放射線遮蔽工学
Radiation Shielding Engineering

- 講義のねらい
  原子核工学の基礎応用科目として、放射線遮蔽工学を講義する。実験装置や実施設に対する遮蔽安全解析手法を習得する。
- 講義範囲
  遮蔽工学の歴史、放射線源、中性子およびγ線等と物質の相互作用を記述した核データ、断面積処理、線量等の放射線応答関数、遮蔽物質、幾何形状、簡易計算手法、輸送計算手法、スカイシャイン、結果の検証・評価

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放射線遮蔽工学
Radiation Shielding Engineering

- 講義日程
  10/6, 12/8, 12/22, 1/19, 1/26, 2/2, 2/9 (全7回)
  (予備日2/16) 第3, 4時限(10:40-12:10)
- 成績評価
  毎回の出席票およびレポート
- テキスト
  特になし。handoutによる。
- 参考書
  Radiation Shielding J. Kenneth Shultis, Richard E. Faw, ANS Publication (2000) ISBN 0-89448-456-7

放射線は身近なユビキタス*

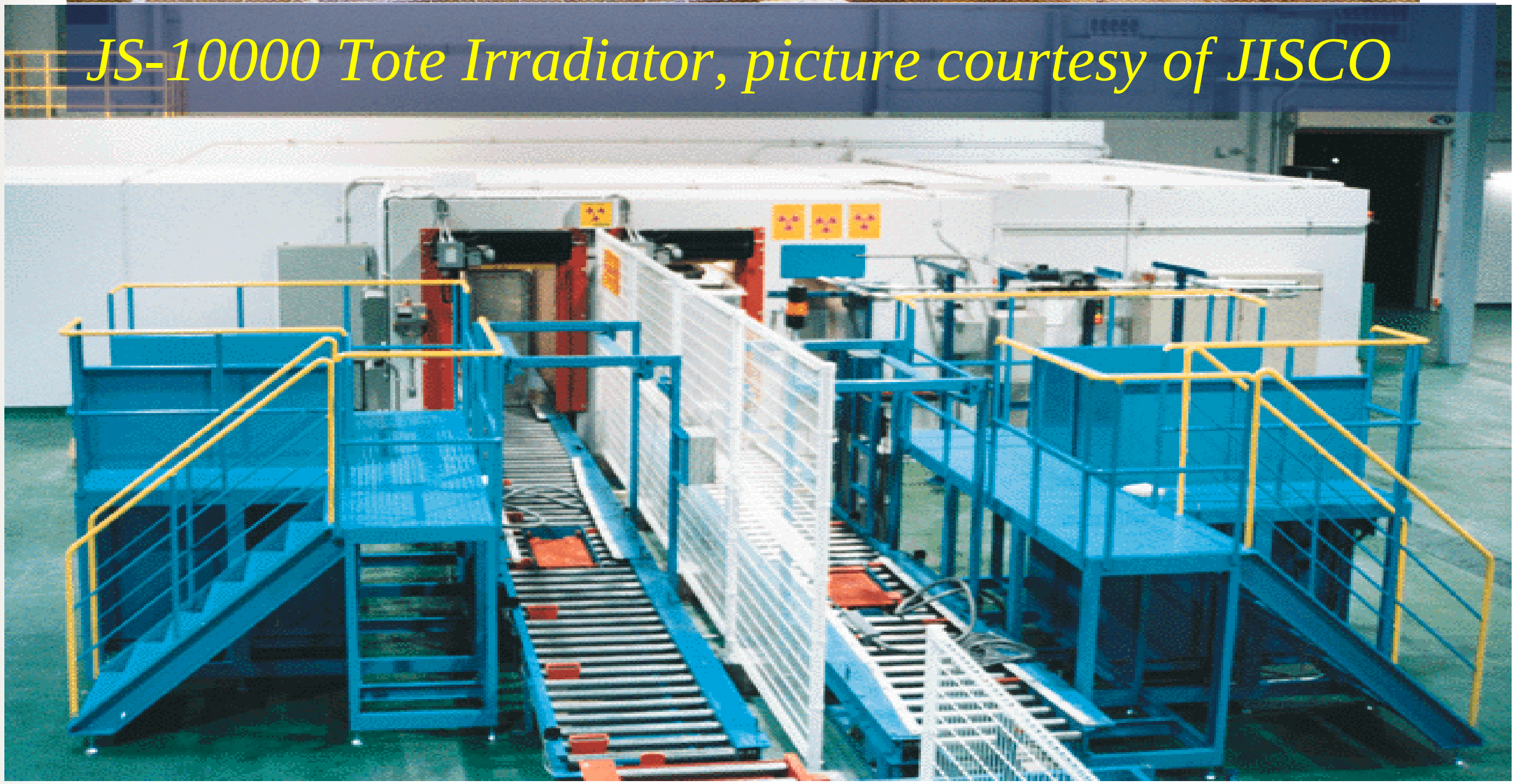
- 放射線遮蔽　Shielding (Screeningとはいわない)
  - 人体に有害な放射線を有効に遮蔽する
- 放射線利用　Radiation Application
  - 放射線を利用した製品は驚くほど私達の身近にたくさんある。放射線を有効に利用する

放射線の制御技術が重要

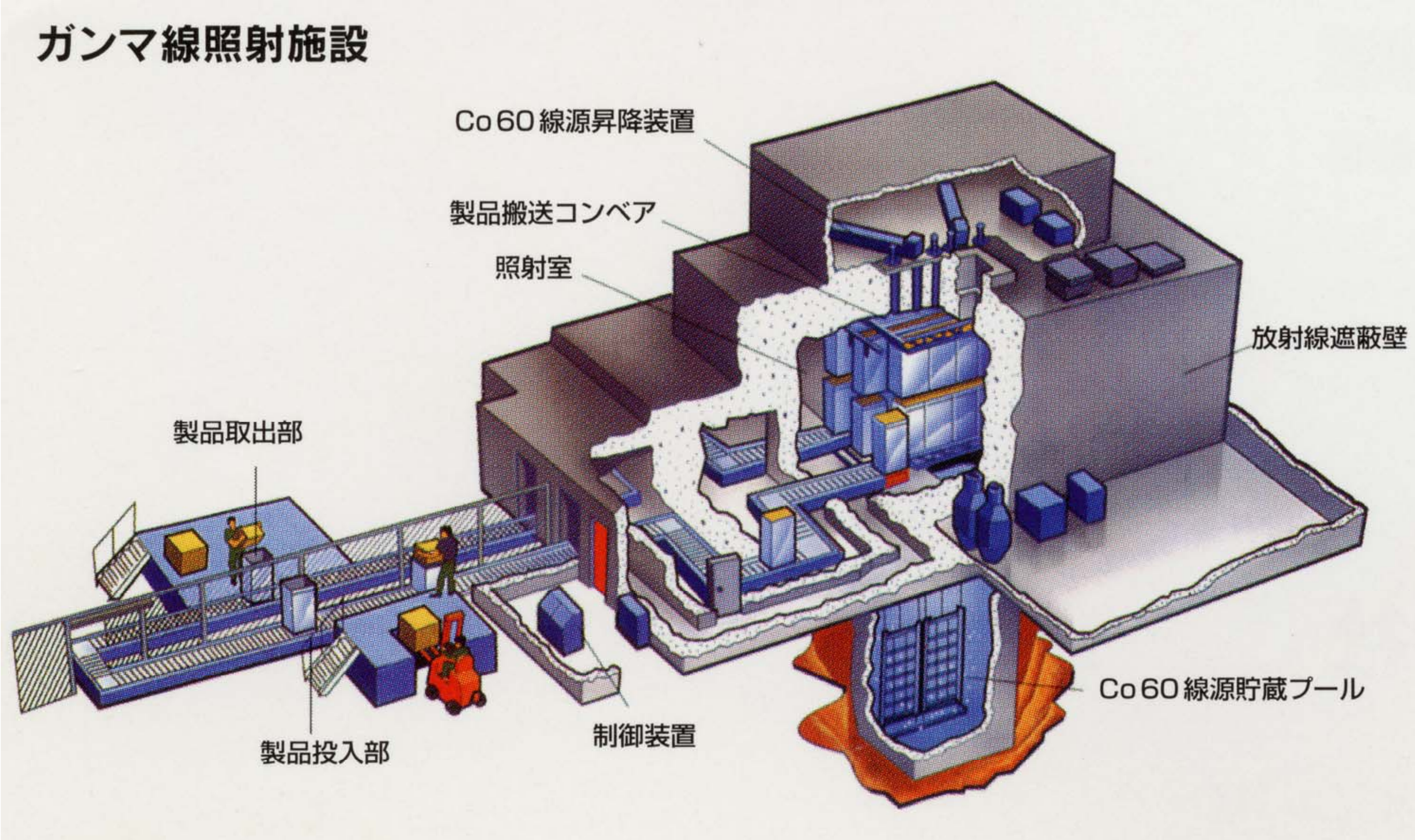
放射線の制御＝遮蔽工学の適用

* ユビキタス(ubiquitous)：語源はラテン語で、いたるところに存在する（遍在）という意味。

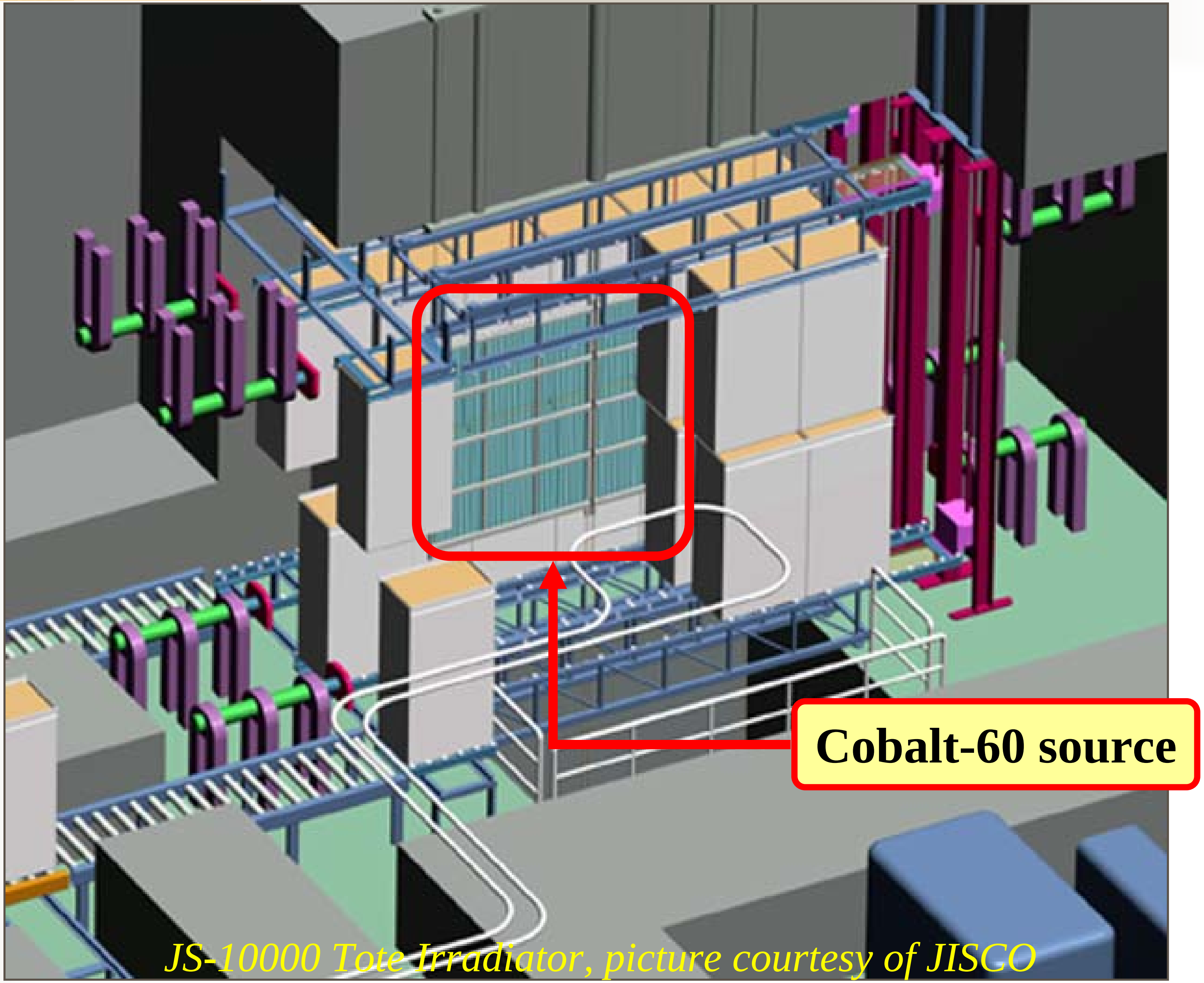
γ -ray irradiation facility



JS-10000 Tote Irradiator, picture courtesy of JISCO

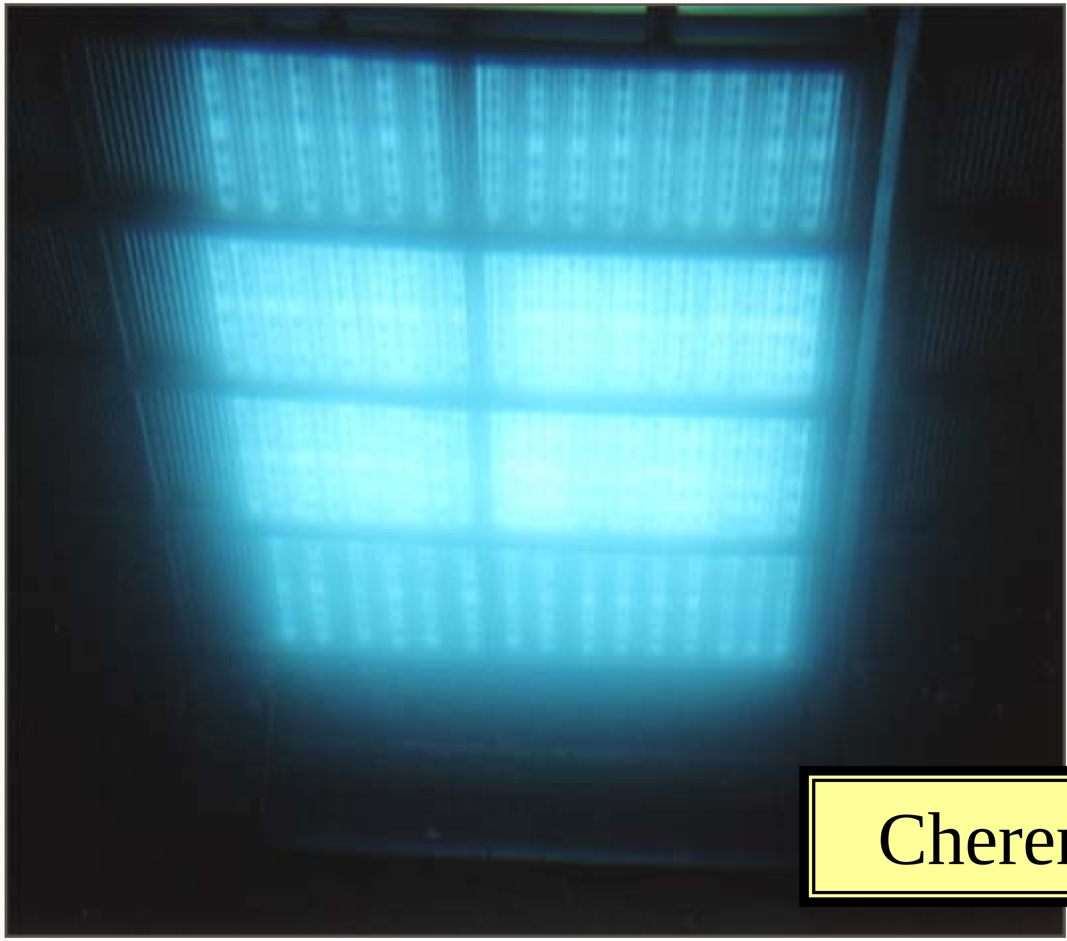


JS-10000 Tote Irradiator, picture courtesy of JISCO



JS-10000 Tote Irradiator, picture courtesy of JISCO

Cobalt-60 source : ~ 3 MCi (× 3.7 × 10^{10} Bq)



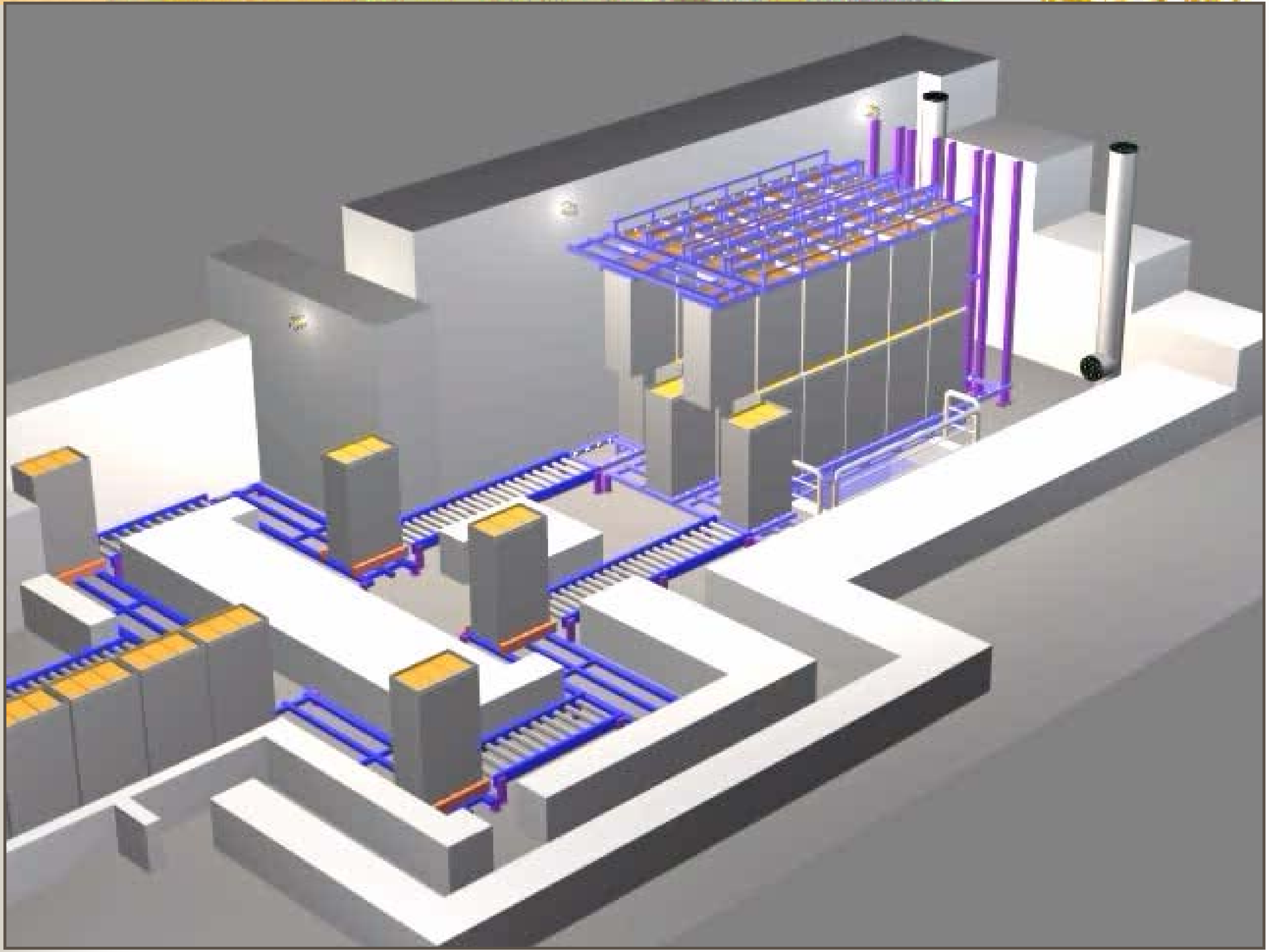
γ-ray energy:

1.17 MeV,

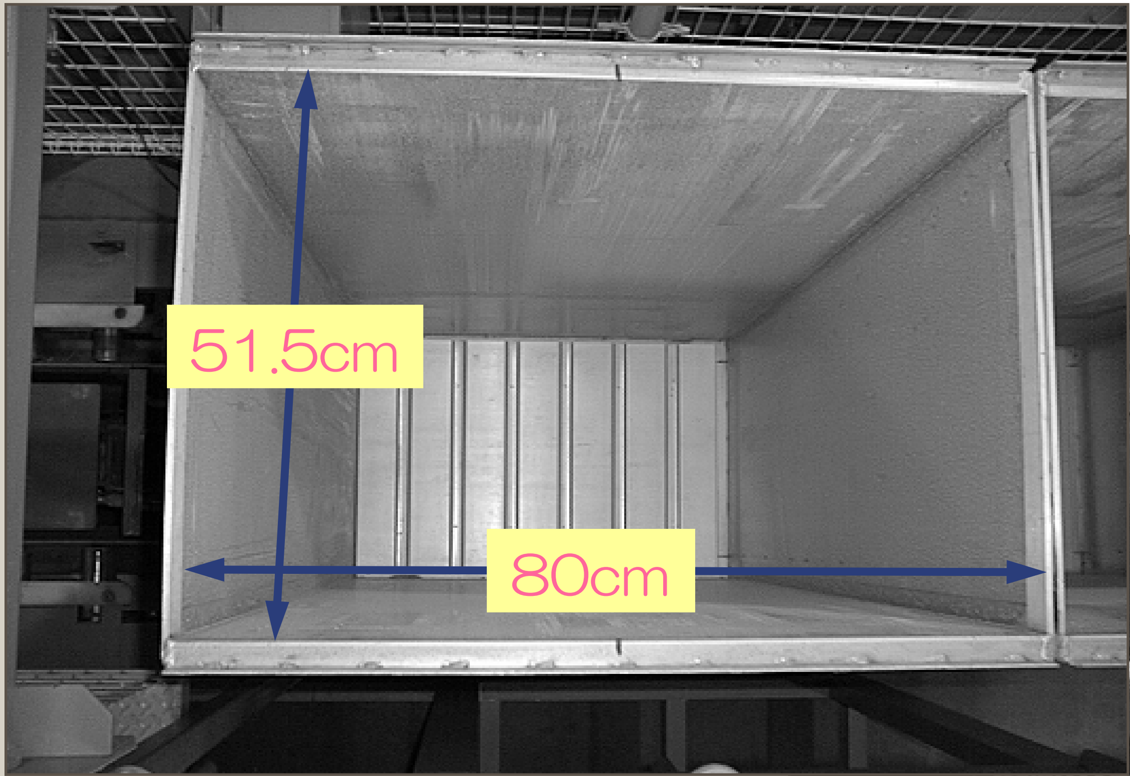
1.33 MeV

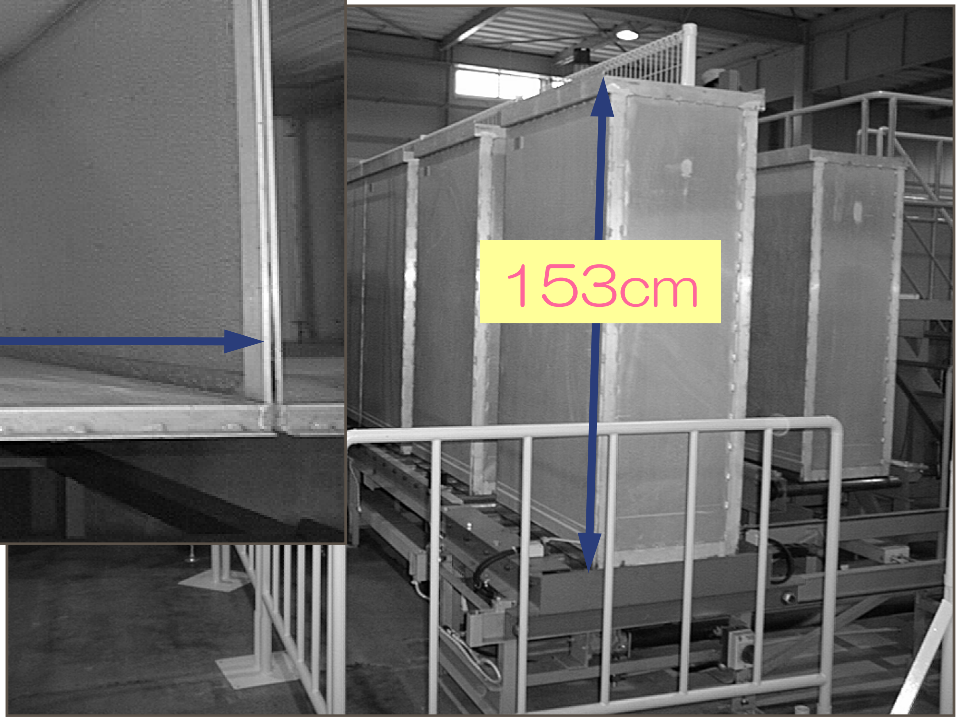
Cherenkov radiation

JS-10000 Tote Irradiator, picture courtesy of JISCO



照射容器（Tote box）





※ サイズは全て内寸

JS-10000 Tote Irradiator, picture courtesy of JISCO

照射容器（Tote box）と被照射物

直径４０cm、高さ５０cm
Net２５kg／本

直径７５cm、幅１６.５cm
１２.２kg／巻、３列２段積み

JS-10000 Tote Irradiator, picture courtesy of JISCO

照射施設の特徴

- 照射中は遮蔽扉は開放
  - 照射物はベルトコンベアにより連続照射
- 迷路構造
  - 複雑な幾何形状
- 照射物の均一線量管理－要求線量を厳格に評価
  - 照射物の回転，反転，循環，撹拌
- 放射線の有効利用
  - 照射時間の低減＝作業時間の低減＝照射コストの低減

↓

放射線遮蔽工学の適用

- 放射線遮蔽 Shielding の観点
  - 従事者被曝の防止
  - 環境に放射線を漏らさない

    （ 法令: 0.115 μSv/h (1 mSv/y) 以下 ）
- 放射線利用 Radiation Application の観点
  - 放射線を有効に利用する＝照射コストの低減

    γ-ray energy emitted from Co-60

    1.17 MeV, 1.33 MeV ; total: 2.5 MeV

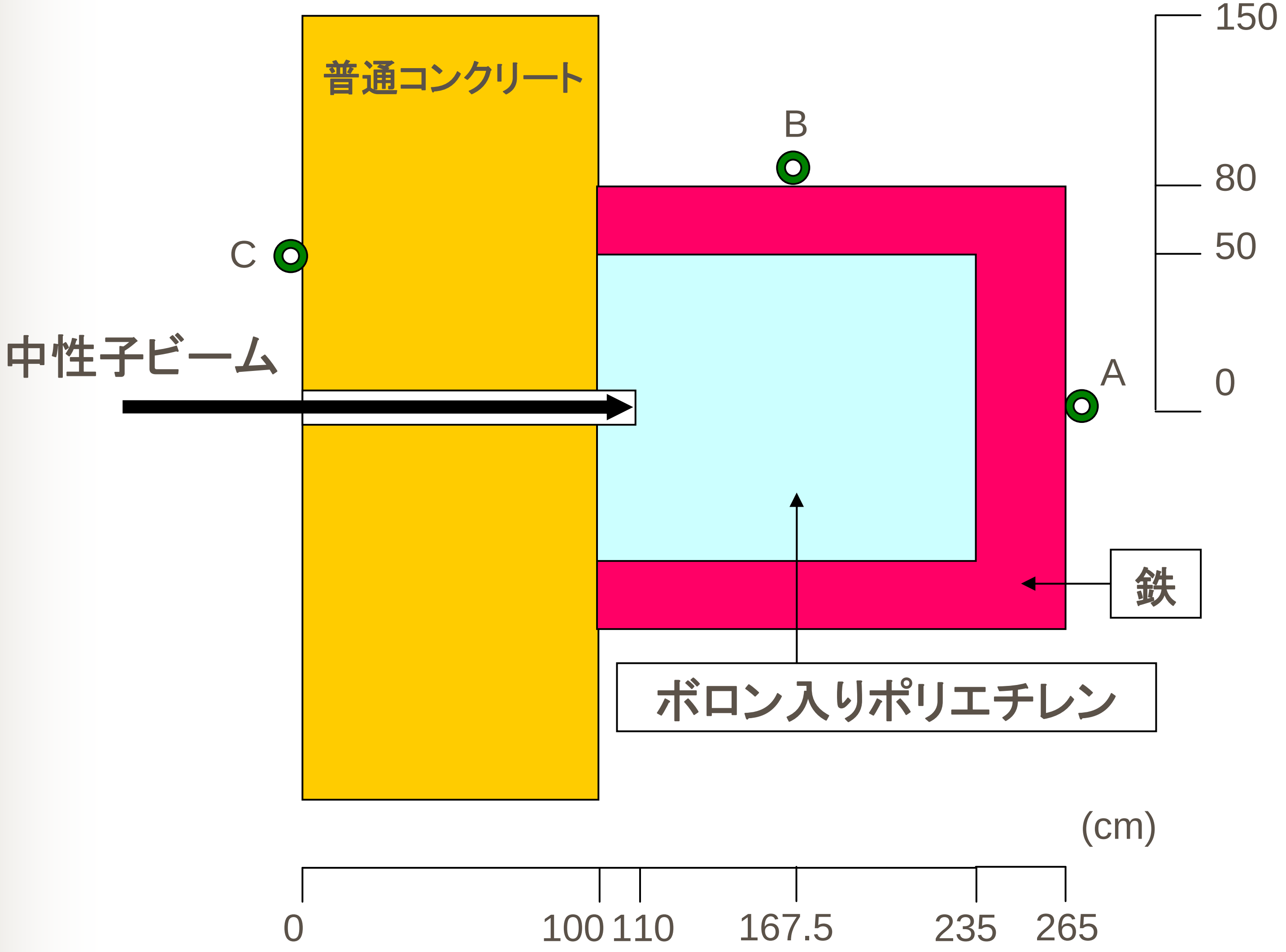
    1 Ci : 3.7×10^{10} /s

    3.7×10^{10} /s × 2.5 MeV = $3.7 \times 2.5 \times 10^{16}$ eV/s

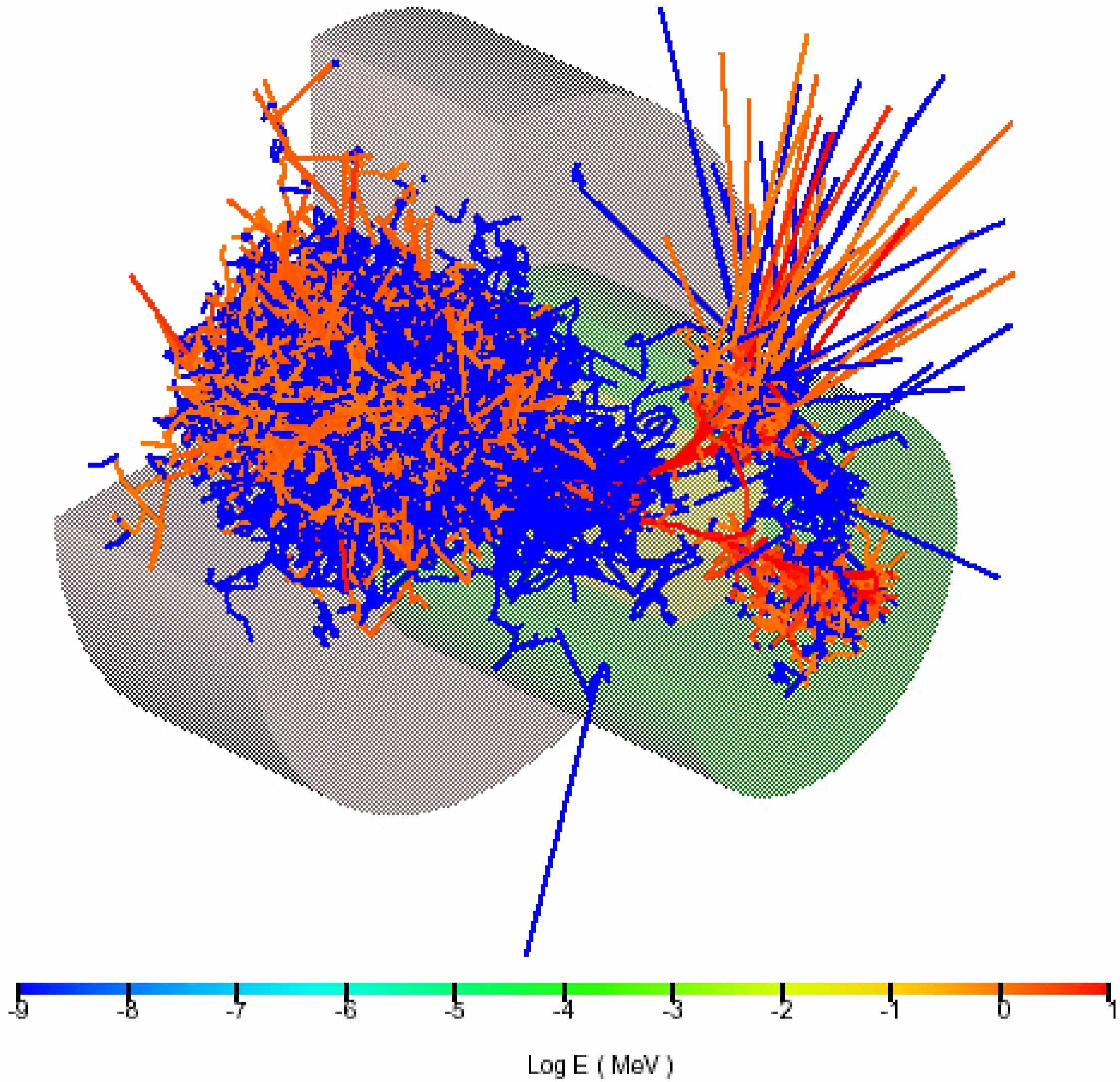
    = 0.0148 W

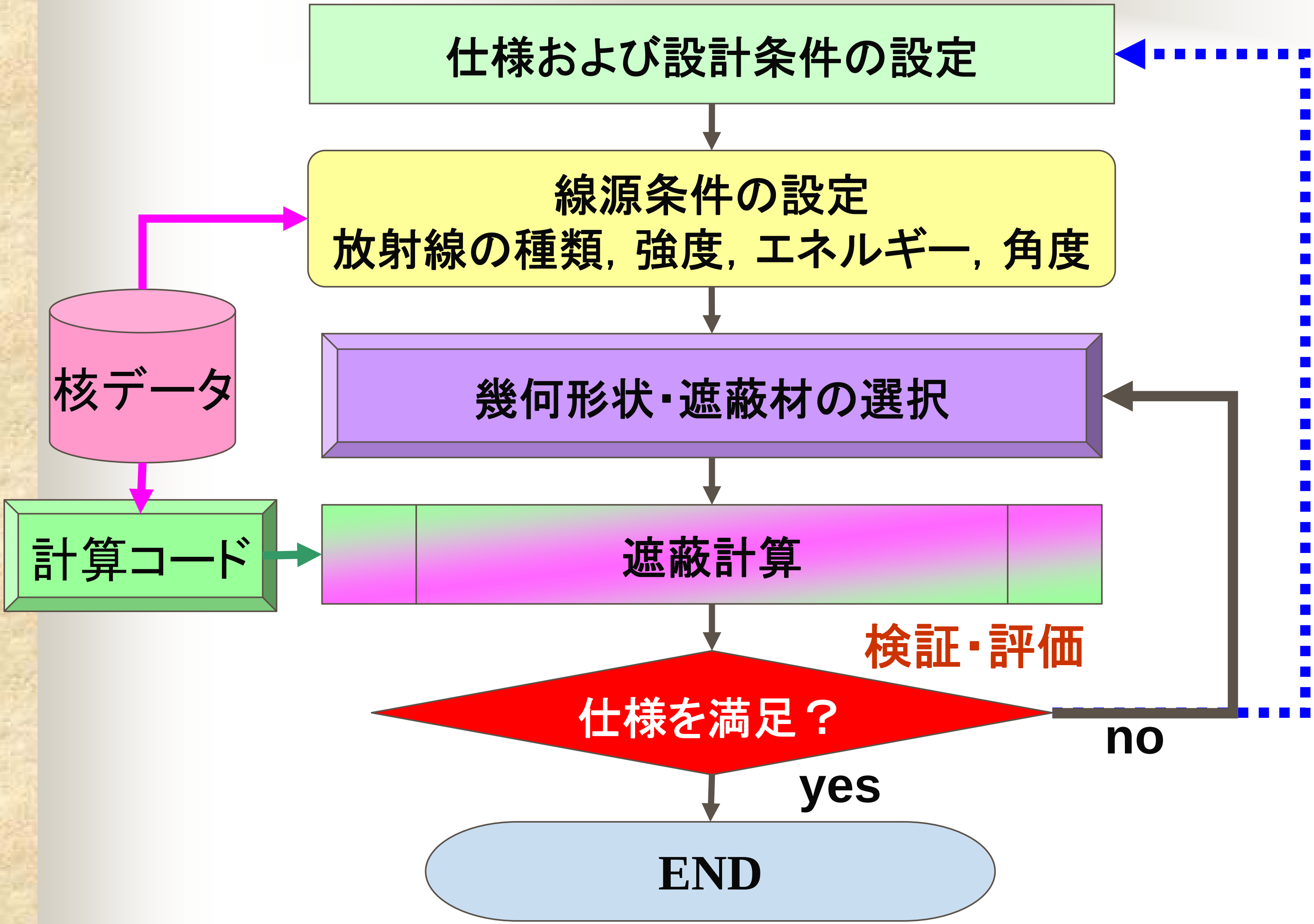
    1 MCi corresponds to 14.8 kW

中性子ビームダンプの例（加速器実験）



ビームダンプの中性子透過シミュレーション(mcnp4c-sabrina)





仕様および設計条件の設定
線源条件の設定
放射線の種類，強度，エネルギー，角度
核データ
幾何形状･遮蔽材の選択
計算コード
遮蔽計算
検証･評価
仕様を満足？
no
yes
END

放射線制御の方法

- 計算方法
  - 放射線減衰・反射，輸送計算
    - ハンドブック，経験式，点減衰核法，S*n*法，モンテカルロ法
- 幾何形状
  - 構造
    - バルク，配管，ダクト，迷路，スリット，ボイド
  - 物質の選択
    - 放射線と物質の相互作用を理解
- 評価方法
  - 線源評価，計算結果の評価
    - 放射線の流れる経路や反射を的確に評価

評価量

- 実効線量

  $\phi(\boldsymbol{r}, \mathrm{E}) \times \mathrm{D(E)}$

- 放射線発熱量

  $\phi(\boldsymbol{r}, \mathrm{E}) \times \mathrm{H(E)}$

- 放射線損傷量

  $\phi(\boldsymbol{r}, \mathrm{E}) \times \sigma_{\mathrm{DPA}}(\mathrm{E})$

- 放射化量

  $\phi(\boldsymbol{r}, \mathrm{E})$ を基に核種生成・消滅計算

- スカイシャイン線量

  天井を透過した放射線が空中で散乱して地上に降り注ぐ成分

↓

放射線束×変換係数, 断面積等で評価

遮蔽材料

ガンマ線

- コンクリート，鉄，鉛，タングステン，ウラン
- 土，セラミクス
- ガラス，鉛ガラス，水

中性子

- 鉄，ベリリウム，グラファイト，水，パラフィン
- ポリエチレン，木，土，セラミクス
- Gd, Sm, Eu, Cd, Dy, B
- コンクリート
- ZrH_2, TiH_2, LiH, CaH_2 , H_3BO_3, B_2O_3, B_4C

遮蔽構造

幾何形状	例
バルク	単一層，多重層（遮蔽扉，遮蔽窓，遮蔽プラグ）
配管	直管，屈曲配管，円環配管
ダクト	直ダクト，屈曲ダクト，円環ダクト，スクリューダクト
迷路	屈曲迷路
スリット	単一オフセット，多重オフセット，屈曲スリット
ボイド	空隙，フィン
補償遮蔽	補助遮蔽ブロック，ライニング，鉛毛

放射線減衰，輸送計算法

計算法	計算コード
ハンドブック，経験式	遮蔽ハンドブック　**適用範囲に注意**
点減衰核法	QAD-CGGP2, G-33GP2, RANKERN　**適用範囲に注意**
S_N法	ANISN, DOT3.5, DORT, TORT, TWODANT
モンテカルロ法	MCNP4C/5, MCBEND, TRIPORI4, MORSE-CG, MVP, EGS4, ITS-TIGER
高エネルギー	MCNPX, NMTC/JAM, PHITS, HERMES, LAHET, MARS

断面積ライブラリ	JSD100/120, JSSTDL-300, VITAMIN-C/-E/-B6/-J, FSXLIB-J33, FENDL-2/MG/MC, LA150

電子線照射施設	EDMULT
制動X線照射施設	DEX

イオン	IBM-SRIM/TRIM, PHITS

Radiation Sources

- Gamma-Ray Sources（ガンマ線源）
  - Fission Gamma Rays: (per ^{235}U fission)（核分裂ガンマ線）

    Prompt, $t \lesssim 0.05$ μsec (7.25 MeV).
    Short-life, $0.05 < t \lesssim 1.0$ μsec (0.43 MeV).
    Intermediate-life, 1.0 μsec $< t \lesssim 1.0$ sec (0.55 MeV).
    Delayed, $t > 1.0$ sec (6.65 MeV).

    Prompt fission gamma rays: 10 keV ~ 10 MeV（即発ガンマ線）

    $\Gamma(E) = 6.6$ $0.1 < E \lesssim 0.6$ MeV
    $= 20.2 \exp(-1.78E)$ $0.6 < E \lesssim 1.5$ MeV
    $= 7.2 \exp(-1.09E)$ $1.5 < E \lesssim 10.5$ MeV

    8.1 ± 0.3 photons/fission; 7.25 ± 0.26 MeV

    Short-life and Intermediate-life intervals are similar to the prompt in energy distribution.
  - Fission-Product-Decay Gamma Rays（核分裂生成物からの崩壊ガンマ線）

    6.65 MeV is emitted by the fission product as delayed gamma rays; over three-quarters of this energy is released with 1000 sec following fission. Delayed gamma rays can be classified into two groups, depending on the time of their emission following fission. Early fission-product gamma rays are those emitted within a few minutes after fission. Late fission-product gamma rays (those which are emitted several minutes or longer after fission) are not of much importance during reactor operation, but they can be a very significant source following reactor shutdown.

    JENDL FP decay Data File 2000: decay data for 1229 nuclides are stored.

Radiation Sources

- Gamma-Ray Sources（ガンマ線源）
  - Capture Gamma Rays（捕獲ガンマ線）
    Radiative capture of neutrons by nuclei at thermal and epithermal energies produces secondary gamma rays, commonly called capture gamma rays. They are emitted promptly after neutron capture, and the total energy available for gamma rays from capture is the sum of the kinetic energy of the incident neutron and its binding energy in the compound nucleus. Since the probability of capture decreases rapidly with increasing kinetic energy, capture reactions generally are of importance only for neutrons with kinetic energies below 25 keV. Typically, neutron binding energies are in the region of 6 to 8 MeV, although they can range from 2.2 to about 11 MeV.
    Capture gamma rays are a significant source and occasionally constitute the most important consideration in shield design because of their high energy and the fact that they are generated throughout the shield.
  - Inelastic-Scattering Gamma Rays（非弾性散乱によるガンマ線）
    In neutron inelastic scattering, part of the energy of the incident neutrons is carried off by the scattered neutron and part is absorbed by the target nucleus. The latter is left in an excited state and subsequently decays by gamma-ray emission. (10^{-14} sec)

Radiation Sources

- Gamma-Ray Sources（ガンマ線源）
  - Reaction-Product Gamma Rays（核反応による生成ガンマ線）
    The reaction-product source results from a process resembling that of inelastic scattering except that some particle other than a neutron is ejected from the nucleus. The nucleus is left unstable and emits a gamma ray. An example is the $^{10}B(n,\alpha)^{7}Li$ reaction, which is accompanied by the emission of gamma rays of 0.48 MeV.
  - Activation-Product Gamma Rays（放射化ガンマ線）
    The nucleus formed by a neutron interaction may be radioactive and decay with a half-life that can range from seconds to years, emitting photons and other radiations in the process. For example, the $^{16}O(n,p)^{16}N$ reaction produced by fast-neutron activation of water emits gamma rays with energies of 6.1 and 7.1 MeV. The half-life of ^{16}N is 7.13 sec, short enough to produce high activities in irradiated-water-coolant systems. Liquid-metal fuels and coolants must also be considered as a source of activation-product gamma rays. In sodium mixtures, $^{23}Na(n,\gamma)^{24}Na$ produces 1.38- and 2.76-MeV photons with half-life of 14.8 hr.

Radiation Sources

- Gamma-Ray Sources (ガンマ線源)
  - Annihilation Gamma Rays（消滅ガンマ線）
    A few activated materials decay by the emission of positrons, which are annihilated by subsequent combination with electrons. Two 0.511-MeV photons are emitted from each positron-electron reaction. High-energy gamma rays also can react in a converse process called pair production to produce electron-positron pairs. These positrons also are annihilated near their source in an identical manner and contribute further to the source of 0.511-MeV gamma rays.
  - Bremsstrahlung（制動輻射ガンマ線）
    The acceleration and deceleration of electrons in the atomic electric field produces electromagnetic radiation called Bremsstrahlung. The process is identical to that occurring in the X-ray tube and is an important consideration only where high-energy beta particles (or accelerated electrons) interact with materials of high atomic number. An example is found in the use of lithium as a coolant. Neutron absorption in ^{7}Li produces ^{8}Li. The latter undergoes decay to ^{8}Be by emission of beta particles with energies as high as 13 MeV. Bremsstrahlung produced by these high-energy electrons as they slow down in piping or containment materials requires evaluation as a gamma-ray source.

Radiation Sources

- Neutron Sources（中性子線源）
  - Fission Neutrons（核分裂中性子）

    Approximately 2.44 neutrons are emitted per fission event in ^{235}U by thermal neutrons (more in higher energy). Although energies can range from thermal to beyond 18 MeV, the average energy of a ^{235}U fission neutron is about 2 MeV, and an upper limit is often taken to be 14 MeV. In fact, less than 1% of the total energy of fission neutrons is shared by neutrons whose energies exceed 10 MeV. However, these high-energy neutrons are very penetrating, and in some cases they can be overriding importance.

    For shielding purposes, fission neutrons may be assumed to be evolved simultaneously with the fission events. The small fraction (<1%) with delayed emissions requires consideration as a separate source only in the case of a circulating-fuel reactor where the fuel loop extends beyond the core shield.

    Watt fission spectrum

    $N(E) = C \exp(-E/0.988)\sinh(2.249E)^{1/2}$ (neutrons MeV^{-1} fission $^{-1}$)
  - Activation Neutrons（放射化反応による中性子）

    Under certain circumstances the decay of a radioactive nucleus can be followed by the emission of a neutron. This occurs when the energy of excitation of the daughter nucleus is in excess of the binding energy of the last neutron in the nucleus. An example is the beta decay of ^{17}N with a 4.14-sec half-life, which leaves an ^{17}O nucleus with more than enough excitation energy to eject a neutron. The most probable energy around 1.0 MeV. ^{17}N is formed by the $^{17}O(n,p)^{17}N$ reaction and can be important in fast-neutron bombardment of water.

Radiation Sources

- Neutron Sources（中性子線源）
  - Photoneutrons（光中性子）

    A photon whose energy is greater than the neutron binding energy of a nucleus can impact enough energy to the nucleus to cause neutron emission. The photon energy required to make such a reaction possible exceeds 7 MeV for all but few nuclei, and the probability for the photoneutron reaction is quite low until photon energies above 10 MeV are reached. The few nuclei whose neutron binding energy are low enough to create a possible problem in reactor shielding include ^{2}D, ^{9}Be, ^{13}C, and ^{6}Li. The threshold photon energies for these isotopes are 2.23, 1.62, 4.9, and 5.3 MeV.
  - Particle-Reaction Neutrons（荷電粒子核反応による中性子）

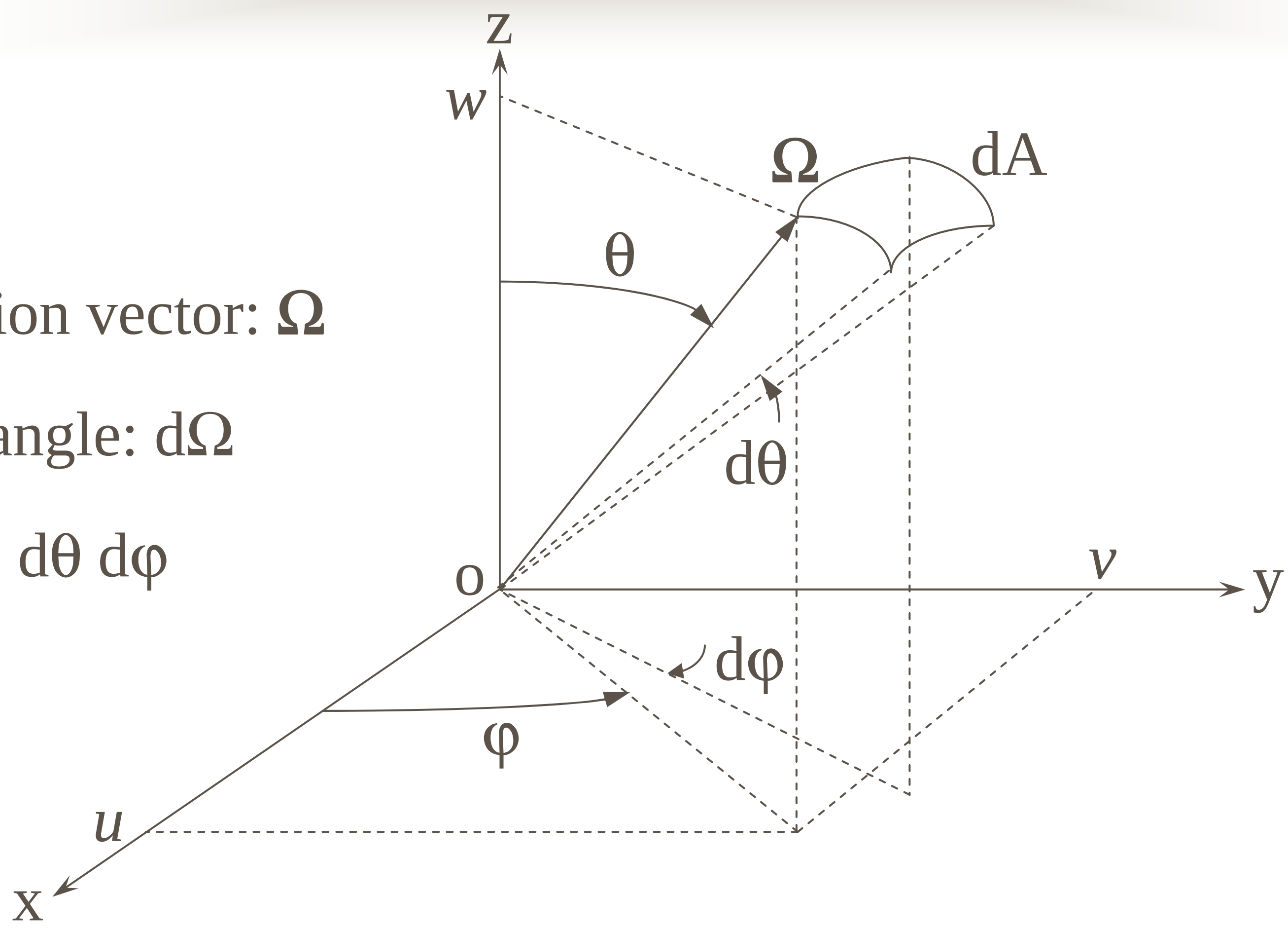
    The (α, n) reaction with nuclei of lithium, beryllium, oxygen, boron, and fluorine produces neutrons. Thus these elements are often combined with alpha-active isotopes, such as polonium or plutonium, to form neutron sources for use in experimentation or reactor start-up. Similarly, neutrons from (α, n) reactions in oxygen (^{17}O, ^{18}O) may be dominant in oxide fuel elements which contain alpha emitters such as ^{238}Pu, ^{241}Am, ^{242}Cm, or ^{244}Cm.

Directions and Solid Angles

The direction vector: **Ω**

The solid angle: dΩ

dA = sinθ dθ dφ



$\mathbf{\Omega} = \mathbf{i}u + \mathbf{j}v + \mathbf{k}w = \mathbf{i}\sin\theta\cos\varphi + \mathbf{j}\sin\theta\sin\varphi + \mathbf{k}\cos\theta$

$d\Omega = \sin\theta \, d\theta \, d\varphi$: dimensionless but assigned *steradians*, *sr*

Measures of Radiation Intensity

- Particle Densities

$$n\,(\mathbf{r}, E, \boldsymbol{\Omega}, t)\;\; dE\, d\Omega$$

the number of particles per unit volume at space point **r** and time *t* having energies in *dE* about energy *E* and directions in *d*Ω about the unit direction vector **Ω**.

steady-state, or time-independent definition

$$n\,(\mathbf{r}, E)\, dE = \int_{4\pi} n\,(\mathbf{r}, E, \boldsymbol{\Omega})\, d\Omega\, dE$$

total particle density

$$n\,(\mathbf{r}) \;=\; \int_{4\pi} \int_{0}^{\infty} n\,(\mathbf{r}, E, \boldsymbol{\Omega})\, d\Omega\, dE$$

Measures of Radiation Intensity

- Flux Densities

$$\phi(\mathbf{r}, E, \mathbf{\Omega}, t) = v\, n(\mathbf{r}, E, \mathbf{\Omega}, t)$$

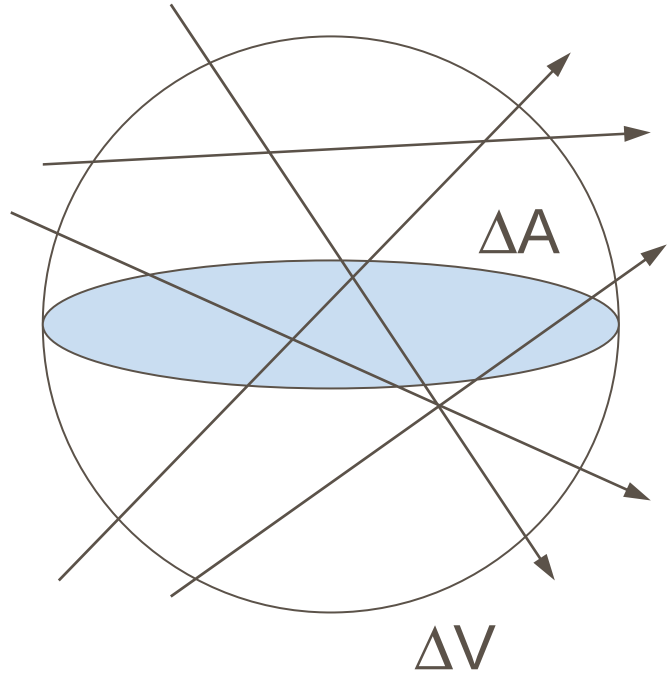
where, v is the particle's speed and corresponds to the energy E. (The speed is the scalar magnitude of the particle's velocity vector $\mathbf{v}$)

- Fluence

$$\Phi \equiv dNp/dA = \lim_{\Delta A \to 0} [\Delta Np / \Delta A]$$

$$= \lim_{\Delta V \to 0} [\Sigma_i s_i / \Delta V]$$

$$\phi \equiv d\Phi/dt = d^2Np/dAdt$$



Measures of Radiation Intensity

- Current Densities

$$\mathbf{J}(\mathbf{r}, v, \mathbf{\Omega}, t)\, dv\, d\Omega = \mathbf{\Omega} v\, n(\mathbf{r}, v, \mathbf{\Omega}, t)\, dv\, d\Omega$$

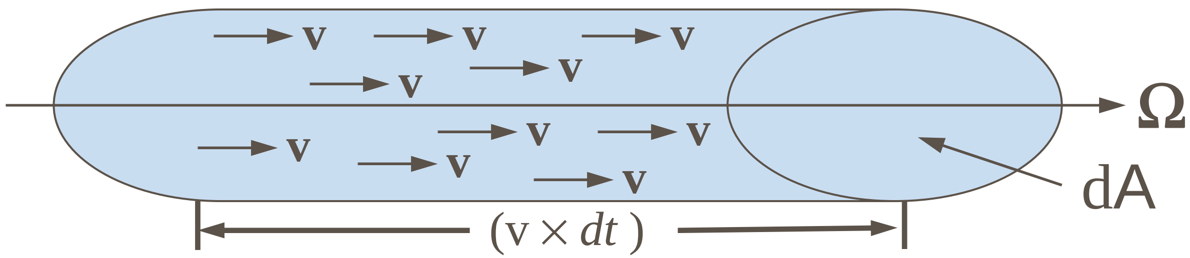
$\mathbf{J}(\mathbf{r}, v, \mathbf{\Omega}, t)$ is *angular current*, $\mathbf{J} = n\mathbf{v}$, and is defined as the directed flow per unit area (normal to the $\mathbf{\Omega}$ direction) and time at the space point $\mathbf{r}$ and time t of particles having speeds in dv about v and direction in $d\Omega$ about $\mathbf{\Omega}$.

$$\mathbf{J}(\mathbf{r}, E, \mathbf{\Omega}, t)\, dE\, d\Omega = \mathbf{\Omega} v\, n(\mathbf{r}, E, \mathbf{\Omega}, t)\, dE\, d\Omega$$

where, $\mathbf{J}(\mathbf{r}, E, \mathbf{\Omega}, t)\, dE = \mathbf{J}(\mathbf{r}, v, \mathbf{\Omega}, t)\, dv$ and

$n(\mathbf{r}, E, \mathbf{\Omega}, t)\, dE = n(\mathbf{r}, v, \mathbf{\Omega}, t)\, dv$.

$$\mathbf{J}(\mathbf{r}, E, \mathbf{\Omega}, t)\, dE\, d\Omega = \mathbf{\Omega}\, \phi(\mathbf{r}, E, \mathbf{\Omega}, t)\, dE\, d\Omega$$



Radiation Shielding

- Historical Review (1) Empirical Approach (~1950)
  - Exponential attenuation behavior was recognized so that “ray” approach in geometric optics has been carried over and was useful in many shielding analyses including photons and neutrons. Cross sections were unknown.
  - It was also evident that simple exponential attenuation based on the total cross section was thoroughly inadequate concept for determining layer thickness.
  - ANL graphite pile in 1943 was adequate for photons and was overdesigned for neutrons.
  - X-10 reactor at ORNL included a 2.1-m concrete shield. This shield was also overdesigned for neutrons and about adequate for gamma rays, although streaming problems were evident for both radiations around access holes in the shield.

Radiation Shielding

- Historical Review (2) Experimental Approach (~1950)
  - E. Fermi and W. Zinn had made some provisional attenuation experiment in Chicago in 1943.
  - In 1946 the Navy initiated an intensive study program for a nuclear-powered submarine, and the Air Force, a similar study for a nuclear-powered aircraft. Space and weight limitations for for these nuclear applications added more impetus to the open question in shielding.
  - In the spring of 1947, E. P. Blizard, then a Navy physicist assigned by Capt. H. Rickover to ORNL, was directed to start a program of shielding measurements. He proposed a program of neutrons and gamma-ray attenuation measurements through several types of concrete placed in the rear core hole of the X-10 reactor. C. E. Clifford was assigned to work with him because of his experience with measurements for the Hanford shield in 1944.

Radiation Shielding

- Historical Review (3) Experimental Approach (~1960)
  - Blizard and Clifford suggested a shielding experimental facility, Lid Tank Shielding Facility which began operating in 1949. Bulk Shielding Reactor (BSR) was completed in 1950 and the ORNL Tower Shielding Facility began operation under Clifford's direction in 1954.
  - Although destined for cancellation in 1961, the aircraft nuclear propulsion (ANP) program produced a number of other useful shielding efforts. The demise of the ANP program and the successes of the nuclear submarine are well known. The U.S.S. *Nautilus* sailed on nuclear power for the first time in January 1955. This date is to be compared with 1954, 1956, and 1957, the year in which nuclear-fueled electric plants first went on line in Russia, Great Britain, and the United States, respectively.

Radiation Shielding

- Historical Review (4) Experimental Approach (~1960)
  - United Kingdom shielding research efforts were started in 1948. The research reactor BEPO had just completed; It had a 15-cm iron thermal shield followed by a bulk shield of barytes concrete and had a layout similar to X-10 reactor in ORNL. The Windscale reactors were under construction in 1948 and included a thermal shield similar to BEPO but Portland concrete was used rather than barytes. A shielding group was set up under C. C. Horton as part of F. W. Fenning's reactor physics group at Harwell to investigate shielding problems connected with large concrete shields, heating effects, and radiation streaming in the large ducts. Horton, later with K. Spinney, developed some models to predict the distribution of heat generation by neutrons and gamma rays. The LIDO reactor was completed in 1956 and dry mock-ups could be placed at three caves in the shield wall. (* barytes: 重晶石)

Radiation Shielding

- Historical Review (5) Experimental Approach (~1990)
  - Japan shielding research efforts were started in 1960. The research reactor JRR-4 had completed in 1965.
  - YAYOI reactor had completed in 1971.
  - Nuclear Ship MUTSU was completed in 1974 but could not sail on nuclear power because of neutron streaming accident from the reactor vessel.
  - Extended shielding studies were carried on the shielding experiments by using JRR-4 and YAYOI in 1970s.
  - For the development of fusion reactors, FNS at JAERI, and OKTAVIAN at Osaka Univ. had constructed to investigate neutron and gamma-ray attenuation of 14MeV neutrons.
  - For the development of MONJU fast reactor, JASPER experiment had performed in joint research project between Japan and United States by using the TSF facility at ORNL.

Radiation Shielding

- Historical Review (6) Theoretical Approach (~1950)
  - By the early 1950s an intensive program in radiation physics was under way at the National Bureau of Standards (NBS): (National Institute of Standards and Technology: NIST) under the direction of U. Fano. G.W. Grodstein published a definitive set of X-ray attenuation coefficients, and L. V. Spencer's method-of-moments solution of the Bolzmann transport equation was first described. Shortly afterward a group at Nuclear Development Associates, Inc., under the direction of H. Goldstein joined with Spencer and Fano in an intensive program of moments-method calculations, which culminated in 1954 with publication of the Goldstein and Wilkins report on gamma-ray buildup factors. Fano, Spencer, and M. J. Berger published a definitive exposition of gamma-ray penetration in 1959, which included a summary of the moments method as well as other techniques.

Radiation Shielding

- Historical Review (7) Theoretical Approach (~1990)
  - In the development and application of gamma-ray buildup factors to kernel techniques, the work of J. Taylor, M. Capo, M. Berger, J. Hubbell, D. Trubey, A. Chilton should be listed as principals in devising empirical representations of the data and simplified schemes for its application.
  - In 1980s, a GP (Geometric Progression) fitting method was developed by Y. Harima of Tokyo Tech for gamma-ray buildup factors. The GP fitting method had been adopted in ANSI/ANS standard 6.4.3. The data have been incorporated in QAD-CG and G33 codes called QAD-CGGP and G33-GP.

Radiation Shielding

- Historical Review (8) Theoretical Approach (~1990)
  - Monte Carlo techniques applied to shielding: E. Cashwell and C. Everett (LASL) in early 1950s.
  - O5R system of Monte Carlo programs by R. Coveyou at ORNL in 1958.
  - MORSE Monte Carlo code of E. Straker, P. Stevens, D. Irving, and V. Cain was completed in 1969.
  - B. Carlson of LASL had developed a discrete-ordinates method for reactivity calculations in 1955 which became known as *Sn* method. F. Mynatt and W. Engle of ORNL developed ANISN in 1965, and a two-dimensional version of ANISN called DOT was described a year later by F. Mynatt, F. Muckenthaler, and P. Stevens.
  - In 1970s, K. Lathrop developed two-dimensional *Sn* code TWOTRAN. TWODANT and THREEDANT have been developed in LANL.
  - W.A. Rhoades and D.B. Simpson developed DORT and TORT in 1980-1990s.

Radiation Shielding

- Historical Review (9) Theoretical Approach (~2000)
  - MCNP Monte Carlo code of R. C. Little, J. S. Hendricks, and J. Briesmeister was developed in 1990 extended from the MCN and MCP codes originally developed by E. Cashwell and C. Everett.
  - MCNPX of Monte Carlo programs by J. S. Hendricks, R. E. Prael, G. W. McKinney, and L. S. Waters at LANL in 2000.
  - ITS TIGER series of coupled electron/photon Monte Carlo code has been developed by S. M. Seltzer and M. J. Berger in Sandia National Laboratory.
  - PHITS code has been developed by K. Niita, H. Iwase, H. Takada, and H. Nakashima at JAERI