Measurement of LET distributions at CERF facility with RRMD-III

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Outlines

- Introduction (background of this research)
- Purpose of the experiments
- System of the experimental apparatus
- Experimental results
- Summary

Abstract

The LET distributions in front of the 80 cm-thick concrete side shield at the CERF facility were measured with a Si detector telescope (RRMD-III) covered with and without a 1 cm-thick acrylic plate. In these measurements, a slight difference between both LET distributions was observed as a result of recoil protons and/or carbon particles by neutrons. The LET distribution obtained by RRMD-III without 1 cm-thick acrylic plate is compared with lineal energy distributions obtained by DOSTEL detector under the same condition and, also, these dose equivalents are compared with that obtained by HANDI TEPC which are used as the standard in the CERF facility.

Comparison of dose data between RRMD-III, TEPC and DOSTEL onboard theSpace Shuttle (STS-84, -91)

	STS-84						STS-91					
	GCR		Trapped		Total		GCR		Trapped		Total	
Detector (range of LET [keV/μm])	DE [μSv/day]	QF	DE	QF	DE	QF	DE	QF	DE	QF	DE	QF
RRMD-III (0.06 - 600)	433.5	2.87	432.3	1.22	865.8	1.72	449.6	2.95	338.3	1.25	788	1.86
RRMD-III (0.1 - 120)	304.9	2.13	432.1	1.23	736.9	1.49	302.1	2.13	332.9	1.23	634.9	1.54
DOSTEL M6 (0.1 - 120)	343	2.60	303	1.30	657	1.80						
DOSTEL M7 (0.1 - 120)	320	2.50	257	1.20	583	1.70						
RRMD-III (0.4 - 600)							395.3	4.03	321.5	1.26	716.8	2.03
TEPC (0.4 - 600)							549.1	3.52	641.7	2.11	1190.8	2.59
TEPC (0.2 - 1200)							554.1	3.27	669.1	2.13	1223.3	2.53

- Difference between RRMD-III and DOSTEL is reasonable, if surrounding materials of DOSTEL are taken into consideration.
- Dose equivalent (0.4 – 600keV/μm) of TEPC is 66 % higher than that of RRMD-III
- Quality factor of TEPC in SAA region is over 2. (c.f. 1.2 – 1.3 for DOSTEL & RRMD-III)

T. Doke et al., Radiat. Meas., Vol. 33 (2001) 373-387
K. Terasawa et al., Ionizing Radiat., Vol. 28, No. 3 (2002) 169-180 (in Japanese)

Inter-calibration experiments

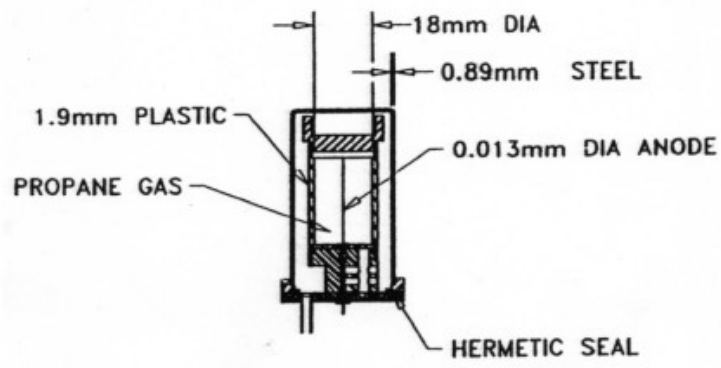
- Comparison of several detectors for space dosimetry at accelerator facilities to reveal the discrepancy.
  (LET distributions and dose data measured by TEPC, DOSTEL and RRMD-III)

・CERN CERF facility (CERN-EU high-energy Reference Field)
→ Radiation field created by cosmic rays at commercial flight

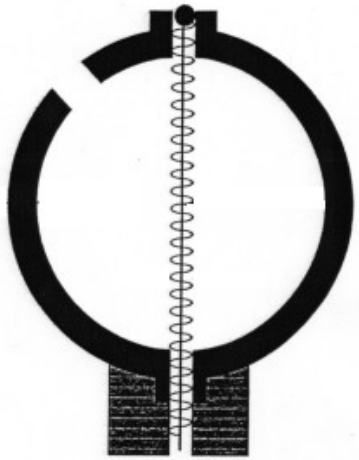
・Proton beams at Loma Linda University (America) and the cyclotron at NIRS (Japan)
→ Proton spectrum at SAA region created by proton beam and absorbers with various thickness

・Heavy ions and their fragment particles from HIMAC at NIRS (Japan)
(ICCHIBAN experiments)

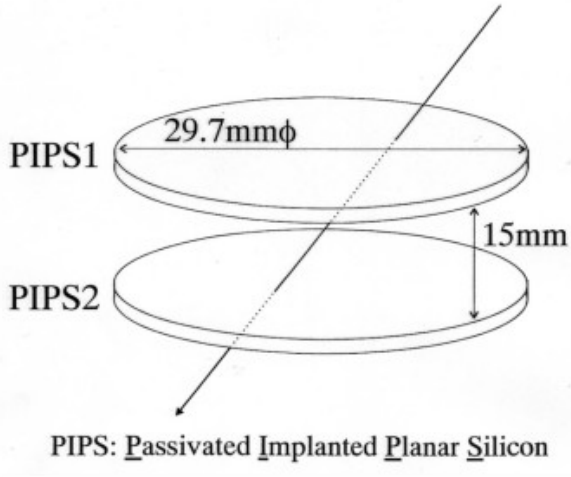
TEPC (Cylindrical)

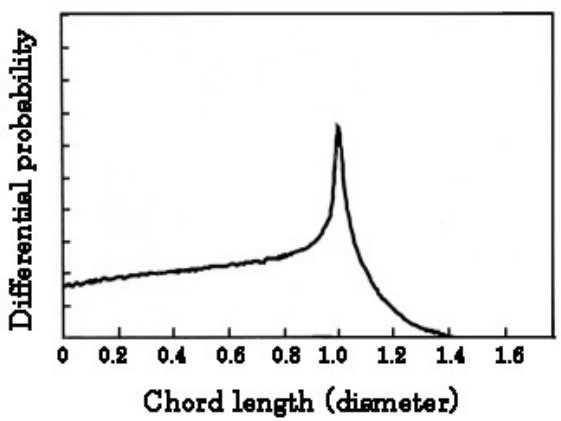


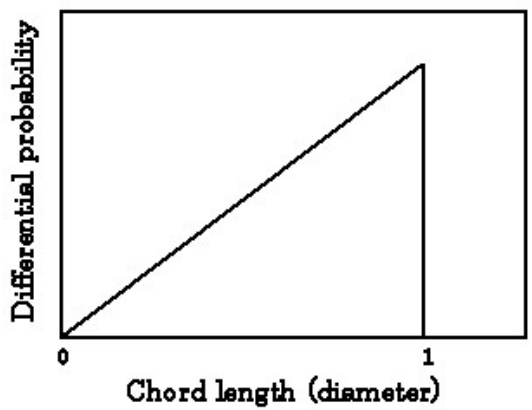
TEPC (Spherical)

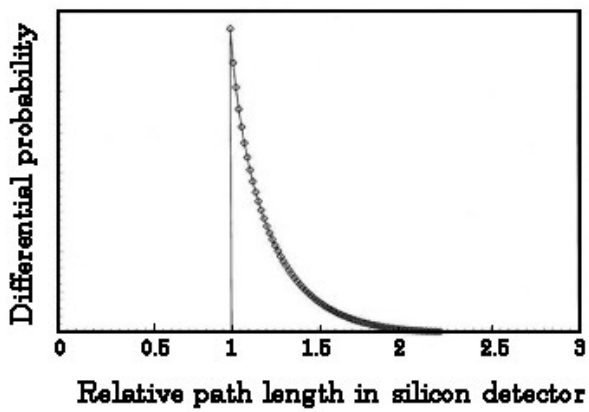


DOSTEL









σ =	51 [%]	35 [%]	17 [%]

Detector structures, response functions and their standard deviations of cylindrical TEPC, spherical TEPC and DOSTEL.

c.f. σ = 0 [%] (RRMD-III)

T. Doke et al., Radiat. Meas. (submitted)

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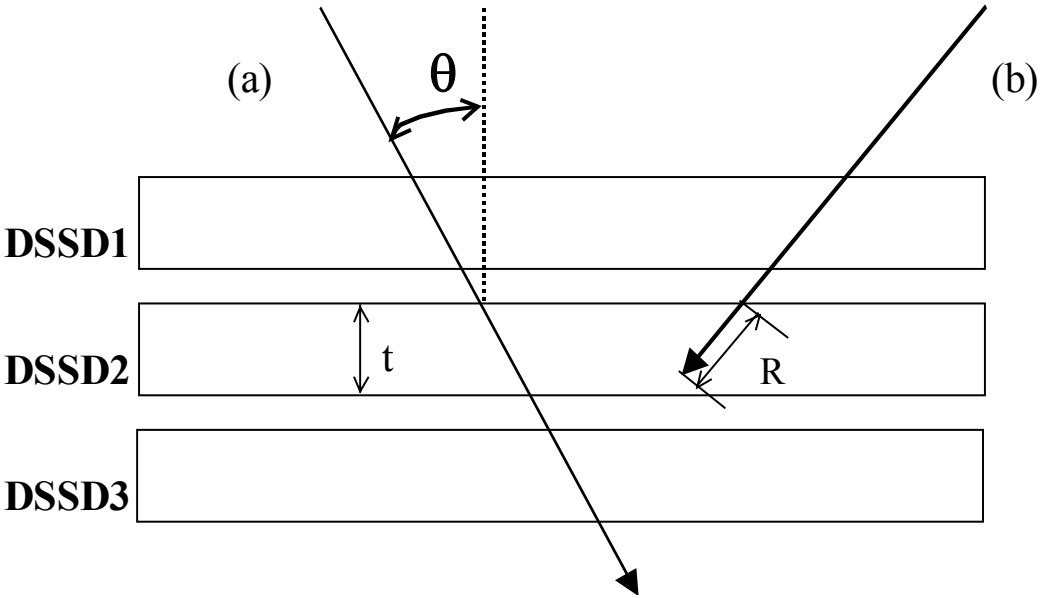

- LET of each particle can be measured.
  - Incident angle
  - Path length in the detector

(a) For penetrating particles

$LET = E_d / (t/\cos\theta)$

(b) For stopping particles

$LET = E_d / R$

Particle identification by $\Delta E \cdot E$

Range – Energy relation

→ determination of R

→ LET_{water}[keV/μ m]

= $LET_{Si} \times 1.198 / 2.33$

E_d : Deposited Energy in the detector

t : Thickness of the detector

θ : Incident angle of each particle

R : Range of a stopping particle in the detector

1.198 : Conversion factor for relativistic particles

2.33 : Density of Si

Method of measuring LET in real time by RRMD-III

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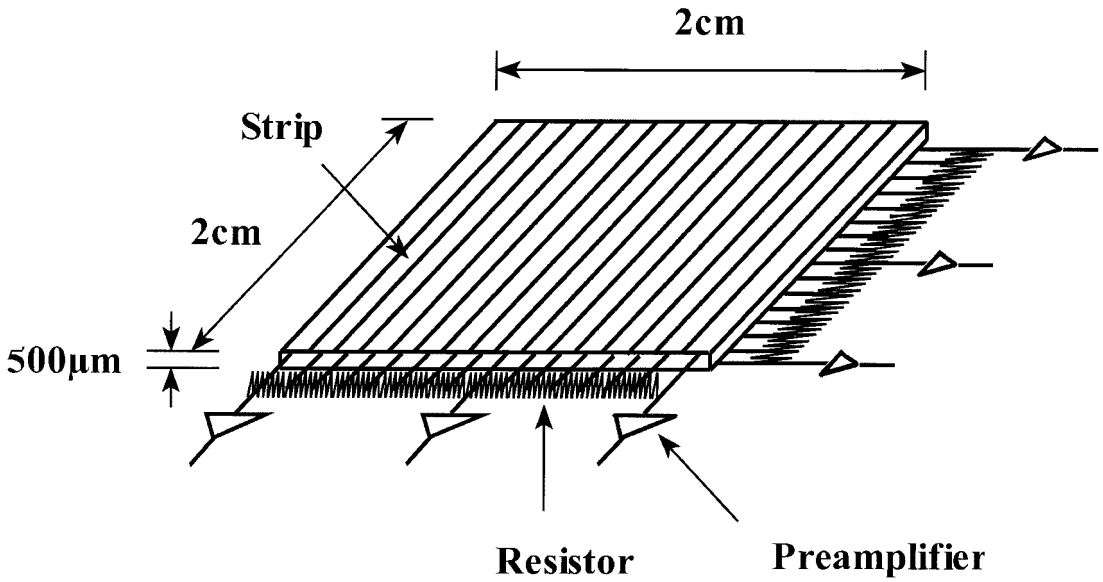
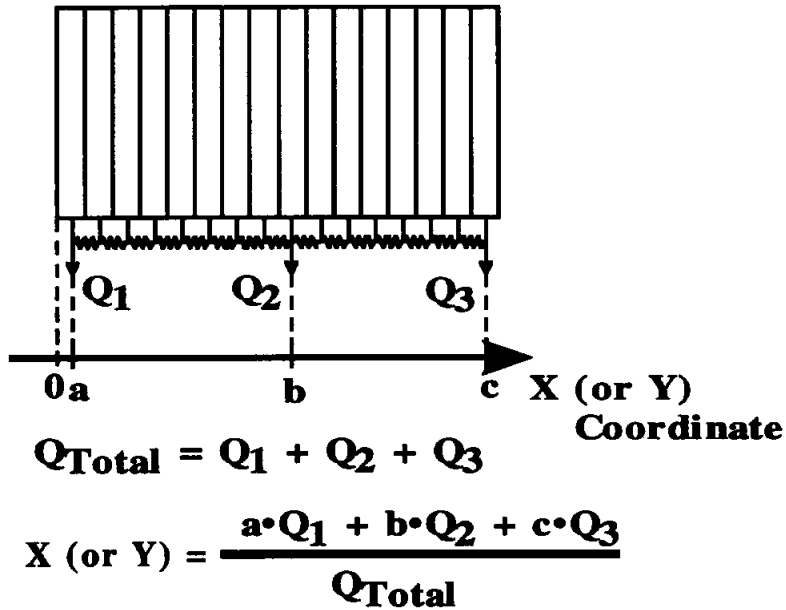
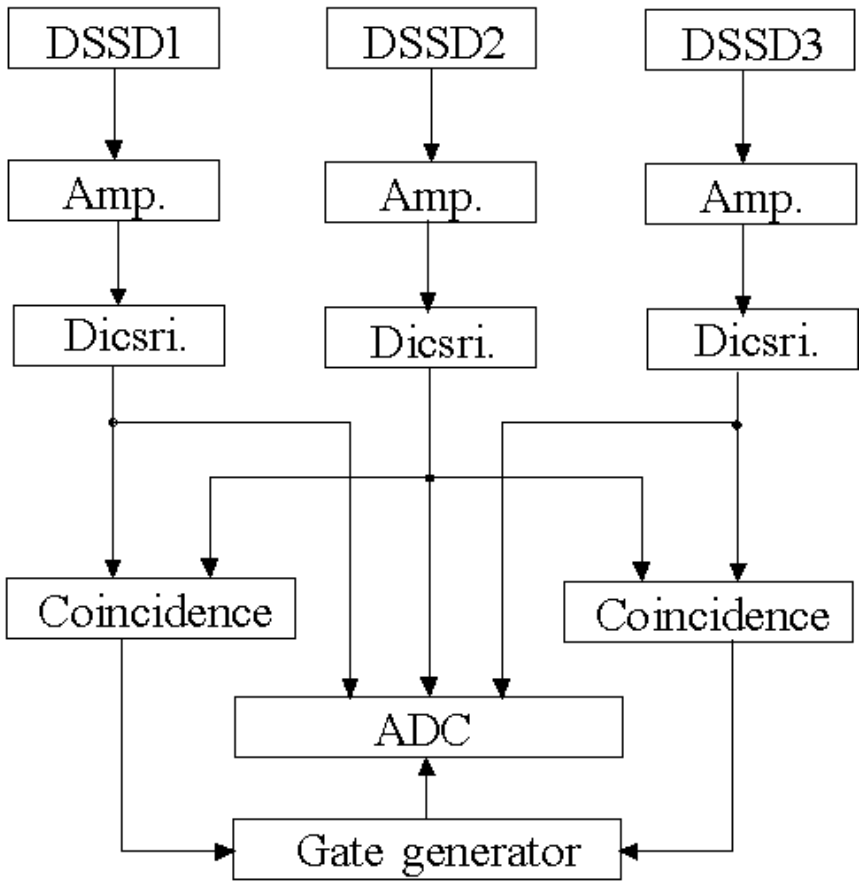




- Reduction of the number of amplifiers to simplify
- Typical charge division type readout system
- 3 Amplifiers for each dimension (x, y) , 6 amps a DSSD

Readout system of signals from DSSD
Method to determine the position and deposit energy



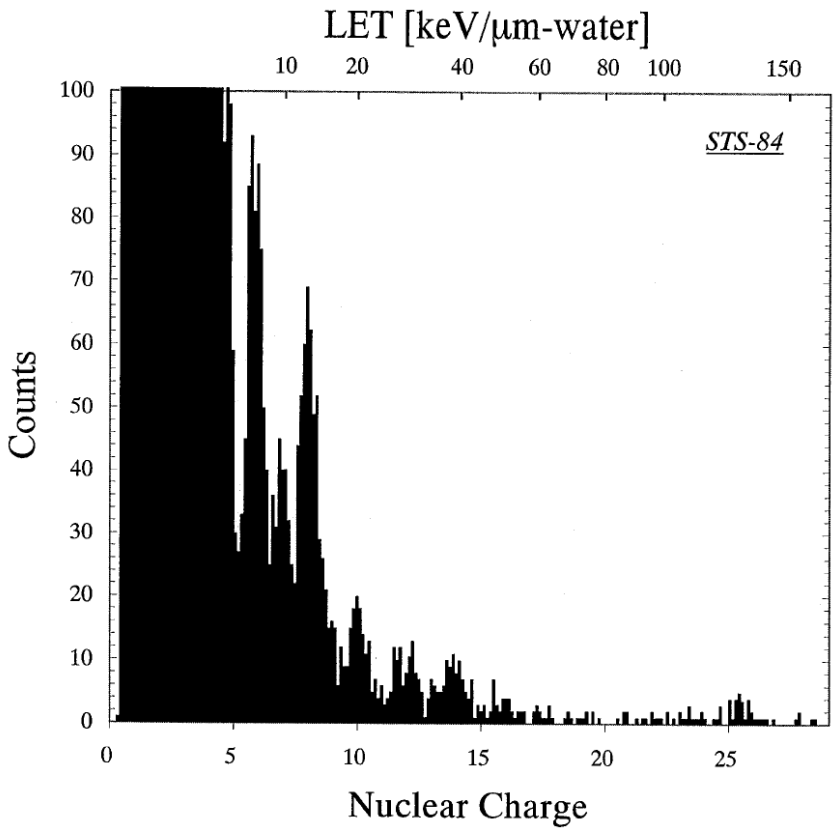
DSSD1 & DSSD2

or

DSSD2 & DSSD3

DSSD2 : standard detector

Trigger logic of RRMD-III



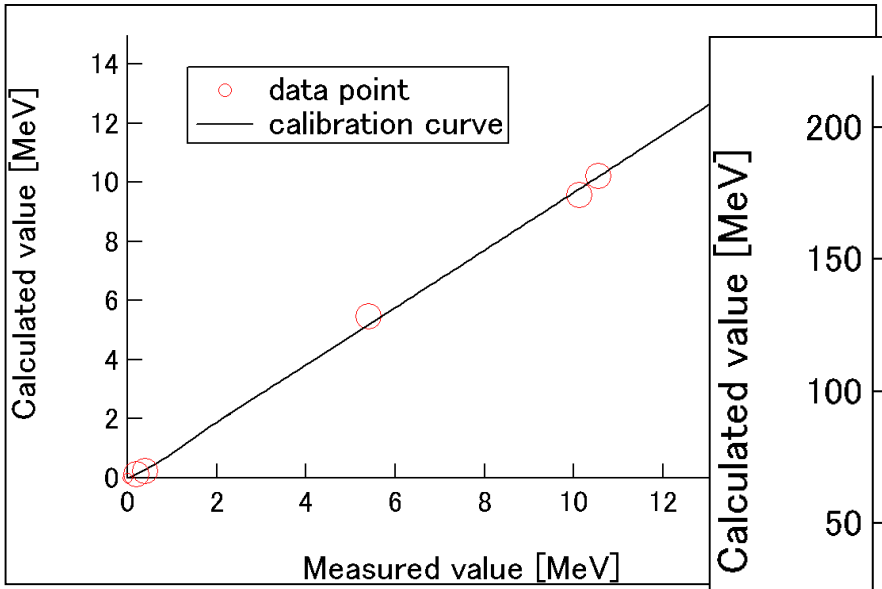
- Energy calibration
  : measurement of the energies deposited by particles penetrating the telescope

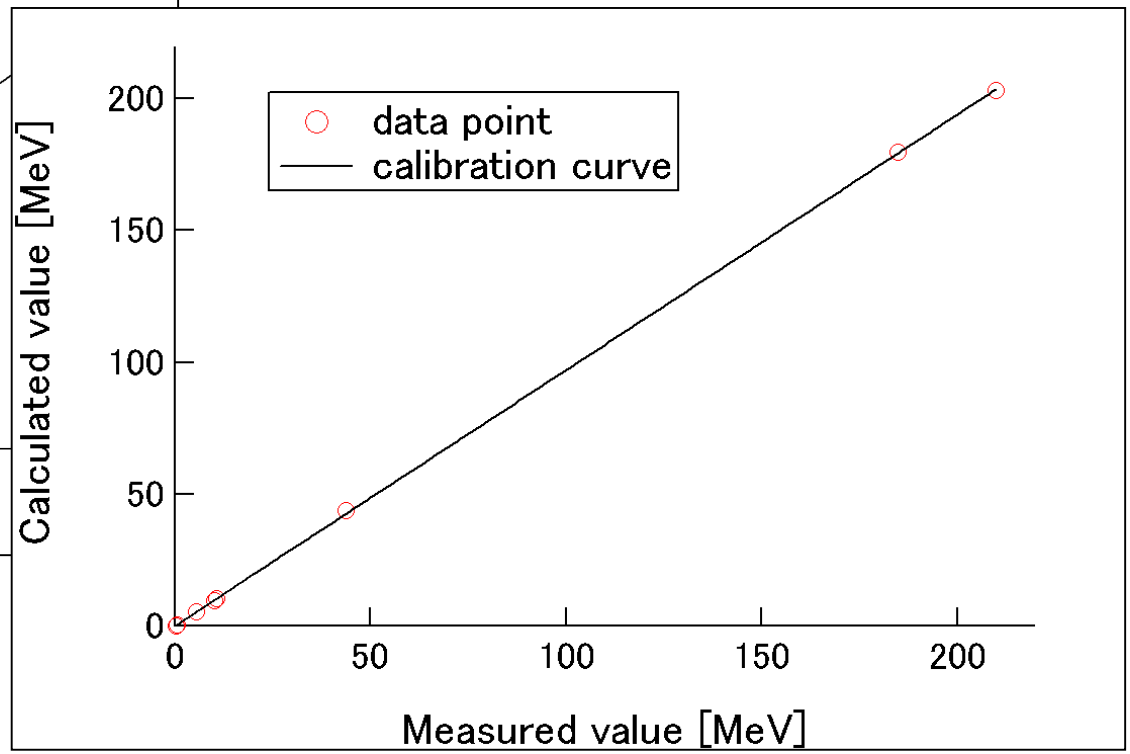
- Major abundant elements of GCR particles

  C : 7.2 keV/ μ m
  N : 9.8
  O : 12.8
  Ne : 20.0
  Si : 39.2
  Fe : 135.2

Nuclear charge distribution of GCR particles
obtained for the energy calibration during the flight (STS-84)

T. Doke et al., Radiat. Meas., Vol. 33 (2001) 373-387





Data points :
- cosmic muon (mip)
- 200 MeV proton
- 400 MeV/n carbon
- 430 MeV/n carbon
- 800 MeV/n silicon
- 400 MeV/n iron
- 500 MeV/n iron

- Calibration error is estimated to be 5 %.

Error for flight experiments :
- For low LET region (relativistic protons), calibration error is ~ 30 %.
- MIPs contribution to total dose equivalent (STS-84) is 20 %.
  → The error is 6 % for total dose equivalent (small error).

Curve for energy calibration

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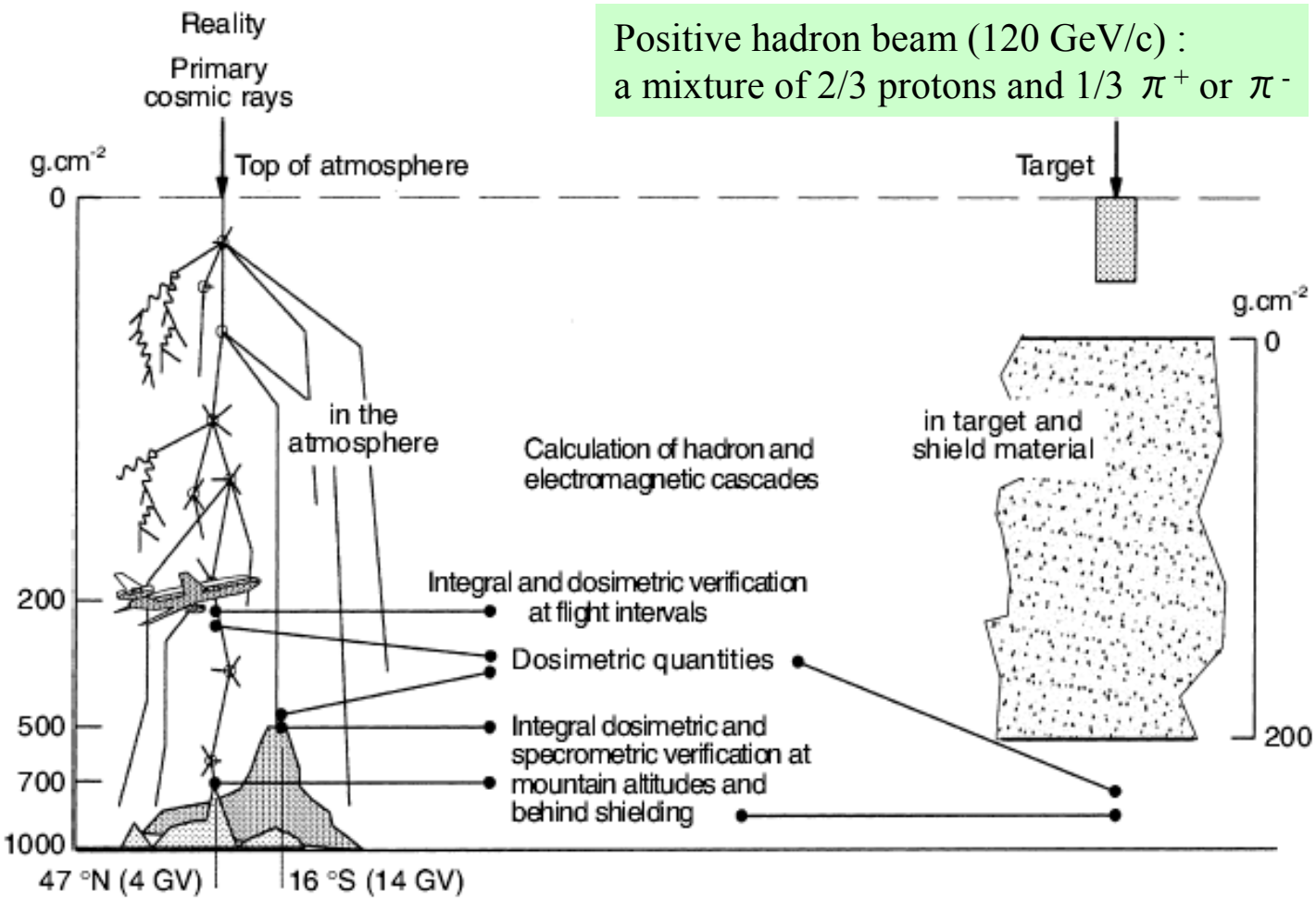
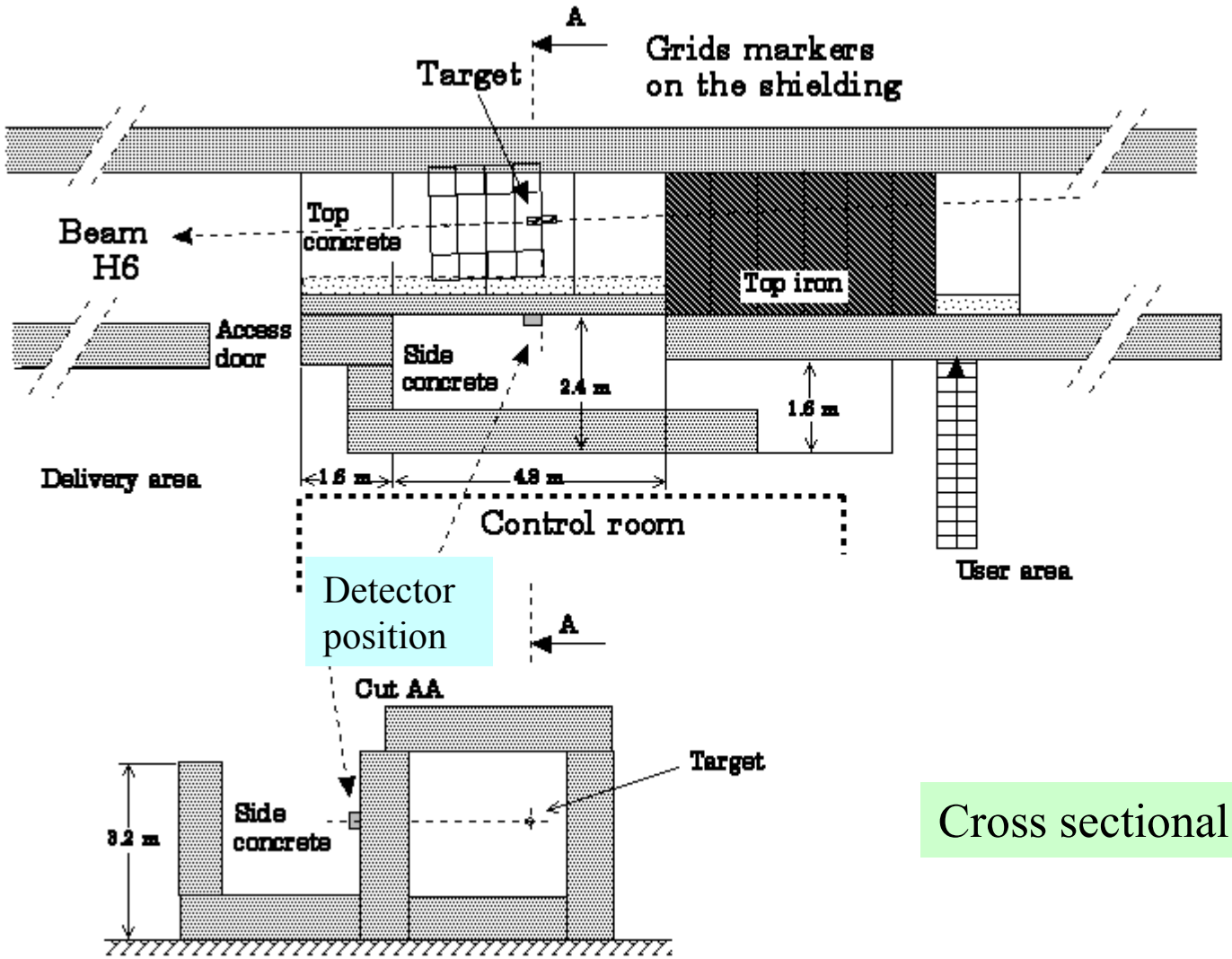


Positive hadron beam (120 GeV/c) :
a mixture of 2/3 protons and 1/3 π^+ or π^-

Cu target
50 cm thick
7 cm in diameter

The cosmic radiation field in the atmosphere and its simulation at CERN
(The CERN-EU high-energy Reference Field (CERF) facility)

A. Mitaroff and M. Silari, Radiat. Prot. Dosim., Vol. 102, No. 1 (2002) 7-22

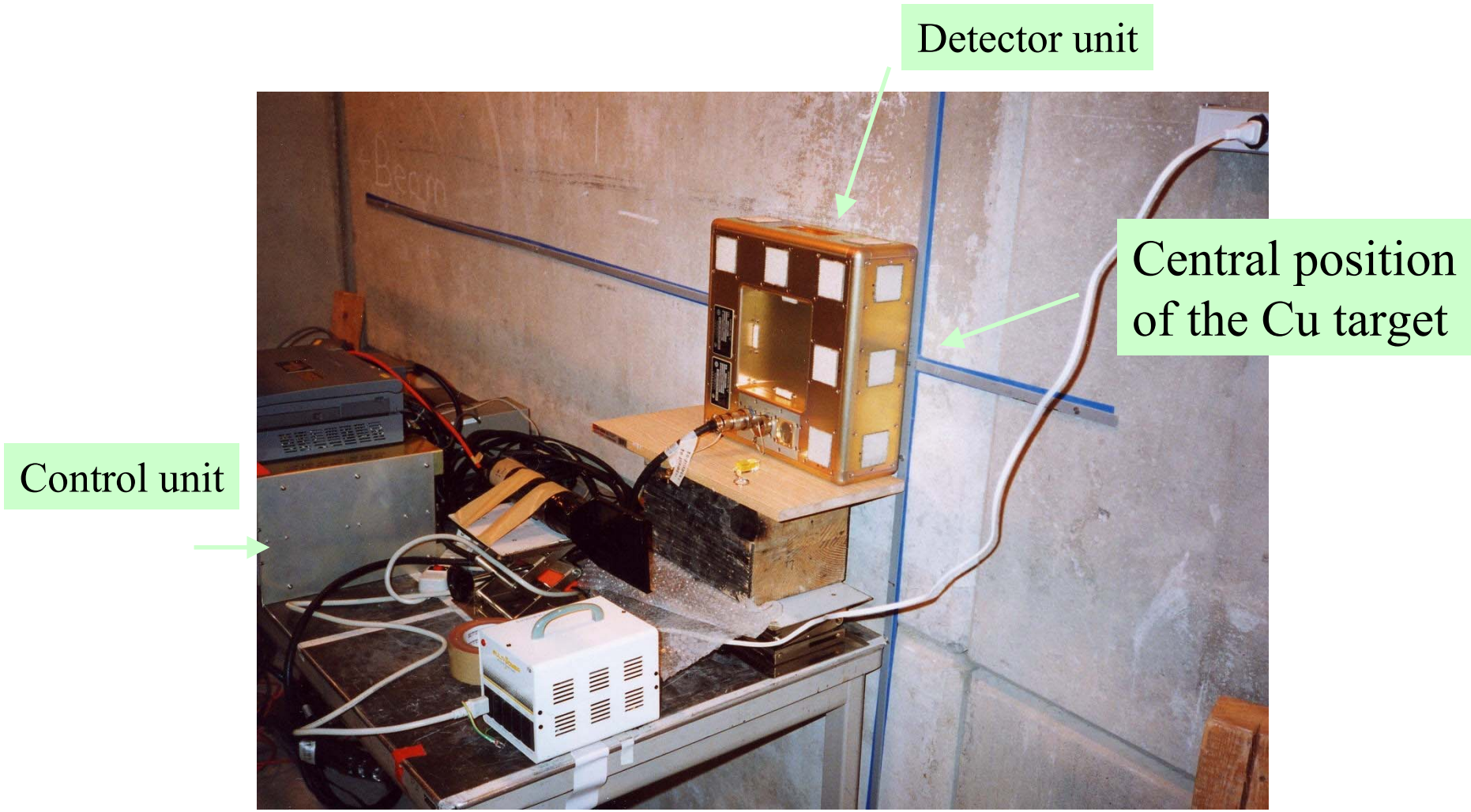


Top view

Cross sectional view

Top view and cross sectional view of the CERF facility and the location of RRMD-III

A. Mitaroff and M. Silari, Radiat. Prot. Dosim., Vol. 102, No. 1 (2002) 7-22



Photograph of RRMD-III detector unit at the CERF facility

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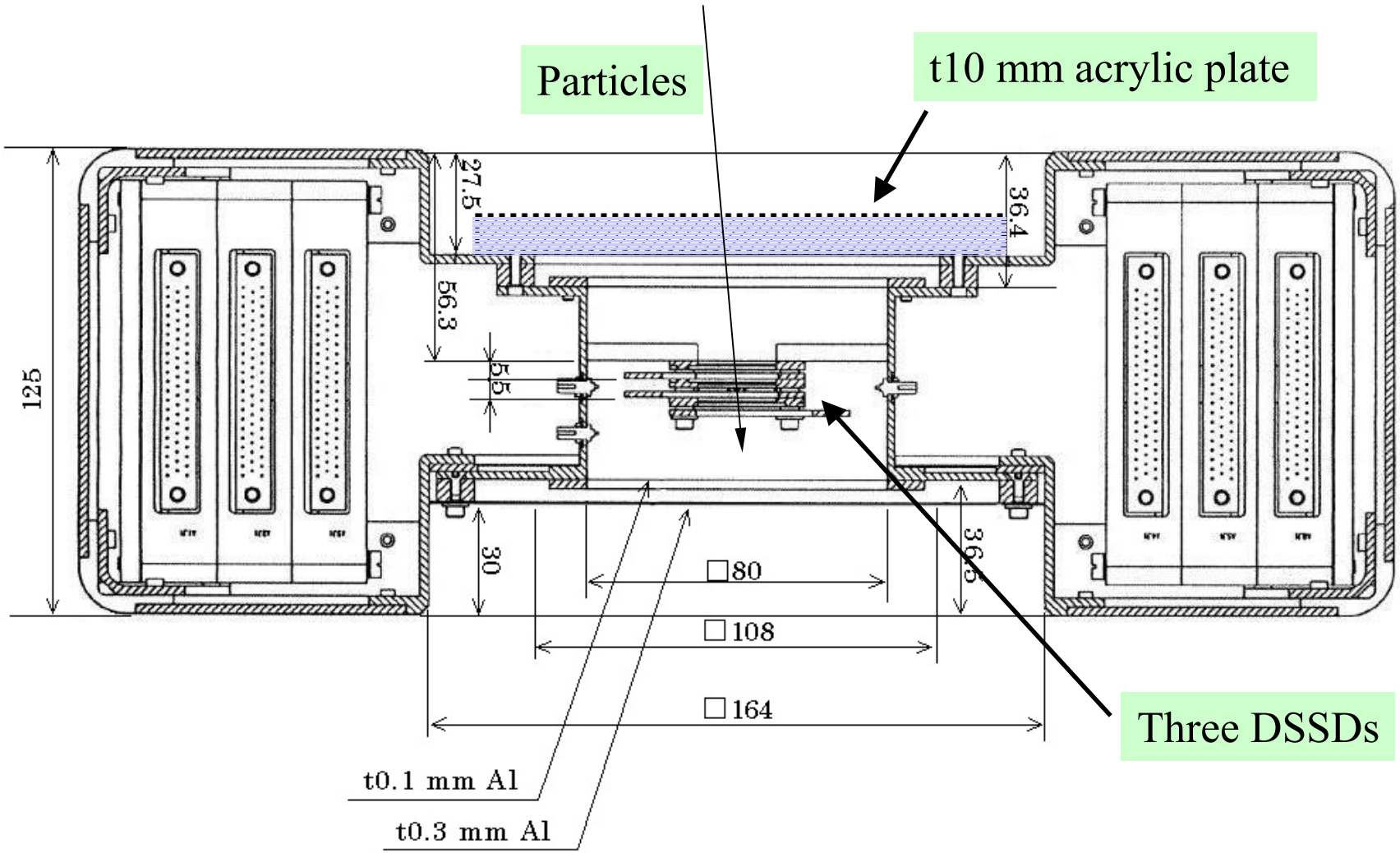

Schematic view of the detector part of RRMD-III

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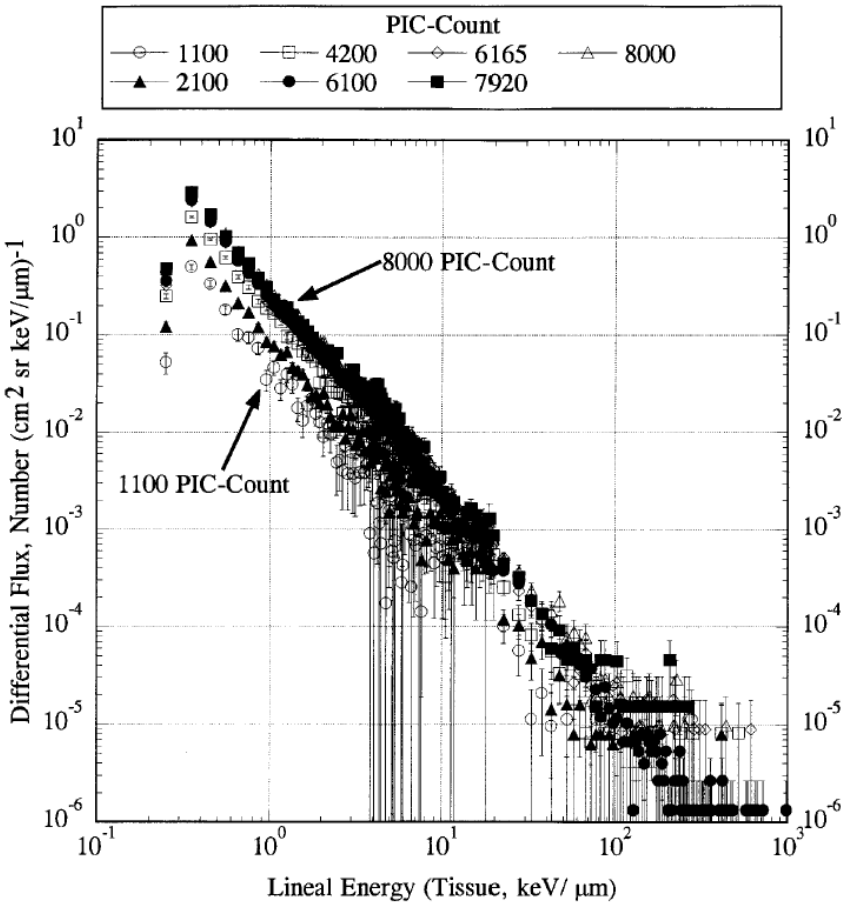


- An air-filled Precision Ionisation Chamber (PIC)

- For monitoring of beam intensity
  1 PIC = 2.2×10^4 particles impinging on the target.

- The unit of longitudinal axis is [keV/ μ m cm^2 sr]$^{-1}$.

→ This unit is used in the case of isotropic incidence

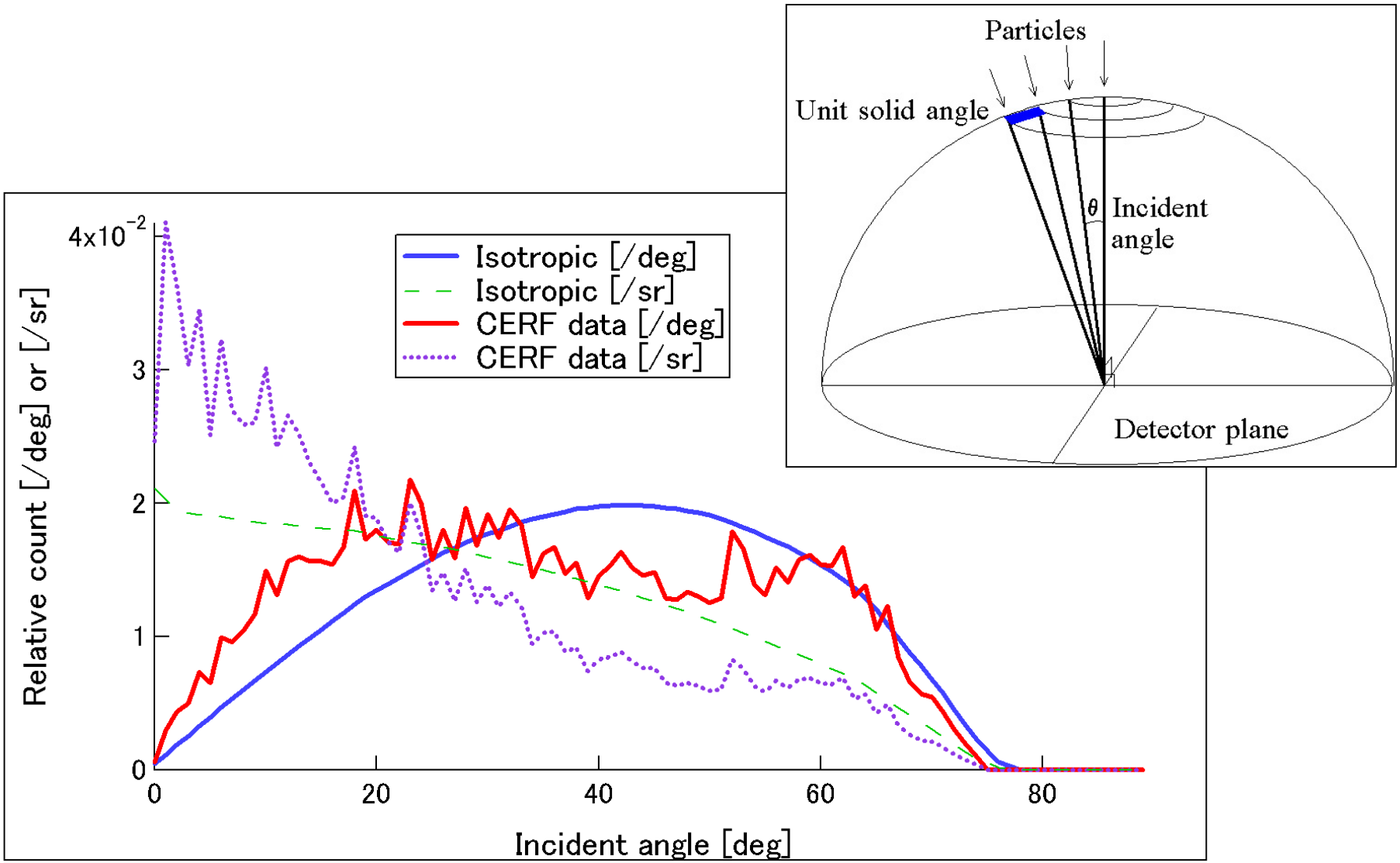
→ not isotropic, but directional incidence
from the target

→ [keV/ μ m cm^2]$^{-1}$

→ Comparison between DOSTEL and RRMD-III

Cylindrical TEPC (NASA) data at the CERF facility

G. D. Badhwar et al., Radiat. Meas., Vol. 35 (2002) 551-556.



Angular distribution measured by RRMD-III @ CERF

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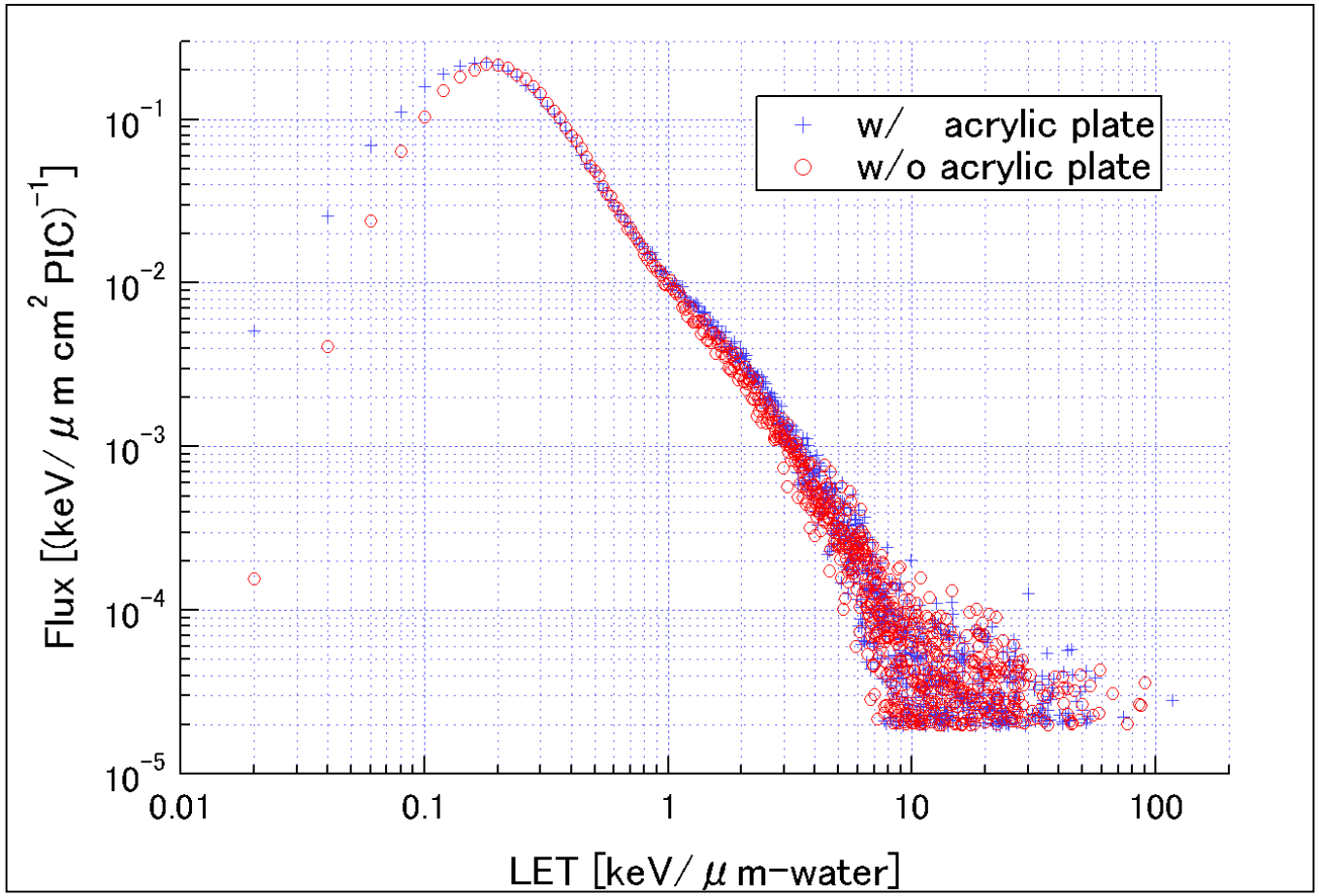

- Dose equivalent with an acrylic plate is 9 % larger than that without the plate.
- Neutron contribution to total dose is only 9 % with 1 cm thick acrylic plate.

LET distribution obtained by RRMD-III
with and without 1 cm acrylic plate

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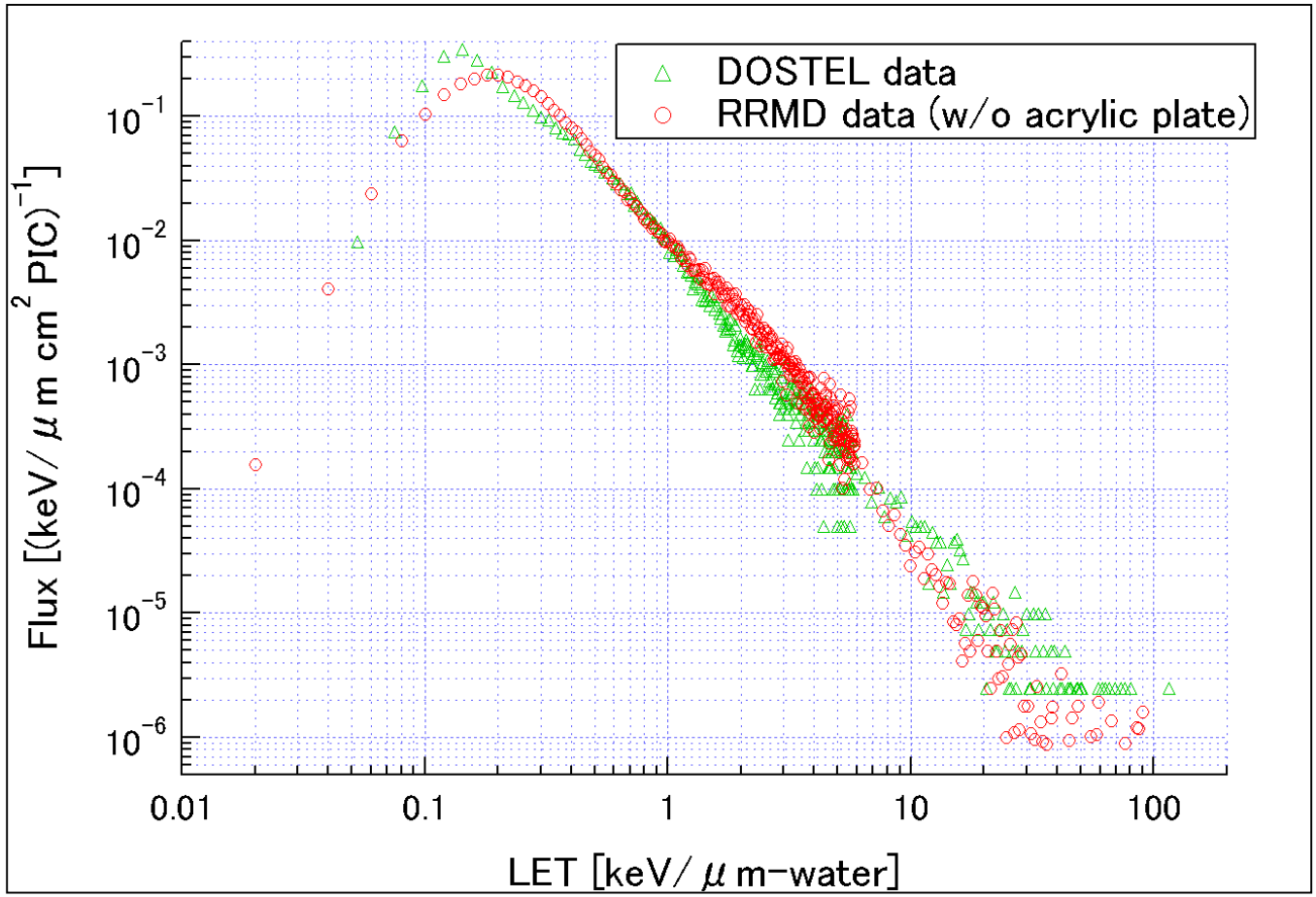

- Dose equivalent by DOSTEL is slightly larger than that of RRMD-III.
  Absorbed dose by DOSTEL is slightly smaller than that of RRMD-III. (next OHP)

→ roughly consistent

Comparison between LET distributions obtained by DOSTEL and RRMD-III

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Dose data alongside the 80 cm concrete-side shield

	Absorbed dose [nGy/PIC]	Dose equivalent [nSv/PIC] ICRP-60	Quality factor
RRMD-III without acrylic plate	0.073	0.107	1.46
RRMD-III with acrylic plate	0.081	0.117	1.44
DOSTEL	0.068	0.137	2.01
HANDI TEPC	–	0.265	–
(c.f.) NASA TEPC @ concrete roof shield	–	0.280	5.48

- Dose equivalent by HANDI TEPC is a few times larger than that by RRMD-III.
- Quality factor > 5 is larger than that from GCR events onboard the Space Shuttle.
- Neutron contribution from 2 mm-thick plastic wall of TEPC is ~ 2 %.
  → not a reason for its (TEPC) large quality factor

T. Doke, K. Terasawa et al., Radiat. Meas. (submitted)
A. Mitaroff and M. Silari, Radiat. Prot. Dosim., Vol. 102, No. 1 (2002) 7-22
G. D. Badhwar et al., Radiat. Meas., Vol. 35 (2002) 551-556.
G. D. Badhwar et al., Radiat. Meas., Vol. 37 (2003) 195.

Summary

- LET distribution by RRMD-III at CERF facility was compared with that by DOSTEL and dose data were also compared with that by TEPC.
- The results of DOSTEL showed rough agreement with those of RRMD-III.
- The results of TEPC differed from those of RRMD-III.
- A reason of these differences may depend on response functions.
- We have acknowledgement of Dr. Petersen in Kiel Universitaet group for sending us their data.