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Neutron Spectrometry and Dosimetry on spacecraft with passive detector system

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Radiation environment inside the aircraft

- is the resut of the interaction of primary cosmic rays (p, α, e, γ rays, HZE) with shielding materials
- The evaluation is very complex because it is constituted by different components (p, e, α, n, HZE) in a wide energy range
- The most dangerous particles are HZE and Neutrons, because of their High LET, both for the astronaut healt and for instrument savety

Neutron Spectrometry

- Neutron energy range covers ten orders of magnitude from thermal energies (0.025 eV) to hundred of GeV
- Different detection techniques are required

Advantages of passive detector system:

- Small size and weight
- No power supply
- No interference with electronic and instrumentation

Neutron Dosimetry

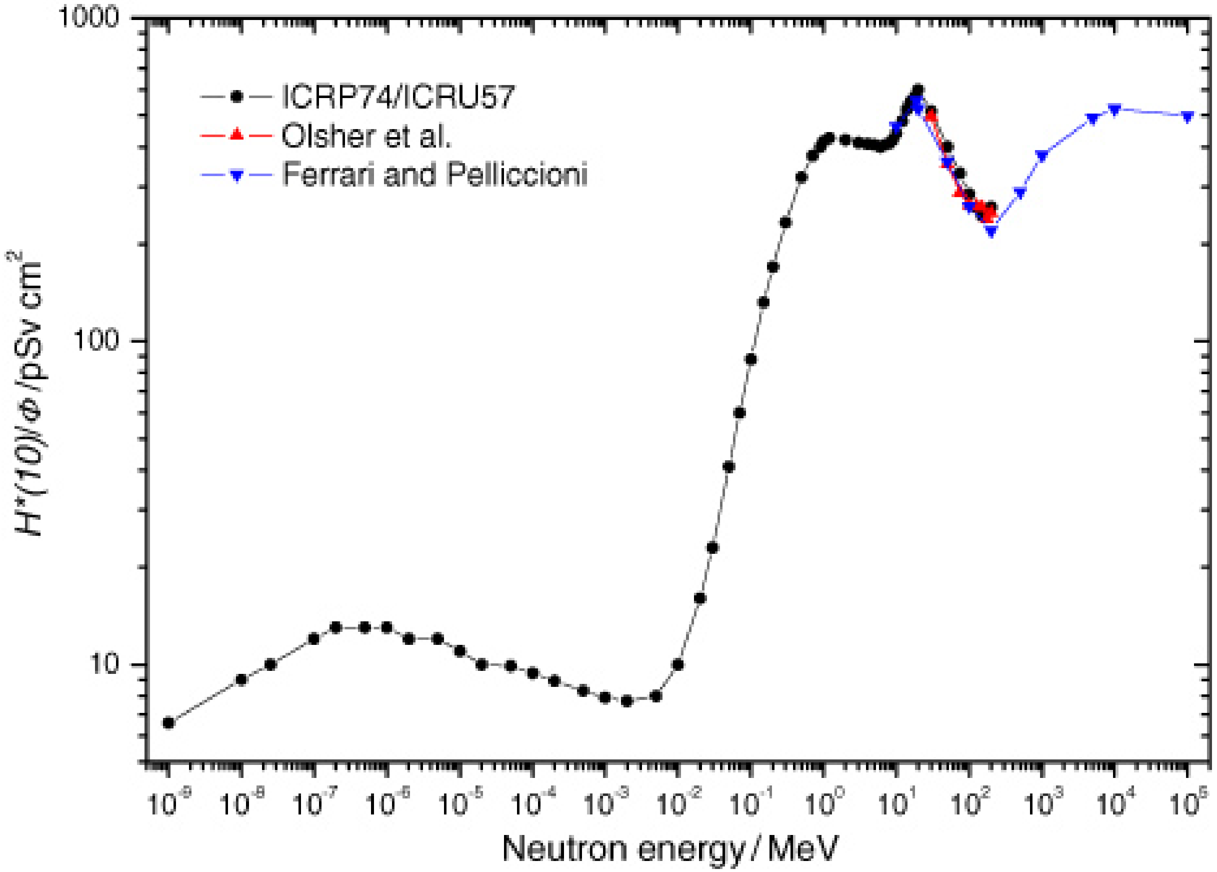
Neutron Ambient Dose equivalent H*(10)

is evaluated from the energy spectra by

using the ICRP 74 conversion factors H/ Φ

Neutron Spectrometry and Dosimetry

Types of radiations and energy intervals	Weighting factors of radiation, W_R
Photons, all energies	1
Electrons, all energies	1
Mesons, all energies	1
Neutrons energies < 10 keV 10 – 100 keV 100 keV – 2 MeV 2 – 20 MeV > 20 MeV	5 10 20 10 5
Protons Heavy Ions	5 20



ICRP-74 - Energy dependence H*(10) /Φ conversion coefficients

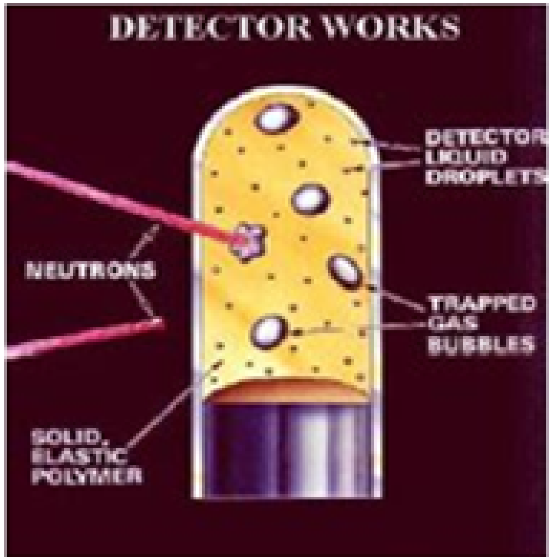
Neutron Spectrometry and Dosimetry

BUBBLE DETECTORS
(BTI , Ontario, Canada)

1-BDT *(0.025 eV- 4 eV)*

2-BDT shielded *(2 eV- 20 keV)*
(Cd 2 mm, Borate Polyethylene 5 mm)

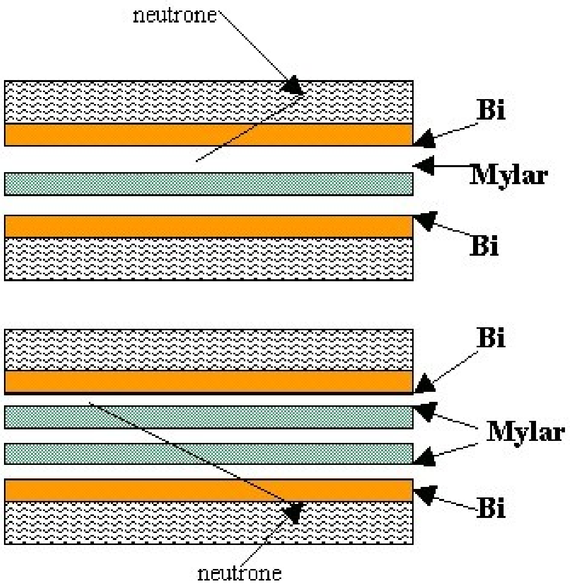
3-BDS-10 *(10 keV-20 Mev)*

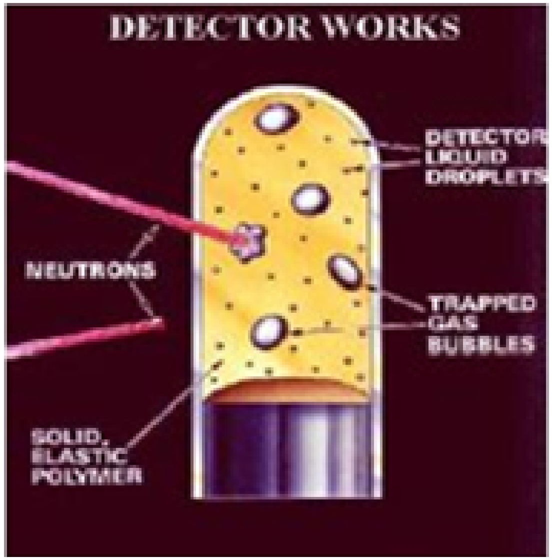


TRACK DETECTORS

4-Polycarbonate foils (Curbell Plastic, USA

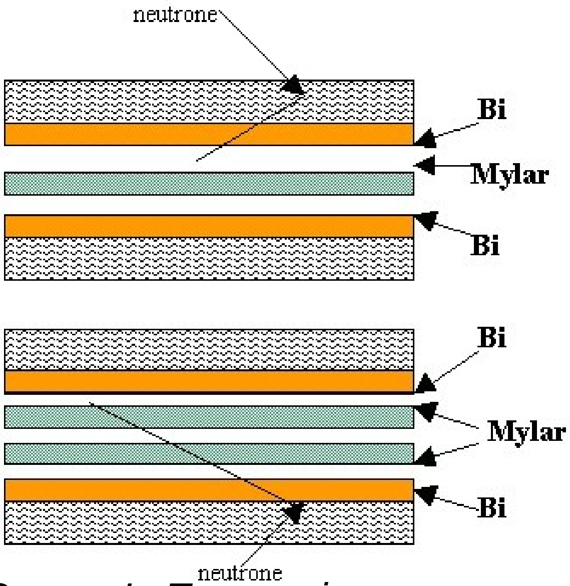
5-Bi209 stack *(50 MeV-100 GeV)*





Bubble detectors consist of polycarbonate vials (d=1.8, h=8 cm) filled by tissue-equivalent gel (H,O,C.F,N) where superheated freon drops, in a metastable state, are dispersed.
Neutrons interact with gel creating chargesecondary particles (α and p) which tranfer their energy to the gel producing a state change with bubbles formation.

BDT - 0.025 eV< En < 4 eV
BD-PND – 100 keV< En < 20 MeV
BDS 10 - 10 keV< En < 20 MeV



W. G. Cross L. Tommasino
Dosimetry of High Energy Neutrons and Protons by 209Bi Fission. Radiation Protection Dosimetry 70(1) April 1997

- **Bi209 Stack detector** is based on bismuth fission.
- Fission fragments produced by the interatction of high energy neutron with Bismuth nuclei deposit their energy in the Mylar detector producing tracks that become visible after a chemical attack.
- The analysis of tracks permit to determine the incident neutron fluence.

A passive detector system for neutron spectrometry
0.025 eV < En < 100 GeV

BUBBLE DETECTORS
(BTI , Ontario, Canada)

1-BDT *(0.025 eV- 4 eV)*

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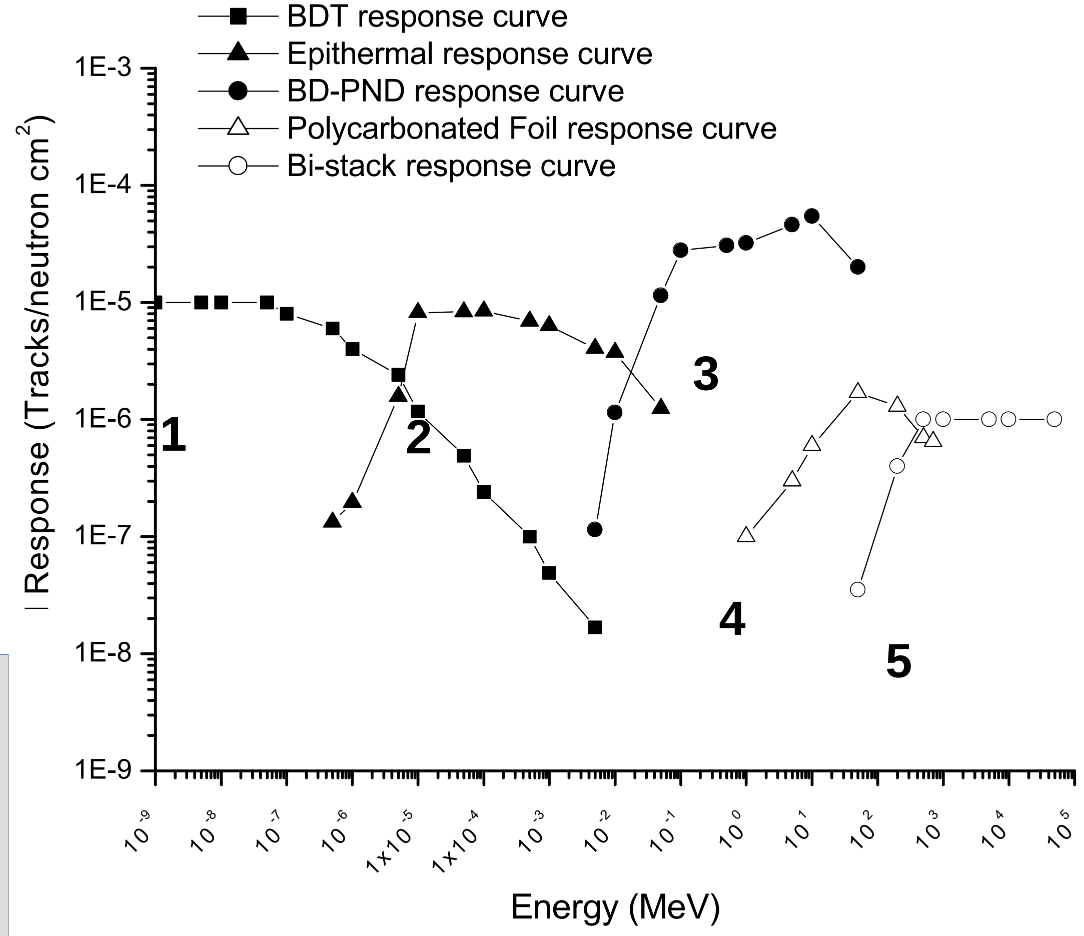
(Cd 2 mm, Borate Polyethylene 5 mm)

3-BDS-10 *(10 keV-20 Mev)*

TRACK DETECTORS

4-Polycarbonate foils (10 MeV-100 MeV)

5-Bi209 stack *(50 MeV-100 GeV)*



BUNTO unfolding code

$$M_j = \int_{E_{\min}}^{E_{\max}} R_j(E)\Phi_E(E)dE \qquad j = 1 \ldots m$$

$$M_j = \sum_{i=1}^{n} R_{ij}\Phi_i \quad i = 1 \ldots N$$

M_j : detector response
$R_j(E)$: response curve values
$\Phi_E(E)$: differential fluence distribution of neutron energy
m : number of energy thresholds
n : number of energy intervals

- It is based on BUNKI's algorithm (SPUNIT), which finds the non negative solution through a iterative perturbation procedure.
- It can find a solution using a starting information on the spectrum shape, but it can also work in lack of information on the initial spectrum.
- The solution $\Phi_E(E)$ is the calculated mean from a number of spectra obtained by a random generation of M_j sampled on a normal distribution, whose parameters m and s are the experimental reading and the associated uncertainty of the j^{th} detector.
- It can be used with different spectrometry systems (like the extended energy and the BDS), if the response matrix of the detectors is known.

Experimental test

Low Energy Neutrons
(Thermal -20 MeV **)**

Medical e-linac accelerators

Bubble detectors

High Energy Neutrons
(20 MeV-100 GeV)

Track detectors

1- CERF Facility

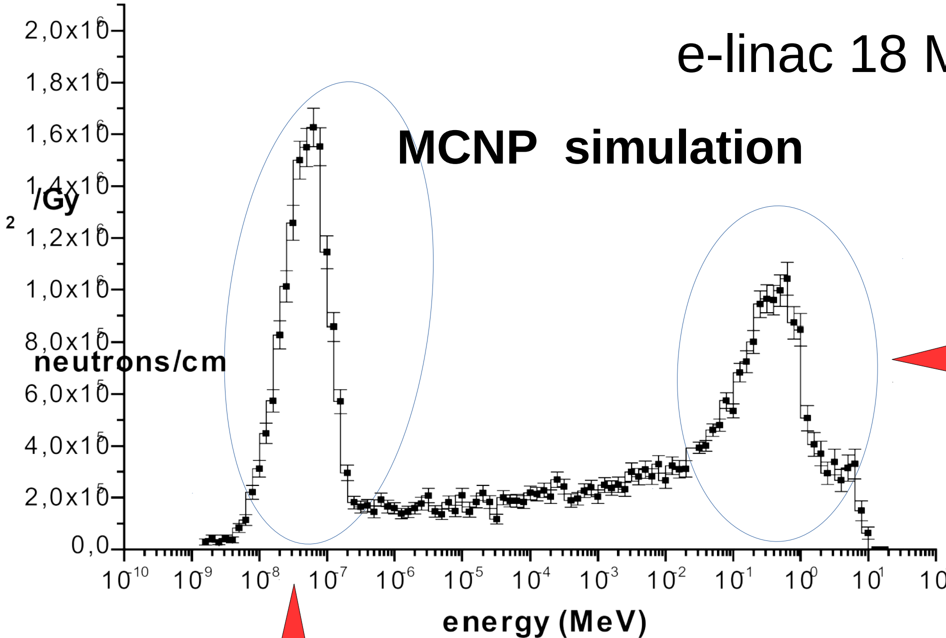
2- High altitude Laboratories (3 -5 km)

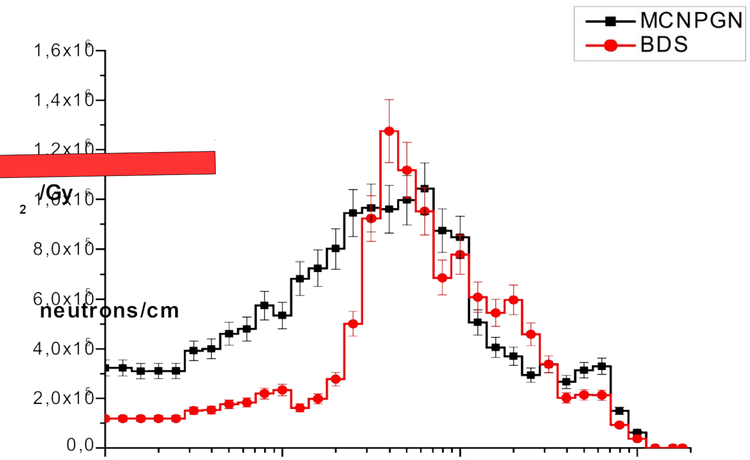
3- High altitude flights (10-12 km)

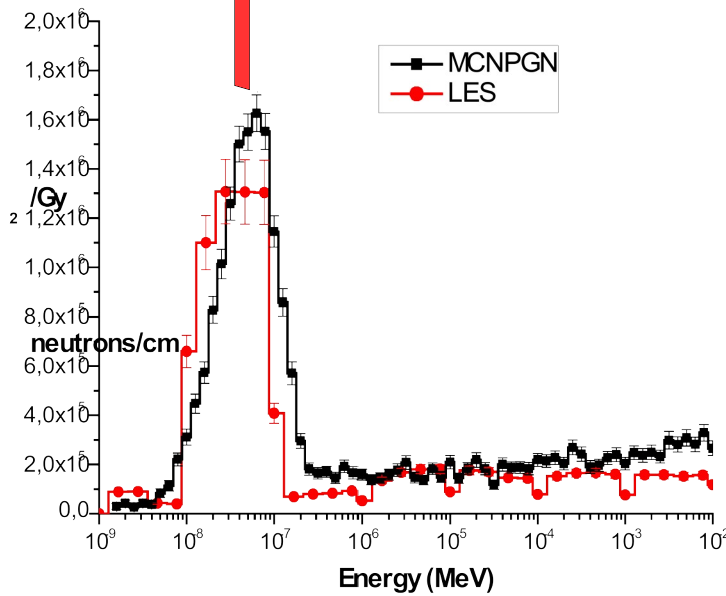
4- Stratospheric balloon flights (20-40 km)

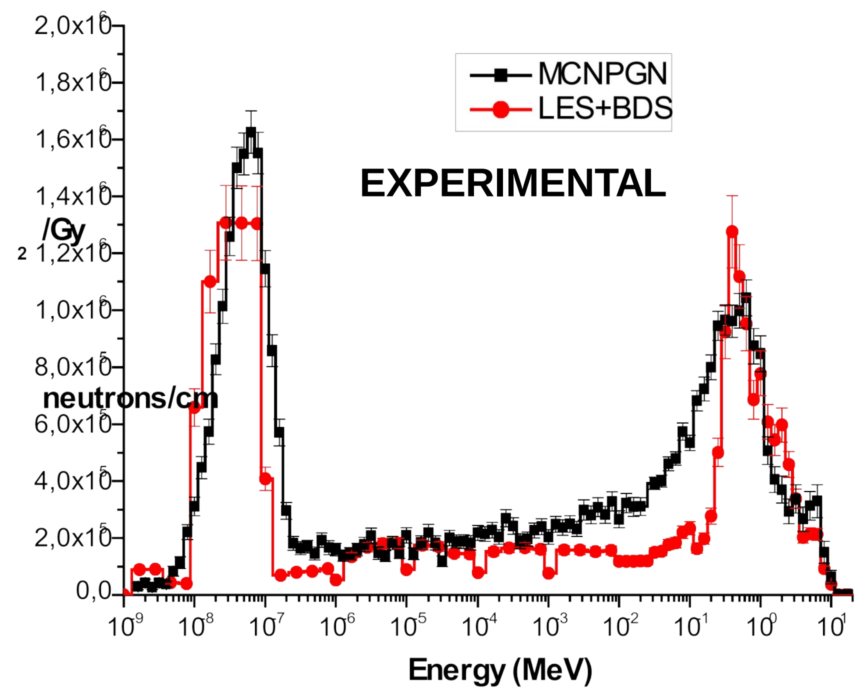
Test neutron spectrometer – Low Enegy (0.025< En < 20 KeV

e-linac 18 MV- Elekta precise- prostate treatment
Neutron spectrum in the patient body





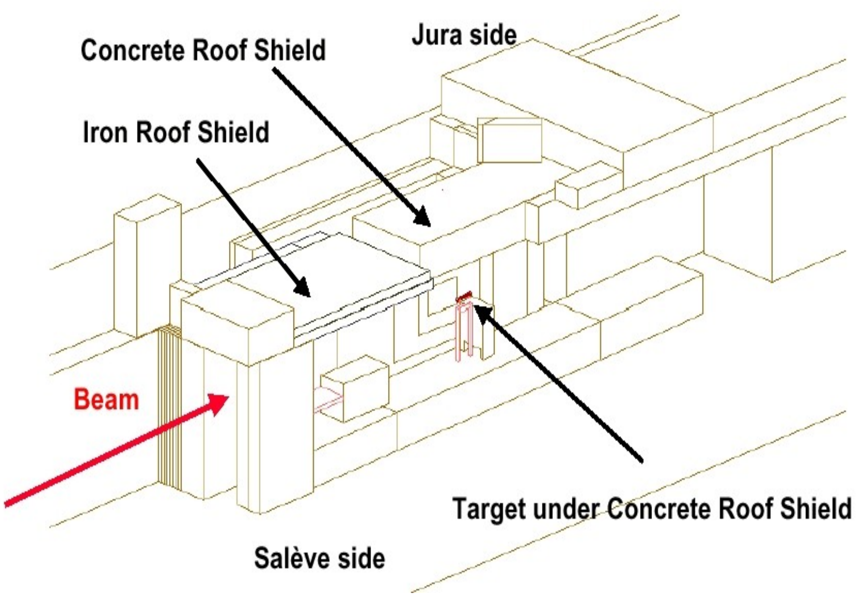


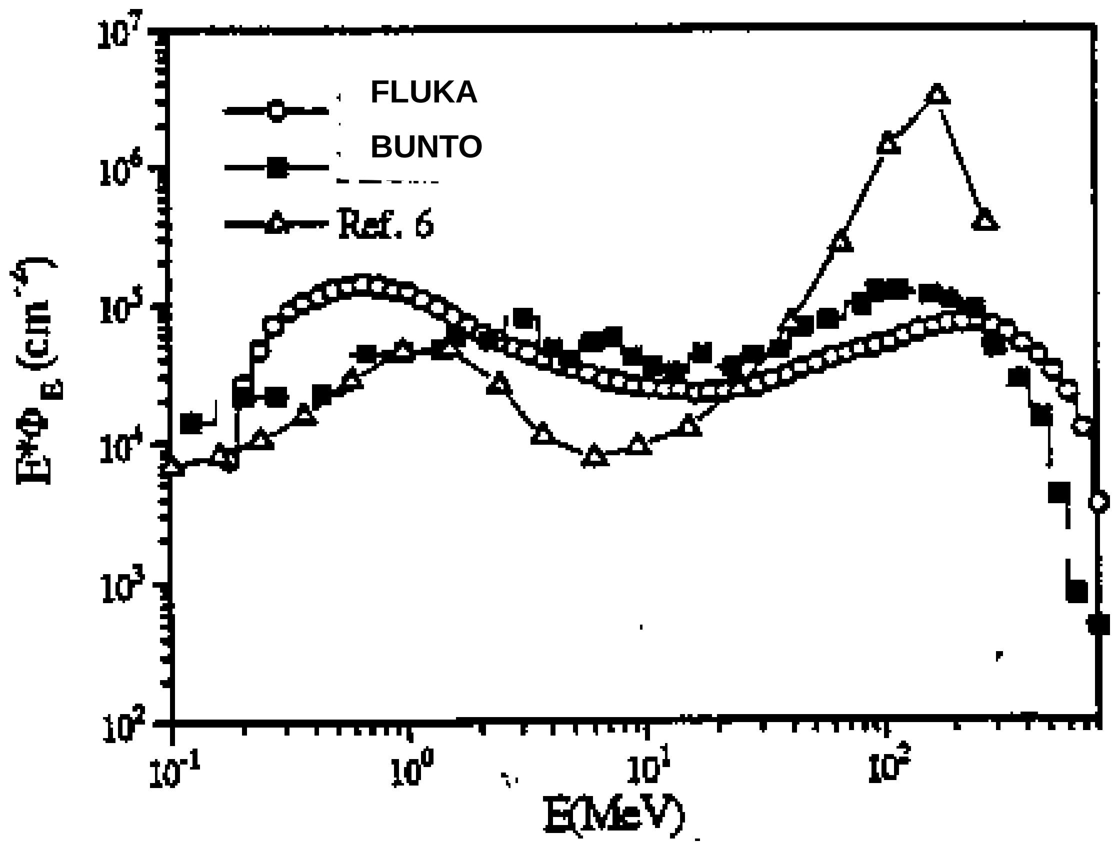


Test at CERF faciity

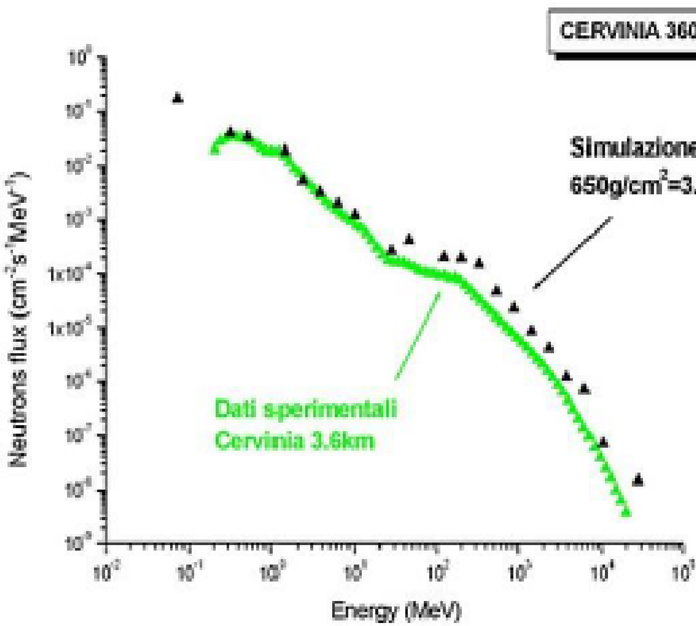
High energy neutrons 20 MeV-100 GeV

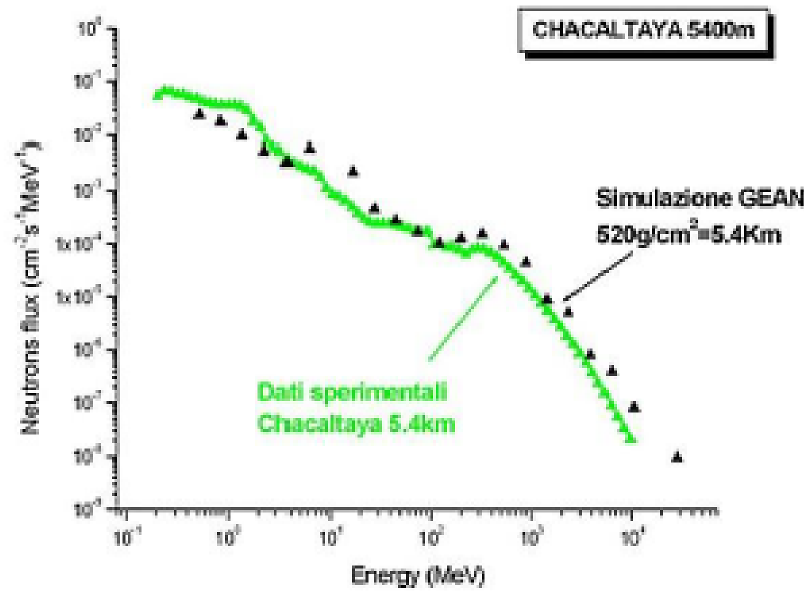
- The calibration of the passive detector system has been performed at CERN (T14 position, H-6SPS beam): this facility is a reference field for the calibration of neutron detection systems to be used in the cosmic ray field.
- The passive detector results, unfolded with the BUNTO code, are compared with the FLUKA simulation of the experim

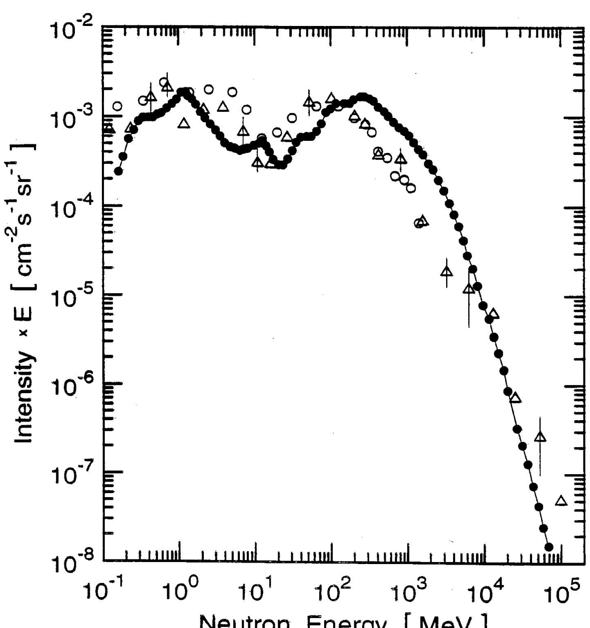




Neutron spectra evaluated by passive spectrometer







Manfredotti C, Zanini A.,et al. Cosmic Rays at Earth
Editor P.K.F. Grieder *pp 207-209*
ISBN: 9780444507105
Elsevier Science, July 2001

Neutron detector set

- Bubble detector BDT — thermal neutrons
- Bubble detector BDT shielded — epithermal neutrons
- Bubble detector BDS-10 — intermediate neutrons

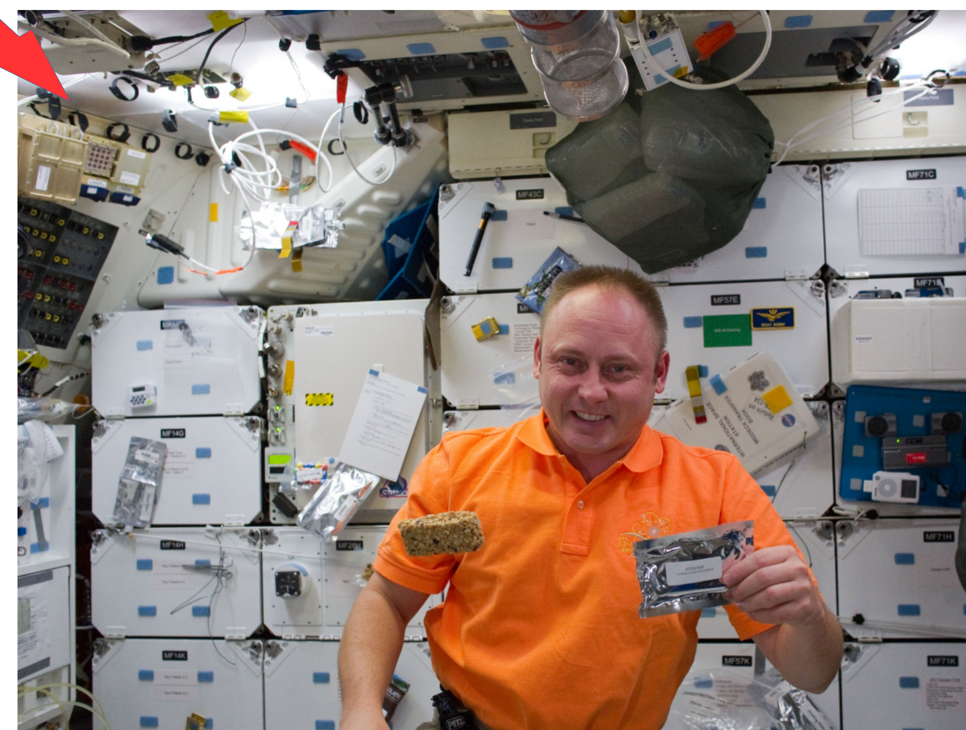
  Polycarbonate foils — fast neutrons
- Fission Bi209 stack — relativistic neutrons

Experimental measurements

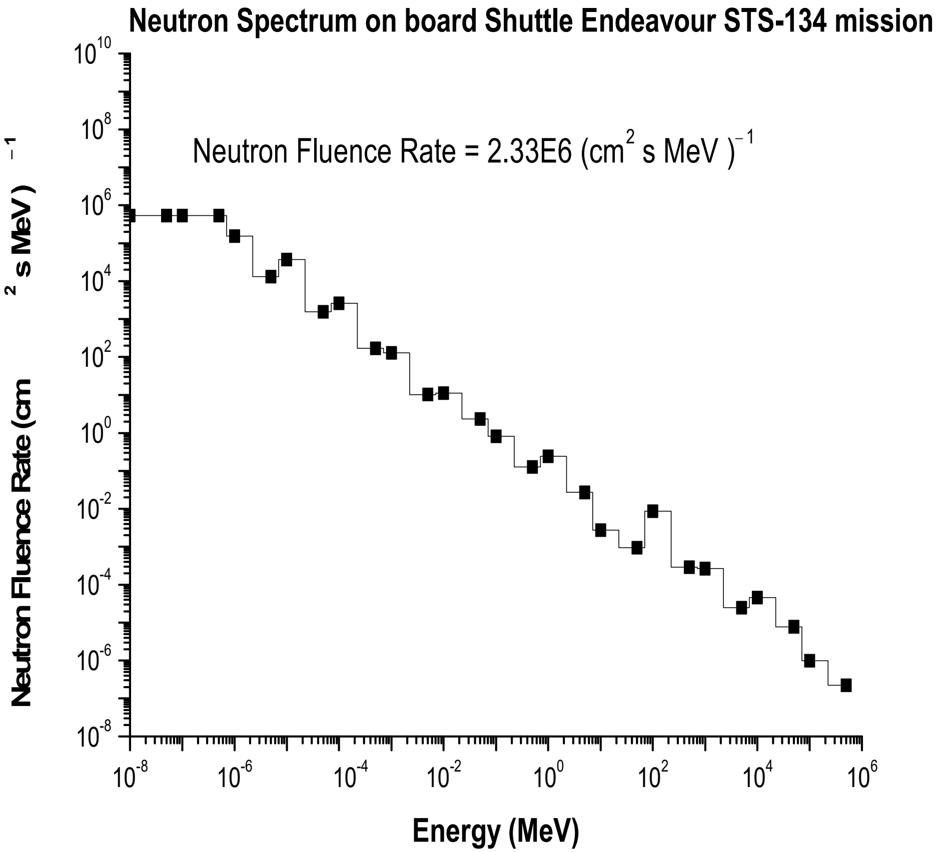
SHUTTLE STS134 MISSION

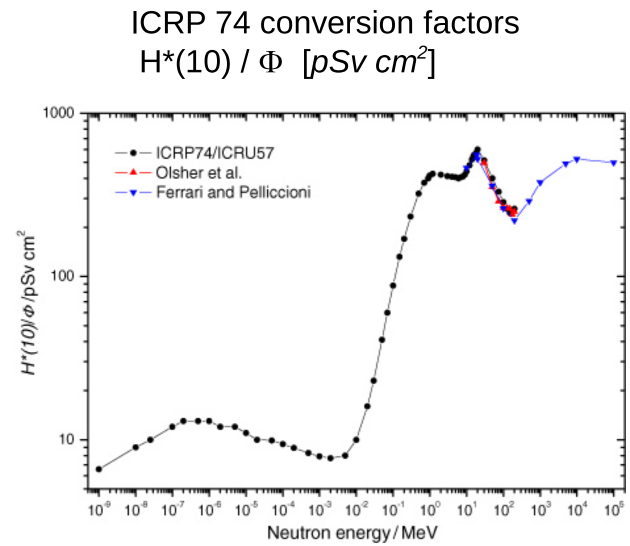
NEUTRON DETECTORS INSIDE ENDEAVOUR SHUTTLE

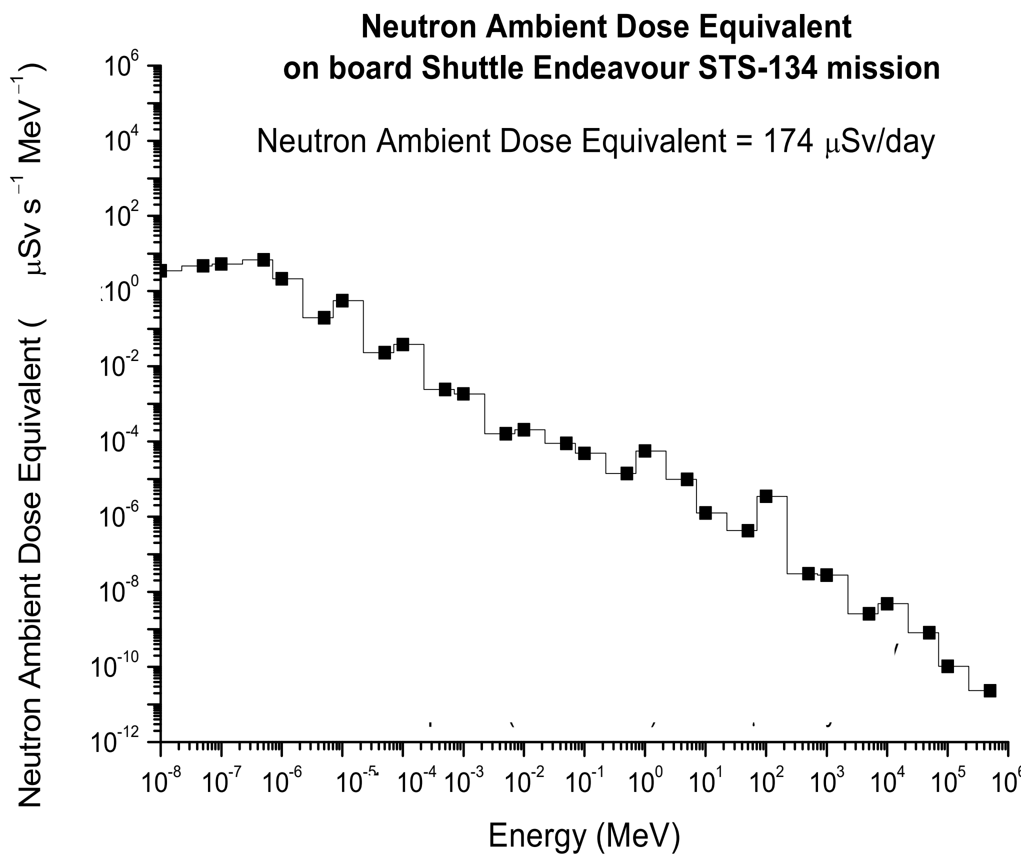
- Bubble detectors
  - BDT — thermal neutrons
  - BDT shielded — epithermal neutrons
  - BDS-10 — fast neutrons
- Fission Bi209 stack — relativistic neutrons



RESULTS

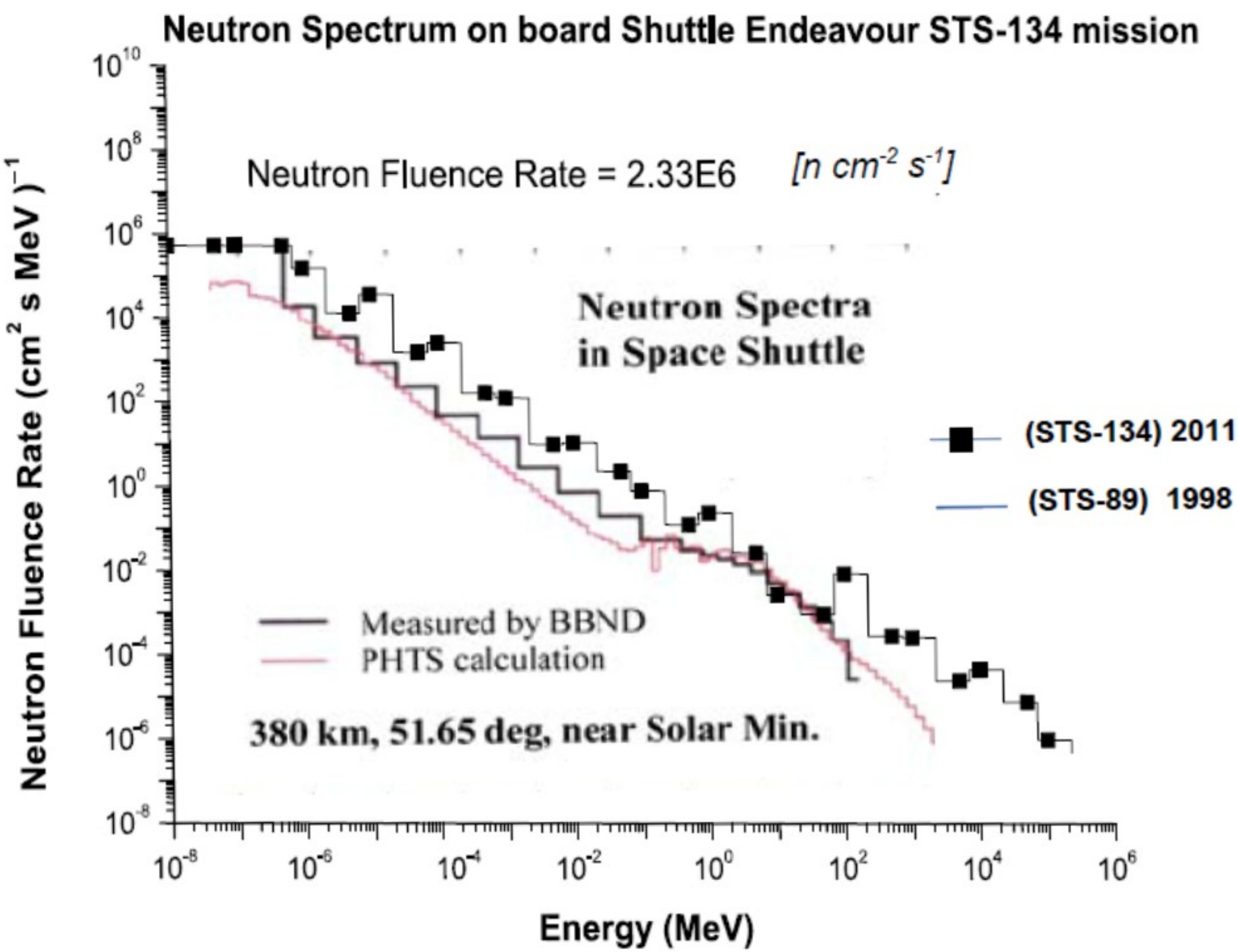






Neutron Ambient Dose Equivalent rate:
174 +- 38 μSv/day

Neutron spectra comparison **STS-134** **STS 89**



STS-134 (16/5-1/6/2011)

51,65°
ISS station

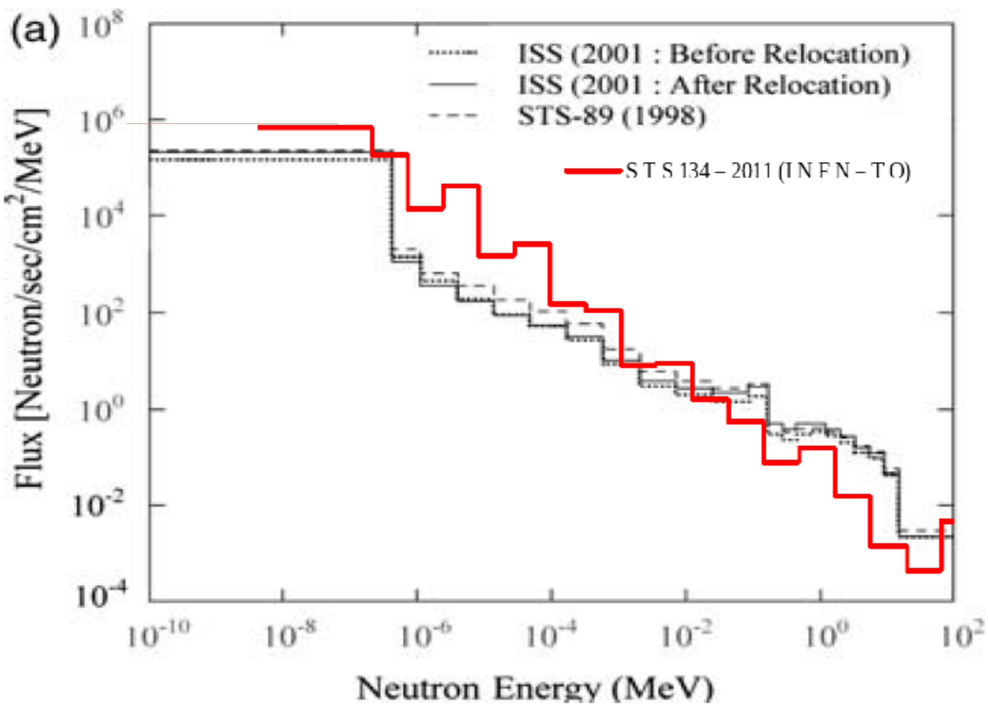
STS -89 (22/1 – 31/1/1998)

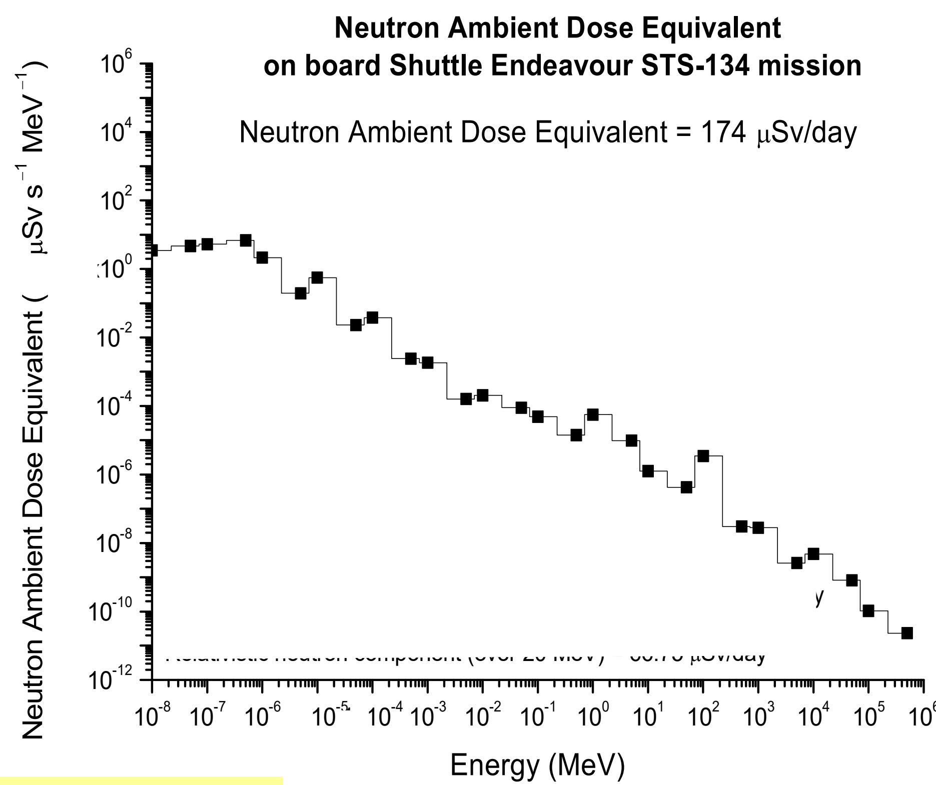
51,65 °
MIR station

(1,2)

1) Koshiishi, H. Evaluation of the neutron radiation environment inside the International SpaceStation based on Bonner Ball neutron detector experiment. Radiat. Meas. 42, 1510–1520 (2007).

2) B.J. Lewis et al., Review of bubble detector response characteristics and results from space Radiation Protection Dosimetry 150(1):1-21 · September 2011



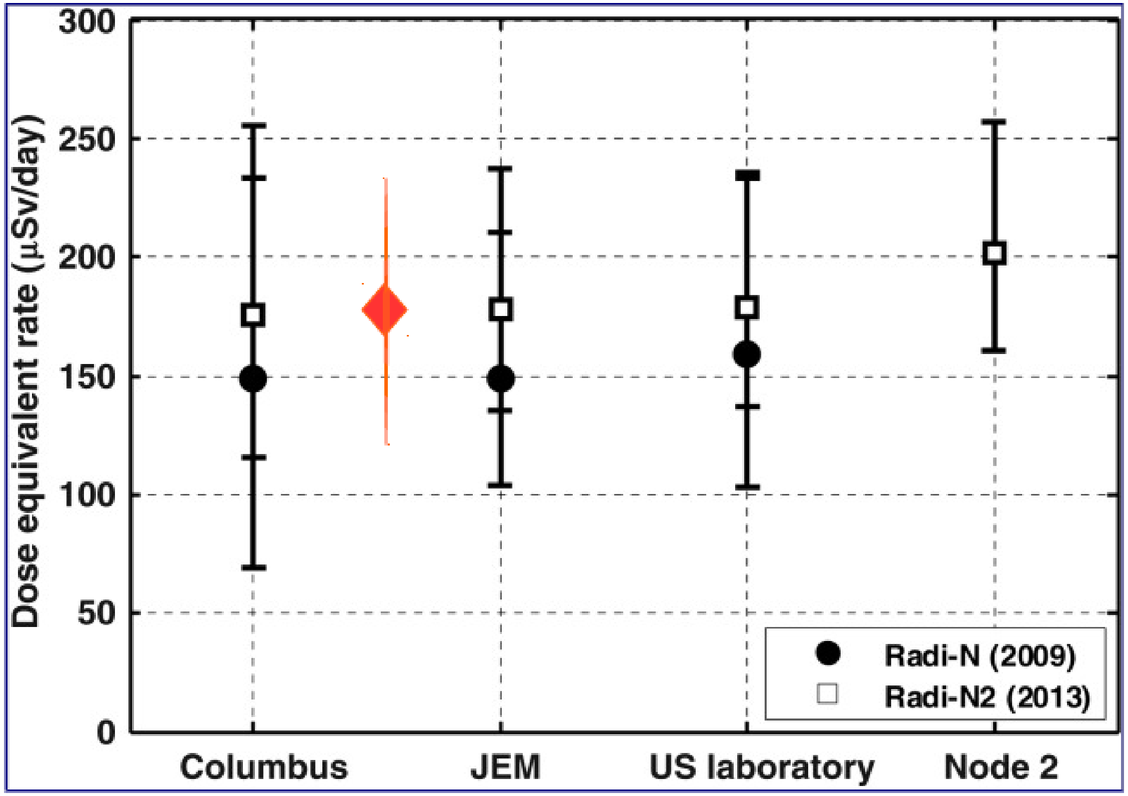


SHUTTLE ENDEAVOUR STS 134

H*(10) 0.025 eV -100 GeV

BDT	(0.025eV-10keV)	14 +- 3 µSv/d
BDPND	(10keV-20MeV)	93 +- 20 µSv/day
Stack Bi209	(20MeV-200GeV)	67+- 15.4 µSv/day

H*Total = 174 +- 38 µSv/day



Measurements performed in various positions of ISS with space bubble-detector spectrometer (SBDS).

December 2012 -October 2013.

M.B. Smith et al., Bubble-detector measurements of neutron radiation in the international space station: ISS-34 to ISS-37. 2016 Feb; Rad. Prot.Dos. 168(2): 154–166.

◆ **Endeavour STS 134**

CONCLUSIONS

A passive detector system , based on bubble detectors and track detectors,
Has been used to evaluate the Neutron Ambient Dose Equivalent in a wide energy range (thermal- 100 GeV) on board of Endeavour shuttle STS 134.

The obtained values for H*(10) are in agreement both with previous neutron energy spectra measurements (Koshiishi, H., 2007) and with recent integral measurements
(M.B.Smith et al., 2016)
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Thank you for your attention