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

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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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高エネルギー陽子加速器施設のための概略遮へい計算システム改訂版

日本原子力研究開発機構

J-PARC センター

安全ディビジョン

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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。

Contents

1.	Introduction	1
2.	Simplified shielding calculation system	2
2. 1.	Bulk shielding	2
2. 1. 1.	Limitations	2
2. 1. 2.	Calculation formulae	2
2. 2.	Skyshine	4
2. 3.	System configuration	4
2. 3. 1.	Input sheet	5
2. 3. 2.	Calculation sheet	5
3.	Calculation conditions for J-PARC	7
3. 1.	Density of shielding materials	7
3. 2.	Operation time	7
3. 3.	Calculation for bulk shield	7
3. 3. 1.	Sources	7
3. 3. 2.	Design criteria of dose rates	7
3. 3. 3.	The dose rates for soil activation	7
3. 4.	Skyshine calculation	8
3. 4. 1.	Sources	8
3. 4. 2.	Design criteria of dose rates	8
4.	Concluding remarks	8
	Acknowledgements	8
	References	9

目 次

1. はじめに.....	1
2. 概略遮へい計算システム	2
2.1. バルク遮へい	2
2.1.1. 適用範囲	2
2.1.2. 計算式.....	2
2.2. スカイシャイン	4
2.3. システム構成	4
2.3.1. 入力シート	5
2.3.2. 計算シート	5
3. J-PARC における計算条件.....	7
3.1. 遮へい材の密度	7
3.2. 運転時間	7
3.3. バルク遮へい計算.....	7
3.3.1. 線源.....	7
3.3.2. 線量目標値.....	7
3.3.3. 土壌放射化に対する線量.....	7
3.4. スカイシャイン計算.....	8
3.4.1. 線源.....	8
3.4.2. 線量目標値.....	8
4. おわりに.....	8
謝 辞.....	8
参考文献.....	9

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/cm³ from 1.3 g/cm³. 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 5000h/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 source⁷⁾ 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_{casc} and attenuation coefficient λ , respectively.

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

where,

- dJ/dL : Intensity of the line source (proton/m/s),
- H_{casc} : Dose equivalent per proton due to neutrons with energies higher than 8 MeV at a distance of 1m (Sv m²/proton),
- r : Distance from source to calculation point (m),
- d : Thickness of shielding material(g/cm²) (= density (g/cm³) × Thickness of shielding (cm)),
- $\lambda(E_p)$: Dose equivalent attenuation lengths, 90-degree to the proton beam (g/cm²).

(2) Formula applied to point source for the proton energy below 1 GeV

Tesch's formula for point source⁷⁾ was applied to the calculation of the point source for the proton energy below 1 GeV.

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

where,

H_{casc} : Dose equivalent per proton due to neutrons with energies higher than 8 MeV at a distance of 1 m (Sv m² /proton),

J : Intensity of the point source (number of incident protons) (proton/s),

d : Thickness of shielding material (g /cm²),

$\lambda(E_p)$: Dose equivalent attenuation lengths for concrete, 90-degree to the proton beam (g/cm²),

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 source⁸⁾ 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, λ and H_0 , were applied from the measurement by Ban *et al.*¹³⁾, as shown in Table 1.

$$H = J \cdot H_1(E_p) \cdot r^{-2} \cdot \exp(-d / \lambda(\frac{\pi}{2}, E_p)) \quad (\text{Sv/s}) \quad (3),$$

$$H_1(E_p) = H_0(E_p) \cdot \exp(-\frac{\pi}{2}b) \quad (\text{Sv} \cdot \text{m}^2/\text{proton}) \quad (4),$$

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·m²/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 /cm²) (Parameters from measurements),

r : Distance from a source point to calculation points (m),

d : Thickness of shielding material (g/cm²),

$H_0(E_p)$: Extrapolating dose equivalent when shielding thickness is 0 cm (measurements) (Sv·m²/proton),

b : Parameter (1/radian) (= 2.5).

2. 2. Skyshine

Stapleton's formula⁹⁾ 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.

$$H(r) = \frac{a \cdot \exp\left(-\frac{r}{\lambda(E_c)}\right)}{(b+r)^2} \cdot Q \quad (\text{Sv/h}) \quad (5)$$

$$Q = \frac{d^2}{g} \cdot H(d,t) \cdot \Omega \quad (6)$$

$$\Omega = 2\pi(1 - \cos\theta) \quad (7)$$

where,

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

b : coefficient (= 40 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)

Ω : 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 50GeV 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 μ Sv/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;

against to the full beam loss and point loss : 1.1×10^4 ($\mu\text{Sv/h}$),
against to the line loss : 5.0×10^3 ($\mu\text{Sv/h}$).

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 μSv 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.

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Table 1 Parameters for Moyer's formula

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

Bold : used values of J-PARC design

Table 2 Composite spectrum averaged equivalent dose⁹⁾

Upper energy (MeV)	Composite spectrum averaged equivalent dose (fSv·m ²)
1.6	4.0
2.5	4.8
4.0	5.5
6.3	6.3
10.0	7.1
16.0	7.8
25.0	8.6
40.0	9.4
63.0	10.1
100.0	10.9
160.0	11.7
250.0	12.5
400.0	13.2
630.0	13.7
1000.0	14.1
1600.0	14.4
2500.0	14.5
4000.0	14.6
6300.0	14.6
10000.0	14.7

Table 3 Contents of each sheet in SSCAT

	sheet name	Contents
Input sheet	Conditions (input1)	Parameters; shielding thickness, beam loss, etc.
	Parameters (input2)	Almost fixed parameters; material density, parameters depend on proton energy, operation time, etc.
	Distance	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.
Calculation sheet	Skyshine	Calculation sheet for skyshine. This sheet lists calculation conditions and results.
	[Facility name]	This sheet arranges the calculation results and its process about dose accounting for the soil activation and dose for ground level.
	Detail calculation of 50R skyshine	This sheet calculates skyshine dose rates for 50GeV synchrotron.

Table 4 Parameters depends on the proton energy

Proton energy (GeV)	Attenuation length λ (g/cm ²)		Tesch's formulae ⁷⁾	Moyer model ¹³⁾	Stapleton ^{9), C)}	
	concrete ^{7, 13)}	soil ^{a)}			$\lambda(E_c)$ (m)	g(Sv m ²)
0.2	73	71	3.50E-16	-	438	1.21E-14
0.4	90	88	2.00E-15	-	502	1.32E-14
0.6	100	98	6.00E-15	-	543	1.36E-14
1.0	143	139	-	8.80E-14	622	1.44E-14
2.0	143	139	-	1.76E-13	622	1.44E-14
3.0	143	139	-	2.64E-13	638	1.45E-14
15.0	143	139	-	1.32E-12	670	1.47E-14
50.0	143	139	-	4.4E-12	670	1.47E-14

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 5 The operation time for each facility of J-PARC

Facility	Operation time [hr./yr.]
Linac	5500
3GeV synchrotron	5500
50GeV synchrotron	5000
Material and Life Science Experimental Facility	5000
Hadron Experimental Facility	4000
Neutrino Experimental Facility	4000

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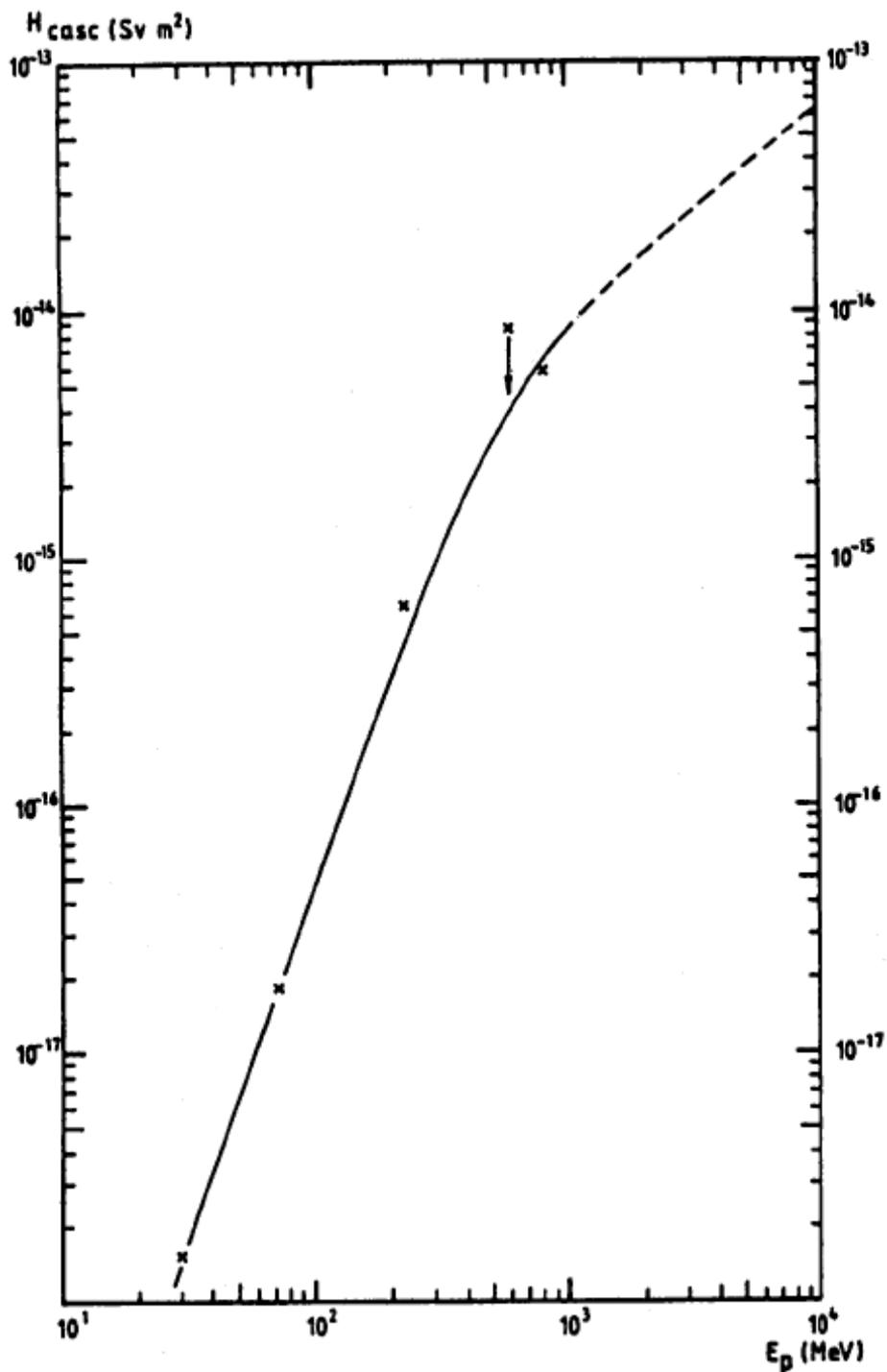
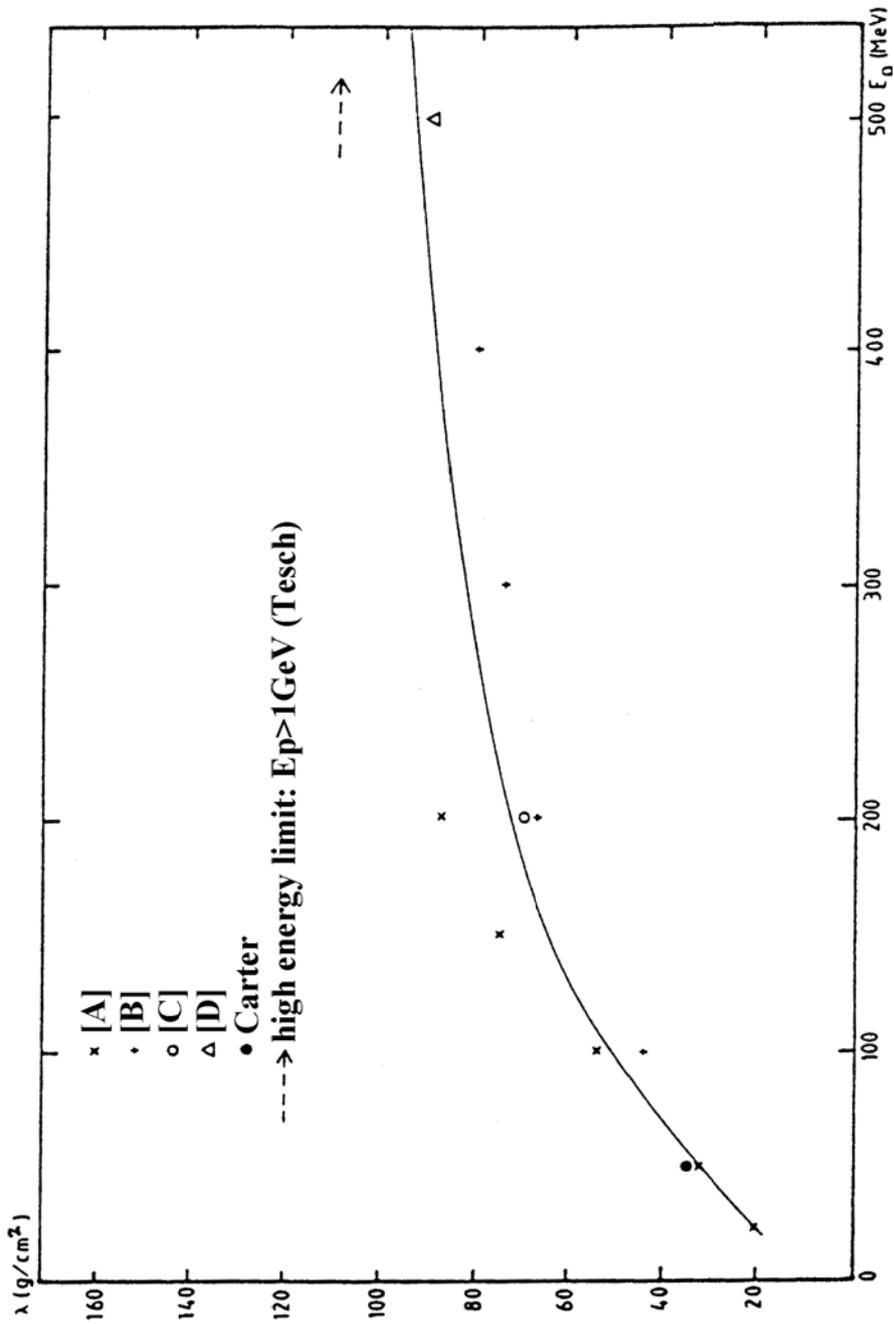


Fig. 1 Dose equivalent (H_{casc})⁷⁾ per proton due to neutrons with energies higher than 8 MeV at a distance of 1 m from a copper target and around 90 degrees to the beam.



[A] H.W.Patterson, R.H.Thomas : "Accelerator Health Physics", Academic Press, New York (1973)

[B] T.H.Braid, R.F.Rapids, R.H.Siemssen, J.W.Tippie, K.O'Brien : IEEE Trans, Nucl. Sci., NS-18, 821(1971)

[C] R.G.Alsmitter, Jr., R.T.Santoro, J.Barish : Particle Accel., 7, 1(1975)

[D] S.Ban, H.Hirayama, K.Katoh : "Transport Calculation of Medium Energy Protons and Neutrons by Monte Carlo Method", KEK-78-13, National Laboratory for High Energy Physics (1978)

Fig. 2 Dose equivalent attenuation lengths (λ)⁷ for concrete, at 90 degrees to the proton beam.

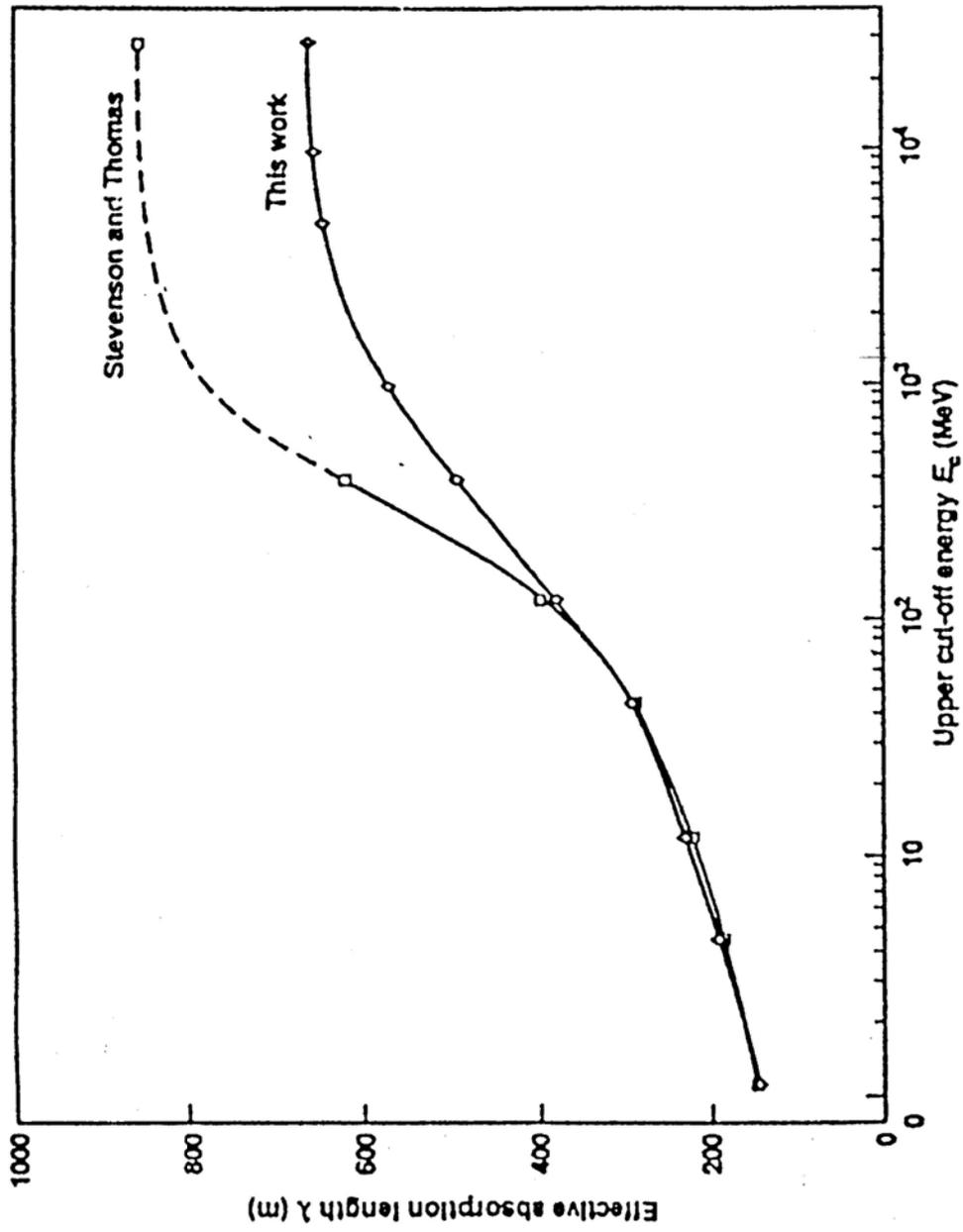


Fig. 3 The effective neutron absorption length (λ) in air as a function of the upper neutron energy cut-off assuming an $1/E$ and a typical accelerator leakage differential energy spectrum.

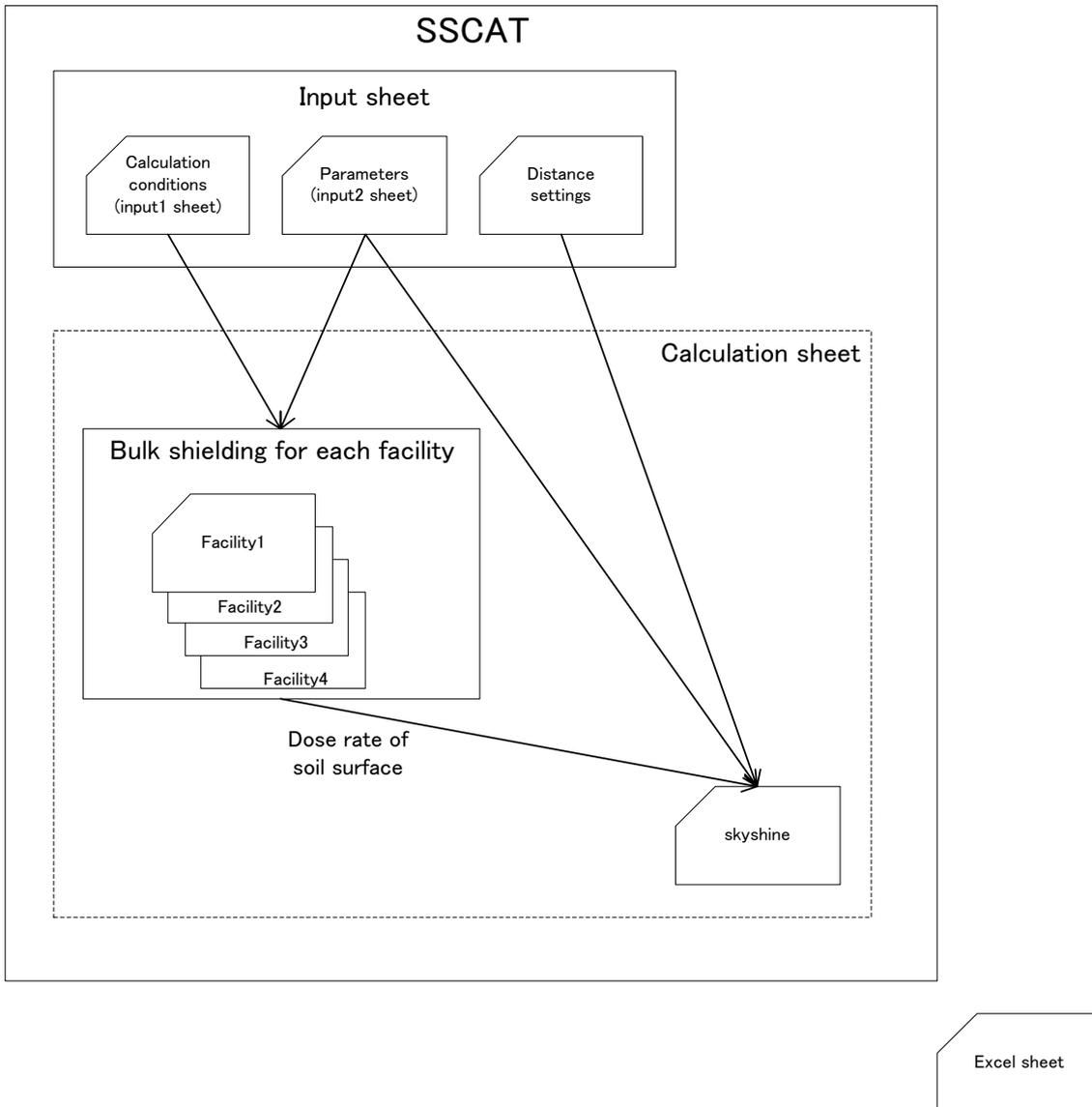


Fig. 4 Relationship of Excel sheets for SSCAT

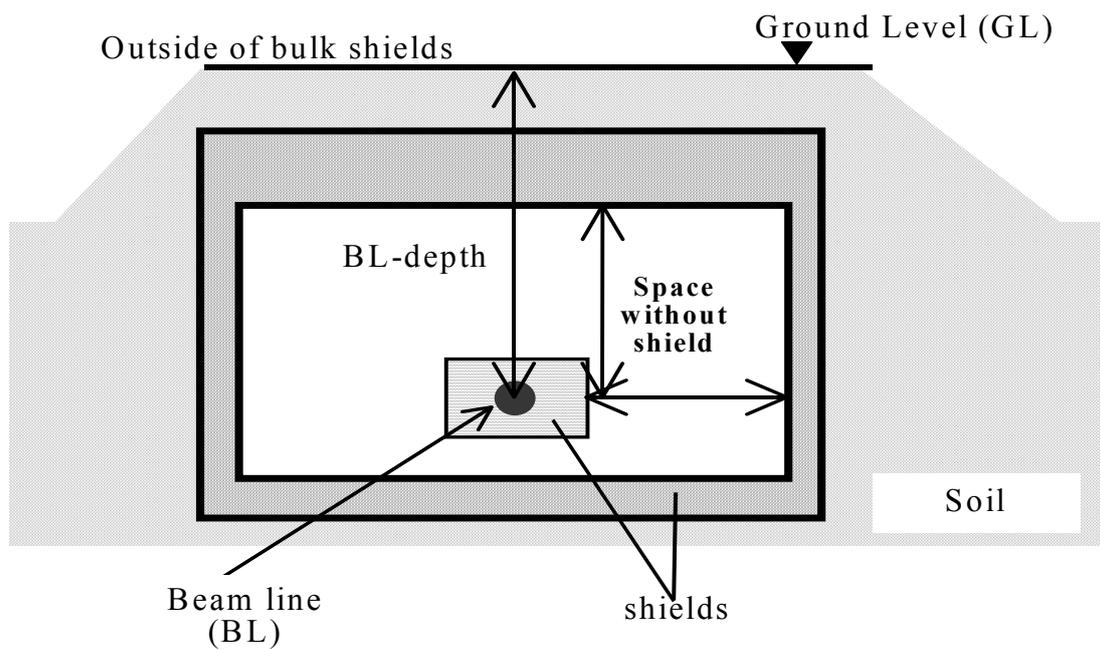


Fig. 5 name of each part (underground buildings)

SSCAT計算修正済み.xls [区換モ-1] - Microsoft Excel

ホーム 挿入 ページレイアウト 数式 データ 検閲 表示 開発

NI20 3.2

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Facility	source	source type	length (m)	ϕ /target (1/g)	beam energy/beam current (GeV) (A)	beam loss (W or W/m)	thickness of shielding materials (cm)	concrete	steel	soil	others	depth from beam line to ground level	air space (m)	BL-TP(m)	GL-TP(m)
3	60MeV Linac	Top	30	-	0.06	666.0	0.1 (W/m)	354	0	0	0	11.56	8.02	3.2	15
4	Bottom						0	0	0	0	0		1.5		
5	Left						0	0	0	0	0		3.4		
6	Right						0	0	0	0	0		4.9		
7	S92-1	Top	30	1	0.062	666.0	11 (W)	40	30	740	0	11.8	3.7	3.2	15
8	Bottom						50	30	30				1.2		
9	Left						50	30	30				2.5		
10	Right						40	30	30				4		
11	S72-1	Top	30	1	0.072	666.0	19 (W)	50	30	730	0	11.8	3.7	3.2	15
12	Bottom						50	30	30				1.2		
13	Left						60	30	30				2.5		
14	Right						50	30	30				4		
15	200MeV Linac	Top	100		0.2	666.0	0.1 (W/m)	440	0	0	0	11.2	6.8	3.2	15
16	Bottom						10	0	0	0	0		1.5		
17	Left						0	0	0	0	0		4.3		
19	Right						0	0	0	0	0		4		
20	MEET2-1	Top	5		0.2	666.0	1.00E+00 (W/m)	40	0	740	0	11.8	1.5	3.2	15
21	Bottom						60	0	0				2.8		
22	Left						50	0	0				4		
23	Right						40	0	0				4.3		
24	D200-1	Top		1	0.2	666.0	108 (W)	50	30	730	0	11.8	3.7	3.2	15
25	Bottom						100	30	30				1.2		
26	Left						70	30	30				2.5		
27	Right						50	30	30				4		
28	400MeV Linac	BT(linear part)	110		0.4	666.0	0.1 (W/m)	435	0	0	0	11.15	6.8	3.2	15
29	Bottom						40	0	0	0	0		1.2		
30	Left						20	0	0	0	0		2.8		
31	Right						10	0	0	0	0		4.3		
32	debuncher-1	Top		1	0.2		1 (W/m)	470	0	0	0	11.5	6.8	3.2	15
33	Bottom						20 (W/m)	20	0	0	0		1.2		
34	Left						0	0	0	0	0		2.8		
35	Right						0	0	0	0	0		7.3		
36	MEET3	Top	10	1	0.4	666.0	0.5 (W/m)	60	0	720	0	11.8	4	3.2	15
37	Bottom						90	0	0				1.2		
38	Left						70	0	0				2.8		
39	Right						60	0	0				4.3		
40	D400-2-1	Top		1	0.4	666.0	6.00E+02 (W)	30	100	750	0	11.8	3	3.2	15
41	Bottom						50	100	30				0.2		
42	Left						30	100	30				2.3		
43	Right						30	100	30				6.3		
44	D400-2-2	Top		1	0.4	666.0	4.00E+00 (W)	30	100	750	0	11.8	3	3.2	15
45	Bottom						50	100	30				0.2		
46	Left						30	100	30				2.5		

Layout and estimation points: Conditions (input1) / Parameters (input2) / distance / Skyshine / Linac / 3GeV Ring / 3-N BT / 500GeV Ring / MLF / Hadron Experimental Facility / Neutrino / 2.5

30%

Fig. 6 The sheet listed the calculation conditions (input1sheet)

SSOAT計算修正済み.xls 国鉄七-101 - Microsoft Excel

ホーム 挿入 ページレイアウト 設定 データ 検閲 表示 印刷

H17

≡ 条件 (input) 1D36

1	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
2	1 Density														
3		concrete	soil												
4	2. Other parameters														
5		beam energy (GeV)	2.2	1.5	7.7										
6		Source position													
7		60MeV/linac													
8		200MeV/linac													
9		400MeV/linac													
10		dehuncher-1													
11		MEBT3													
12		D400-2-1													
13		D400-2-2													
14		D450-1													
15		D400-3a													
16		D400-3b-1													
17		D400-3b-2													
18		D400-3c													
19		D400-4b-1													
20		D400-4b-2													
21		cross over point of linac & ADS													
22		L3BT arch/collimator													
23		L3BT 3GeV Synch. Side													
24		Injection													
25		Injection (septum)													
26		Collection													
27		Injection (grate)													
28		Injection (beam dump)													
29		arch-1													
30		arch-2													
31		arch-3													
32		RF													
33		Extraction (septum)													
34		Extraction (septum)													
35		Extraction (septum)													
36		3NET until beam dump													
37		Beam dump (Extraction)													
38		2N BT (under the HAKKEN road)													
39		Beam line of experimental facility side													
40		T1													
41		mean experimental facility													
42		S													
43		Beam transport between muon target and mercury target													
44		Material and Life science experiment target													
45		3-500a V.BT (-in front of Escaper)													
46		3-500a V. scouter (-in front of HAKKEN road)													
47		3-500a V.BT (-in front of a bulhead)													
48		3-500a V.BT (-at the foot of slope)													
49		Layout and estimation points													
50		Parameters (input1)													
51		Parameters (input2)													
52		Parameters (input3)													
53		Parameters (input4)													
54		Parameters (input5)													
55		Parameters (input6)													
56		Parameters (input7)													
57		Parameters (input8)													
58		Parameters (input9)													
59		Parameters (input10)													
60		Parameters (input11)													
61		Parameters (input12)													
62		Parameters (input13)													
63		Parameters (input14)													
64		Parameters (input15)													
65		Parameters (input16)													
66		Parameters (input17)													
67		Parameters (input18)													
68		Parameters (input19)													
69		Parameters (input20)													
70		Parameters (input21)													
71		Parameters (input22)													
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118		Parameters (input69)													
119		Parameters (input70)													
120		Parameters (input71)													
121		Parameters (input72)													
122		Parameters (input73)													
123		Parameters (input74)													
124		Parameters (input75)													
125		Parameters (input76)													
126		Parameters (input77)													
127		Parameters (input78)		</											

SSCAT 計算修正済み.xls [五換電モード] - Microsoft Excel

ホーム 挿入 ページレイアウト 表式 ツール 表示 印刷 閉

B15 proton number of beam loss (p/s/Q mag) uniform

No.	Description	Injection (septum)		Injection (Grana X1.5 beam dump)		Injection (Grana X1.5 beam dump)		Extraction (septum2)		Extraction (septum1)		Extraction (septum1) beam dump		Extraction (septum1) beam dump	
		Top	Bottom	Top	Bottom	Top	Bottom	Left	Right	Left	Right	Left	Right	Left	Right
1	3GeV Synchrotron														
2	Injection (Grana) (0.4GeV) Tsch's formula for uniform beam loss														
3	Injection (Grana) (1.3GeV) Wolf-Meyer model for uniform beam loss														
4	Injection (Grana) (1.3GeV) Wolf-Meyer model for another section: Monte Carlo code calculation														
5	Parameters														
6	Concrete														
7	Steel														
8	Soil														
9	density (g/cm3)	2.20	7.70	1.50											
10	Attenuation length λ (g/cm2) for 400MeV	90	136	88											
11	Attenuation length λ (g/cm2) above 1GeV	143	188	133											
12	Proton Energy (GeV)	0.4	0.4	1.5	0.4	1.5	0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
13	proton number for its beam loss (p/s/Q mag)	1.56E+13	6.24E+13	1.01E+11	2.68E+10	1.96E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10
14	proton number for its beam loss (p/s/Q mag) uniform	1.01E+11	1.01E+11	1.01E+11	2.68E+10	1.01E+11	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10	2.68E+10
15	proton number for its beam loss (p/s/Q mag) uniform	2.00E+15	2.00E+15	2.00E+15											
16	H ₀ (S/m ² /p)	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13	1.32E-13
17	b (radian)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
18															
19															
20															
21	between beam line and inner surface of shield (cm)	320	330	405	555	320	350	355	565	580	120	400	850	440	400
22	Length between beam line and EP-A (m)	5.8	7	6.25	7.85	6.7	5.85	8.85	11.3	2.5	4.8	9	11.3	5.7	4.8
23	Length between beam line and EP-B (m)	11.8													
24	Concrete thickness of shield (cm)	270	350	220	300	350	350	300	300	550	130	80	50	130	80
25	Steel thickness of shield (cm)	594	770	484	484	770	770	726	660	1210	286	176	110	1210	286
26	Soil thickness of shield (cm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	d (g/cm2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	d (g/cm2)	590													
29	d (g/cm2)	885													
30	d (g/cm2)	6.60	6.56	5.38	6.38	8.56	8.07	7.33	13.44	3.18	1.96	1.22	8.46	2.00	1.23
31	d (g/cm2)	16.66													
32	Dose at EP-A (μSv/h) (empirical)	2.83E+01	2.83E+00	8.27E+01	3.45E+01	3.11E+00	2.83E+00	6.65E+00	3.32E+00	8.23E+00	4.45E+00	3.64E+00	4.10E+01	1.05E+00	3.19E+00
33	Dose at EP-B (μSv/h) (empirical)	3.04E+00	1.28E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00
34	Dose at EP-A (μSv/h) (MARS)	8.10E+00	1.28E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00
35	Dose at EP-B (μSv/h) (MARS)	8.43E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00
36	Dose at EP-A (μSv/h) (total)	1.27E+01	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00	1.68E+00
37	Dose at EP-B (μSv/h) (total)														
38	Is the dose at EP-A under the reference value for soil activation? Yes(O)/No(X)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	reference value(A) (μSv/h)	1.10E+04													
40	reference value(B) (μSv/h)	0.25													
41															
42															
43															
44															
45															
46															
47															
48															
49	between beam line and inner surface of shield (cm)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
50	Length between beam line and EP-A (m)	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
51	Length between beam line and EP-B (m)	11.5													
52	Concrete thickness of shield (cm)	150	150	150	150	150	150	150	150	150	150	150	150	150	150
53	Steel thickness of shield (cm)	330	330	330	330	330	330	330	330	330	330	330	330	330	330
54	Soil thickness of shield (cm)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
55	d (g/cm2)	770	770	770	770	770	770	770	770	770	770	770	770	770	770
56	d (g/cm2)	880													
57	d (g/cm2)														
58	d (g/cm2)														
59	thickness of shield (cm)	880													
60	thickness of shield (cm)														

Layout and estimation points / Parameters (input1) / Parameters (input2) / distance / Skyshine / Linac / 3GeV Ring / 9-N BT / 50GeV Ring / MLF / Hadron Experimental Facility / 780

Fig. 9 The each facility sheet (Ex. 3GeV synchrotron)

SSCAT 計算修正済み.xls [互換モード] - Microsoft Excel

E34 ホーム 挿入 ページレイアウト 数式 ツール 表示 関数 開発

skyshine estimation for 50GeV synchrotron by circle approximation model

soil
 Estimation point B (EP-B)
 Estimation point A
 beam line
 EL depth

line of circle mo
 $\Delta\theta$
 249 (m)
 1.666666667 (degree)

coefficient a
 $2.00E-15$ (Sv m²)
 2.050505118 (deg)
 670

coefficient b
 $1.47E-14$ (Sv m²)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	skyshine estimation for 50GeV synchrotron by circle approximation model																	
2	Dose rate of soil surf	3.846E-02																
3	arch length	156735 (m)																
4	number of Q-magnet	216 (個)																
5	operation time	5000 (hour/year)																
6	EL depth (m)	11.55																
7																		
8	Stapleton式																	
9	coefficient a	$2.00E-15$ (Sv m ²)																
10	θ	2.050505118 (deg)																
11	λ (Ec)	670																
12																		
13																		
14																		
15	ce from center of a circle to estimation points (m)	409																
16	shortest distance to the estimation points (m)	190																
17	radius (m)	249																
18	skyshine(μ Sv/h)	2.276E+00																
19																		
20	detail calculation																	
21	θ (deg.)	0																
22	θ (rad.)	0																
23	distance(m) skyshine	160.00	4.559E-02	120.00	7.561E-02	90.00	1.198E-01	100.00	1.017E-01	100.00	1.017E-01	50.00	2.659E-01	80.00	1.427E-01	190.00	3.298E-02	
24		160.27	4.544E-02	120.23	7.572E-02	90.40	1.190E-01	100.37	1.013E-01	100.37	1.013E-01	50.63	2.614E-01	80.43	1.416E-01	190.24	3.298E-02	
25		3.393333333	4.503E-02	121.29	7.426E-02	91.59	1.169E-01	101.46	9.943E-02	101.46	9.943E-02	50.47	2.504E-01	81.72	1.393E-01	190.07	3.264E-02	
26		5	4.435E-02	122.89	7.264E-02	93.51	1.130E-01	103.26	9.668E-02	103.26	9.668E-02	55.39	2.342E-01	83.82	1.333E-01	192.18	3.224E-02	
27		6.666666667	4.343E-02	125.69	7.049E-02	96.15	1.092E-01	106.73	9.310E-02	106.73	9.310E-02	59.25	2.152E-01	86.67	1.268E-01	193.66	3.170E-02	
28		8.333333333	4.230E-02	127.85	6.799E-02	99.44	1.027E-01	108.82	8.897E-02	108.82	8.897E-02	63.96	1.951E-01	90.20	1.194E-01	196.00	3.108E-02	
29		11.666666667	4.100E-02	131.15	6.499E-02	103.31	9.692E-02	112.47	8.421E-02	112.47	8.421E-02	69.07	1.759E-01	94.33	1.115E-01	198.57	3.024E-02	
30		15.333333333	3.953E-02	134.94	6.189E-02	107.70	9.037E-02	116.63	7.930E-02	116.63	7.930E-02	74.75	1.578E-01	98.99	1.034E-01	201.57	2.997E-02	
31		19.666666667	3.801E-02	139.17	5.895E-02	112.54	8.411E-02	121.24	7.481E-02	121.24	7.481E-02	80.79	1.408E-01	104.07	9.549E-02	204.96	2.884E-02	
32		24.333333333	3.639E-02	143.81	5.629E-02	117.78	7.891E-02	126.26	6.937E-02	126.26	6.937E-02	87.13	1.258E-01	109.55	8.790E-02	208.74	2.740E-02	
33		29.333333333	3.474E-02	148.81	5.201E-02	123.95	7.218E-02	131.63	6.458E-02	131.63	6.458E-02	94.99	1.128E-01	115.95	8.076E-02	212.87	2.659E-02	
34		34.333333333	3.308E-02	154.13	4.881E-02	129.22	6.677E-02	137.30	6.001E-02	137.30	6.001E-02	100.42	1.011E-01	121.43	7.412E-02	217.32	2.592E-02	
35		39.333333333	3.142E-02	159.74	4.278E-02	135.33	6.154E-02	143.23	5.569E-02	143.23	5.569E-02	107.29	9.098E-02	127.73	6.801E-02	222.09	2.420E-02	
36		44.333333333	2.990E-02	165.60	4.278E-02	141.66	5.679E-02	149.40	5.164E-02	149.40	5.164E-02	114.27	8.208E-02	134.22	6.243E-02	227.14	2.311E-02	
37		49.333333333	2.822E-02	171.69	3.999E-02	148.16	5.242E-02	157.29	4.788E-02	157.29	4.788E-02	121.33	7.392E-02	140.87	5.739E-02	232.45	2.205E-02	
38		54.333333333	2.666E-02	177.97	3.739E-02	154.82	4.841E-02	162.29	4.441E-02	162.29	4.441E-02	128.45	6.739E-02	147.66	5.274E-02	238.00	2.100E-02	
39		59.333333333	2.522E-02	184.41	3.491E-02	161.61	4.475E-02	168.96	4.121E-02	168.96	4.121E-02	135.62	6.131E-02	154.55	4.857E-02	243.77	1.998E-02	
40		64.333333333	2.388E-02	191.01	3.262E-02	168.50	4.142E-02	175.75	3.826E-02	175.75	3.826E-02	142.83	5.596E-02	161.54	4.479E-02	249.74	1.906E-02	
41		69.333333333	2.250E-02	197.73	3.050E-02	175.48	3.837E-02	182.65	3.556E-02	182.65	3.556E-02	150.06	5.128E-02	168.60	4.137E-02	255.89	1.809E-02	
42		74.333333333	2.124E-02	204.56	2.852E-02	182.53	3.590E-02	189.63	3.308E-02	189.63	3.308E-02	157.31	4.708E-02	175.71	3.828E-02	262.20	1.714E-02	
43		79.333333333	2.006E-02	211.49	2.670E-02	189.65	3.308E-02	196.69	3.081E-02	196.69	3.081E-02	164.57	4.328E-02	182.88	3.547E-02	268.65	1.628E-02	
44		84.333333333	1.894E-02	218.49	2.501E-02	196.81	3.079E-02	203.80	2.874E-02	203.80	2.874E-02	171.82	3.998E-02	190.08	3.293E-02	275.24	1.545E-02	
45		89.333333333	1.789E-02	225.56	2.345E-02	204.00	2.868E-02	210.96	2.683E-02	210.96	2.683E-02	179.07	3.693E-02	197.81	3.063E-02	281.94	1.467E-02	
46		94.333333333	1.691E-02	232.69	2.200E-02	211.22	2.670E-02	218.16	2.500E-02	218.16	2.500E-02	186.32	3.428E-02	204.55	2.853E-02	288.74	1.392E-02	
47		99.333333333	1.598E-02	239.85	2.067E-02	218.47	2.501E-02	225.38	2.348E-02	225.38	2.348E-02	193.54	3.180E-02	211.80	2.662E-02	295.64	1.322E-02	
48		104.333333333	1.512E-02	247.05	1.943E-02	225.72	2.341E-02	232.62	2.201E-02	232.62	2.201E-02	200.75	2.960E-02	219.05	2.488E-02	302.61	1.256E-02	
49		109.333333333	1.431E-02	254.28	1.829E-02	232.98	2.194E-02	239.87	2.066E-02	239.87	2.066E-02	207.93	2.761E-02	226.81	2.329E-02	309.65	1.198E-02	
50		114.333333333	1.355E-02	261.52	1.724E-02	240.23	2.060E-02	247.13	1.942E-02	247.13	1.942E-02	215.09	2.581E-02	233.55	2.188E-02	316.74	1.138E-02	
51		119.333333333	1.285E-02	268.78	1.628E-02	247.48	1.939E-02	254.38	1.829E-02	254.38	1.829E-02	222.22	2.417E-02	240.79	2.050E-02	323.88	1.078E-02	
52		124.333333333	1.219E-02	276.03	1.535E-02	254.71	1.823E-02	261.63	1.722E-02	261.63	1.722E-02	229.32	2.267E-02	248.00	1.928E-02	331.06	1.028E-02	
53		129.333333333	1.151E-02	283.29	1.451E-02	261.93	1.719E-02	268.86	1.619E-02	268.86	1.619E-02	236.38	2.130E-02	255.19	1.815E-02	338.27	9.769E-03	
54		134.333333333	1.099E-02	290.53	1.374E-02	269.12	1.621E-02	276.08	1.535E-02	276.08	1.535E-02	243.40	2.005E-02	262.36	1.712E-02	345.50	9.302E-03	

Conditions (input) \ Parameters (input2) \ distance \ Skyshine \ Lineac \ 3GeV Ring \ 3-NUBT \ 50GeV Ring \ M.F. \ Hadron Experimental Facility \ Neutron \ 50GeV sync. skyshine detail

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

基本量	SI基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質の量	モル	mol
光度	カンデラ	cd

表2. 基本単位を用いて表されるSI組立単位の例

組立量	SI基本単位	
	名称	記号
面積	平方メートル	m ²
体積	立法メートル	m ³
速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s ²
波数	毎メートル	m ⁻¹
密度, 質量密度	キログラム毎立方メートル	kg/m ³
面積密度	キログラム毎平方メートル	kg/m ²
比体積	立方メートル毎キログラム	m ³ /kg
電流密度	アンペア毎平方メートル	A/m ²
磁界の強さ	アンペア毎メートル	A/m
量濃度 ^(a) , 濃度	モル毎立方メートル	mol/m ³
質量濃度	キログラム毎立方メートル	kg/m ³
輝度	カンデラ毎平方メートル	cd/m ²
屈折率 ^(b)	(数字の)	1
比透磁率 ^(b)	(数字の)	1

(a) 量濃度 (amount concentration) は臨床化学の分野では物質濃度 (substance concentration) ともよばれる。
 (b) これらは無次元量あるいは次元1をもつ量であるが、そのことを表す単位記号である数字の1は通常は表記しない。

表3. 固有の名称と記号で表されるSI組立単位

組立量	SI組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン ^(b)	rad	1 ^(b)	m/m
立体角	ステラジアン ^(b)	sr ^(e)	1 ^(b)	m ² /m ²
周波数	ヘルツ ^(d)	Hz		s ⁻¹
力	ニュートン	N		m kg s ⁻²
圧力, 応力	パスカル	Pa	N/m ²	m ⁻¹ kg s ⁻²
エネルギー, 仕事, 熱量	ジュール	J	N m	m ² kg s ⁻²
仕事率, 工率, 放射束	ワット	W	J/s	m ² kg s ⁻³
電荷, 電気量	クーロン	C		s A
電位差 (電圧), 起電力	ボルト	V	W/A	m ² kg s ⁻³ A ⁻¹
静電容量	ファラド	F	C/V	m ² kg ⁻¹ s ⁴ A ²
電気抵抗	オーム	Ω	V/A	m ² kg s ⁻³ A ⁻²
コンダクタンス	ジーメン	S	A/V	m ² kg ⁻¹ s ³ A ²
磁束	ウェーバ	Wb	Vs	m ² kg s ⁻² A ⁻¹
磁束密度	テスラ	T	Wb/m ²	kg s ⁻² A ⁻¹
インダクタンス	ヘンリー	H	Wb/A	m ² kg s ⁻² A ⁻²
セルシウス温度	セルシウス度 ^(e)	°C		K
光照射度	ルーメン	lm	cd sr ^(e)	cd
放射線量	グレイ	Gy	J/kg	m ² s ⁻²
放射性核種の放射能 ^(f)	ベクレル ^(d)	Bq		s ⁻¹
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	m ² s ⁻²
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト ^(g)	Sv	J/kg	m ² s ⁻²
酸素活性化	カタール	kat		s ⁻¹ mol

(a) SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
 (b) ラジアンとステラジアンは数字の1に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の1は明示されない。
 (c) 測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
 (d) ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
 (e) セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
 (f) 放射性核種の放射能 (activity referred to a radionuclide) は、しばしば誤った用語で"radioactivity"と記される。
 (g) 単位シーベルト (PV.2002.70,205) についてはCIPM勧告2 (CI-2002) を参照。

表4. 単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI組立単位		
	名称	記号	SI基本単位による表し方
粘力のモーメント	パスカル秒	Pa s	m ⁻¹ kg s ⁻¹
表面張力	ニュートンメートル	N m	m ² kg s ⁻²
角加速度	ラジアン毎秒	rad/s	m m ⁻¹ s ⁻¹ = s ⁻¹
角加減速	ラジアン毎秒毎秒	rad/s ²	m m ⁻¹ s ⁻² = s ⁻²
熱流密度, 放射照度	ワット毎平方メートル	W/m ²	kg s ⁻³
熱容量, エントロピー	ジュール毎ケルビン	J/K	m ² kg s ⁻² K ⁻¹
比熱容量, 比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	m ² s ⁻² K ⁻¹
比エネルギー	ジュール毎キログラム	J/kg	m ² s ⁻²
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	m kg s ⁻³ K ⁻¹
体積エネルギー	ジュール毎立方メートル	J/m ³	m ⁻¹ kg s ⁻²
電界の強さ	ボルト毎メートル	V/m	m kg s ⁻³ A ⁻¹
電荷密度	クーロン毎立方メートル	C/m ³	m ⁻³ s A
電表面電荷	クーロン毎平方メートル	C/m ²	m ⁻² s A
電束密度, 電気変位	クーロン毎平方メートル	C/m ²	m ⁻² s A
誘電率	ファラド毎メートル	F/m	m ³ kg ⁻¹ s ⁴ A ²
透磁率	ヘンリー毎メートル	H/m	m kg s ⁻² A ⁻²
モルエネルギー	ジュール毎モル	J/mol	m ² kg s ⁻² mol ⁻¹
モルエントロピー, モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	m ² kg s ⁻² K ⁻¹ mol ⁻¹
照射線量 (X線及びγ線)	クーロン毎キログラム	C/kg	kg ⁻¹ s A
吸収線量率	グレイ毎秒	Gy/s	m ² s ⁻³
放射線強度	ワット毎ステラジアン	W/sr	m ⁴ m ⁻² kg s ⁻³ = m ² kg s ⁻³
放射輝度	ワット毎平方メートル毎ステラジアン	W/(m ² sr)	m ² m ⁻² kg s ⁻³ = kg s ⁻³
酵素活性濃度	カタール毎立方メートル	kat/m ³	m ⁻³ s ⁻¹ mol

表5. SI接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10 ²⁴	ヨタ	Y	10 ¹	デシ	d
10 ²¹	ゼタ	Z	10 ⁻²	センチ	c
10 ¹⁸	エクサ	E	10 ⁻³	ミリ	m
10 ¹⁵	ペタ	P	10 ⁻⁶	マイクロ	μ
10 ¹²	テラ	T	10 ⁻⁹	ナノ	n
10 ⁹	ギガ	G	10 ⁻¹²	ピコ	p
10 ⁶	メガ	M	10 ⁻¹⁵	フェムト	f
10 ³	キロ	k	10 ⁻¹⁸	アト	a
10 ²	ヘクト	h	10 ⁻²¹	ゼプト	z
10 ¹	デカ	da	10 ⁻²⁴	ヨクト	y

表6. SIに属さないが、SIと併用される単位

名称	記号	SI単位による値
分	min	1 min=60s
時	h	1 h=60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	'	1'=(1/60)°=(π/10800) rad
秒	"	1"=(1/60)'=(π/648000) rad
ヘクタール	ha	1 ha=1 hm ² =10 ⁴ m ²
リットル	L, l	1 L=1 dm ³ =10 ³ cm ³ =10 ⁻³ m ³
トン	t	1 t=10 ³ kg

表7. SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI単位で表される数値
電子ボルト	eV	1 eV=1.602 176 53(14)×10 ⁻¹⁹ J
ダルトン	Da	1 Da=1.660 538 86(28)×10 ⁻²⁷ kg
統一原子質量単位	u	1 u=1 Da
天文単位	ua	1 ua=1.495 978 706 91(6)×10 ¹¹ m

表8. SIに属さないが、SIと併用されるその他の単位

名称	記号	SI単位で表される数値
バール	bar	1 bar=0.1 MPa=100 kPa=10 ⁵ Pa
水銀柱ミリメートル	mmHg	1 mmHg=133.322 Pa
オングストローム	Å	1 Å=0.1 nm=100 pm=10 ⁻¹⁰ m
海里	M	1 M=1852 m
バイン	b	1 b=100 fm ² =(10 ¹² cm) ² =10 ⁻²⁸ m ²
ノット	kn	1 kn=(1852/3600) m/s
ネーパ	Np	SI単位との数値的関係は、 対数量の定義に依存。
ベレル	B	
デジベル	dB	

表9. 固有の名称をもつCGS組立単位

名称	記号	SI単位で表される数値
エル	erg	1 erg=10 ⁻⁷ J
ダイン	dyn	1 dyn=10 ⁻⁵ N
ポアズ	P	1 P=1 dyn s cm ⁻² =0.1 Pa s
ストークス	St	1 St=1 cm ² s ⁻¹ =10 ⁻⁴ m ² s ⁻¹
スチルブ	sb	1 sb=1 cd cm ⁻² =10 ⁴ cd m ⁻²
フオト	ph	1 ph=1 cd sr cm ⁻² =10 ⁴ lx
ガリ	Gal	1 Gal=1 cm s ⁻² =10 ⁻² ms ⁻²
マクスウェル	Mx	1 Mx=1 G cm ² =10 ⁻⁸ Wb
ガウス	G	1 G=1 Mx cm ⁻² =10 ⁻⁴ T
エルステッド ^(c)	Oe	1 Oe _e =(10 ³ /4π) A m ⁻¹

(c) 3元系のCGS単位系とSIでは直接比較できないため、等号「△」は対応関係を示すものである。

表10. SIに属さないその他の単位の例

名称	記号	SI単位で表される数値
キュリー	Ci	1 Ci=3.7×10 ¹⁰ Bq
レントゲン	R	1 R=2.58×10 ⁻⁴ C/kg
ラド	rad	1 rad=1 cGy=10 ⁻² Gy
レム	rem	1 rem=1 cSv=10 ⁻² Sv
ガンマ	γ	1 γ=1 nT=10 ⁻⁹ T
フェルミ	f	1 フェルミ=1 fm=10 ⁻¹⁵ m
メートル系カラット		1メートル系カラット=200 mg=2×10 ⁻⁴ kg
トル	Torr	1 Torr=(101 325/760) Pa
標準大気圧	atm	1 atm=101 325 Pa
カロリ	cal	1 cal=4.1858 J (「15°C」カロリ), 4.1868 J (「IT」カロリ), 4.184 J (「熱化学」カロリ)
マイクロン	μ	1 μ=1 μm=10 ⁻⁶ m

