{Sv/h}), \\
\text{against to the line loss:} & \quad 5.0 \times 10^3 (\mu\text{Sv/h}).
\end{align*}
\]

3.4. Skyshine calculation

3.4.1. Sources

The sources used in the skyshine calculation are dose rates on ground level or building roof calculated for bulk shield. The doses at the site boundary by skyshine were calculated by using all results of the bulk shield without regard to their calculation methods.

3.4.2. Design criteria of dose rates

The design criterion of dose for skyshine on the site boundary was set to 50 \(\mu\text{Sv}\) per year. This value is one twentieth of the dose limit required by the laws and ordinances.

4. Concluding remarks

The simplified shielding calculation table system was revised with progress of the J-PARC project. In addition, since this project has been of the international interest, we have received inquiries about the methods of shielding design from foreign countries. We rewrote notation in English of this calculation file in order to support these inquiries.

Acknowledgements

For revision of SSCAT system, authors received significant advice from the member of Facility Safety Group and other groups in Quantum Beam Science Directorate in JAEA, Hideo Hirayama who is head of Radiation Science Center in KEK, and other members of this center. It describes here and gratitude is expressed.
References

Table 1  Parameters for Moyer’s formula

<table>
<thead>
<tr>
<th>$H_0$(Sv·m$^{-2}$)</th>
<th>b/(radian)</th>
<th>$\lambda$ (g/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;\text{Stevenson et al.}&gt;^{10-12}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2.8 \times 10^{-13}\text{Ep}^{0.8}$</td>
<td>2.3</td>
<td>117 (soil)</td>
</tr>
<tr>
<td>(proton energy 5～30GeV)</td>
<td></td>
<td>120 (concrete)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>144 (steel)</td>
</tr>
<tr>
<td>$1.61 \times 10^{-13}\text{Ep}$</td>
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<td>124 (heavy concrete)</td>
</tr>
<tr>
<td>(proton energy 10～500GeV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&lt;\text{measurements by Ban et al.}&gt;^{13}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0.88 \times 10^{-13}\text{Ep}$</td>
<td>2.5</td>
<td>143 (concrete)</td>
</tr>
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<td></td>
<td></td>
<td>188 (steel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>163 (heavy concrete)</td>
</tr>
<tr>
<td>$&lt;\text{calculation value with FLUKA}&gt;^{14}$</td>
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<td></td>
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<td>133±3 (concrete)</td>
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<td></td>
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<td>135±2 (aluminum)</td>
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<tr>
<td></td>
<td></td>
<td>164±2 (steel)</td>
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<tr>
<td></td>
<td></td>
<td>264±3 (lead)</td>
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<tr>
<td></td>
<td></td>
<td>258±3 (uranium)</td>
</tr>
</tbody>
</table>

Bold: used values of J-PARC design
<table>
<thead>
<tr>
<th>Upper energy (MeV)</th>
<th>Composite spectrum averaged equivalent dose (fSv·m²)</th>
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<td>6300.0</td>
<td>14.6</td>
</tr>
<tr>
<td>10000.0</td>
<td>14.7</td>
</tr>
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</table>
### Table 3 Contents of each sheet in SSCAT

<table>
<thead>
<tr>
<th>Sheet Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input sheet</strong></td>
<td></td>
</tr>
<tr>
<td>Conditions (input1)</td>
<td>Parameters; shielding thickness, beam loss, etc.</td>
</tr>
<tr>
<td>Parameters (input2)</td>
<td>Almost fixed parameters; material density, parameters depend on proton energy, operation time, etc.</td>
</tr>
<tr>
<td>Distance</td>
<td>The values that are read from drawings or CAD are converted to the real distance in this sheet. You can get the real distance when you change the formula setting in [distance] cells as you like. Current settings are to convert values from CAD to real distance.</td>
</tr>
<tr>
<td><strong>Calculation sheet</strong></td>
<td></td>
</tr>
<tr>
<td>Skyshine</td>
<td>Calculation sheet for skyshine. This sheet lists calculation conditions and results.</td>
</tr>
<tr>
<td>[Facility name]</td>
<td>This sheet arranges the calculation results and its process about dose accounting for the soil activation and dose for ground level.</td>
</tr>
<tr>
<td>Detail calculation of 50R skyshine</td>
<td>This sheet calculates skyshine dose rates for 50GeV synchrotron.</td>
</tr>
</tbody>
</table>
Table 4  Parameters depends on the proton energy

<table>
<thead>
<tr>
<th>Proton energy (GeV)</th>
<th>Attenuation length $\lambda$ (g/cm$^2$)</th>
<th>Tesch’s formulae(^7)</th>
<th>Moyer model(^{13})</th>
<th>Stapleton(^9), (^{10})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>concrete(^7,^{13})</td>
<td>soil(^5)</td>
<td>steel(^{13})</td>
<td>$H_{\text{casc}}$ (Sv m$^2$)</td>
</tr>
<tr>
<td>0.2</td>
<td>73</td>
<td>71</td>
<td>-</td>
<td>3.50E-16</td>
</tr>
<tr>
<td>0.4</td>
<td>90</td>
<td>88</td>
<td>-</td>
<td>2.00E-15</td>
</tr>
<tr>
<td>0.6</td>
<td>100</td>
<td>98</td>
<td>131(^b)</td>
<td>6.00E-15</td>
</tr>
<tr>
<td>1.0</td>
<td>143</td>
<td>139</td>
<td>188</td>
<td>-</td>
</tr>
<tr>
<td>2.0</td>
<td>143</td>
<td>139</td>
<td>188</td>
<td>-</td>
</tr>
<tr>
<td>3.0</td>
<td>143</td>
<td>139</td>
<td>188</td>
<td>-</td>
</tr>
<tr>
<td>15.0</td>
<td>143</td>
<td>139</td>
<td>188</td>
<td>-</td>
</tr>
<tr>
<td>50.0</td>
<td>143</td>
<td>139</td>
<td>188</td>
<td>-</td>
</tr>
</tbody>
</table>

a) 0.2~1.0(GeV) : Calculated from the attenuation length of concrete $\times$ (117/120).
117: Attenuation length of soil / 120: Attenuation length of concrete, measured by Stevenson et al.\(^{10}\)
b) Calculated from the attenuation length of concrete $\times$ (188/143).
c) Including the interpolated value from the reference 9.
<table>
<thead>
<tr>
<th>Facility</th>
<th>Operation time [hr./yr.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linac</td>
<td>5500</td>
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<tr>
<td>3GeV synchrotron</td>
<td>5500</td>
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<tr>
<td>50GeV synchrotron</td>
<td>5000</td>
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<tr>
<td>Material and Life Science Experimental Facility</td>
<td>5000</td>
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<td>Hadron Experimental Facility</td>
<td>4000</td>
</tr>
<tr>
<td>Neutrino Experimental Facility</td>
<td>4000</td>
</tr>
</tbody>
</table>

March 2006
Fig. 1  Dose equivalent ($H_{\text{casc}}$) per proton due to neutrons with energies higher than 8 MeV at a distance of 1 m from a copper target and around 90 degrees to the beam.
Fig. 2  Dose equivalent attenuation lengths ($\lambda$)^7 for concrete, at 90 degrees to the proton beam.
Fig. 3  The effective neutron absorption length ($\lambda$) in air as a function of the upper neutron energy cut-off assuming an $1/E$ and a typical accelerator leakage differential energy spectrum.
Fig. 4  Relationship of Excel sheets for SSCAT

Calculation conditions (input1 sheet)
Parameters (input2 sheet)
Distance settings

Bulk shielding for each facility
- Facility1
- Facility2
- Facility3
- Facility4

Dose rate of soil surface

skyshine

Excel sheet
Fig. 5  name of each part  (underground buildings)
Fig. 6 The sheet listed the calculation conditions (input1 sheet)
Fig. 7  The sheet listed the parameters (input2 sheet)
Fig. 8  The distance setting sheet
Fig. 9  The each facility sheet (Ex. 3GeV synchrotron)
Fig. 10  The sheet listed skyshine dose rates for all of J-PARC facilities
Fig. 11 The sheet of detail calculation for 50GeV synchrotron
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### 国際単位系（SI）

| 表1 | SI基本単位 | 表2 | ボルト系を用いて表されるSI基本単位の例 | 表3 | SI補足単位 | 表4 | 単位系 | 表5 | SI補足単位 | 表6 | 役割 | 表7 | SIに定義されないが、SIと併用される単位 | 表8 | SIに定義されないが、SIと併用される単位 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 組立単位 | 名称 | 記号 | SI基本単位に対する数値 | 表示 | 名称 | 記号 | 数値 | 記号 | 名称 | 記号 | 数値 | 記号 | 名称 | 記号 |
| アクセラメータ | m | kg | m/s | アクセルメータ | m/s^2 | kg | m/s^2 | アクセルメータ | m/s^2 | kg | m/s^2 | アクセルメータ | m/s^2 | kg | m/s^2 |
| レベルムーバ | g | kg | m | レベルムーバ | g | kg | m | レベルムーバ | g | kg | m | レベルムーバ | g | kg | m |
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