Spectral Correction Factors for Conventional Neutron Dose Meters Used in High-Energy Neutron Environments

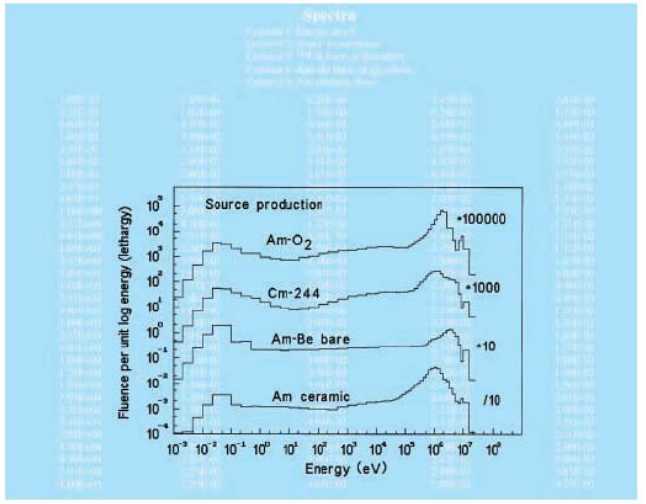
A complete survey of all neutron spectra in IAEA-TRS-403

RadSynch2015, DESY Hamburg, Germany (June 3-5, 2015)

Rong-Jiun Sheu
NES/ESS, NTHU

Motive

- Neutron spectra
  - The accuracy of neutron dose evaluation largely depends on the knowledge of neutron energy distributions.
  - Neutron spectra in workplaces differ from each other, as shown in IAEA-TRS-403.
  - $\phi(E) \rightarrow E$ or $H^*(10)$
  - In most situations, it is difficult to accurately determine the neutron spectrum in the entire range of energies.
  - Reasonably conservative estimates of neutron dose rates in workplaces are sufficient for radiation protection purpose.



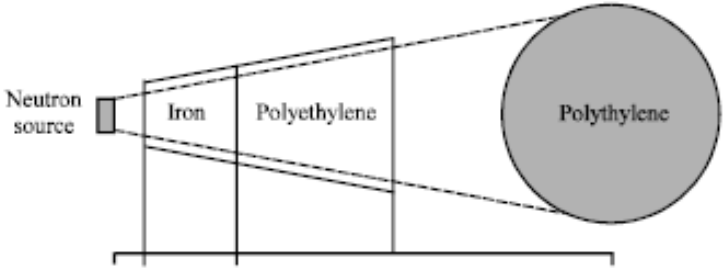
TECHNICAL REPORTS SERIES No. 403

Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes

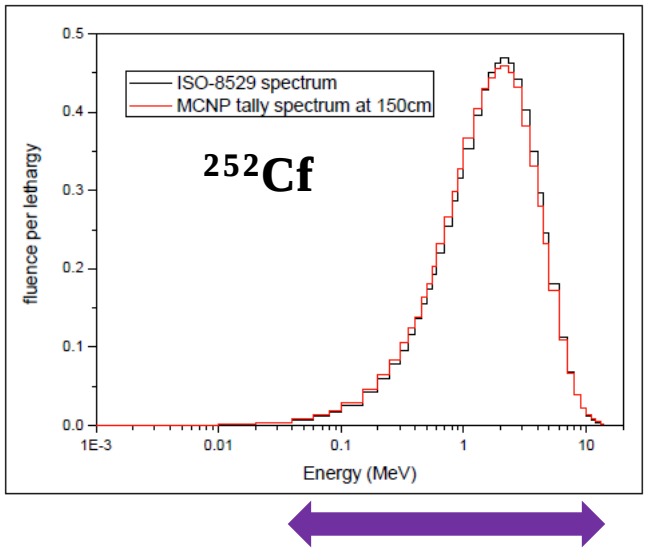
Supplement to Technical Reports Series No. 318

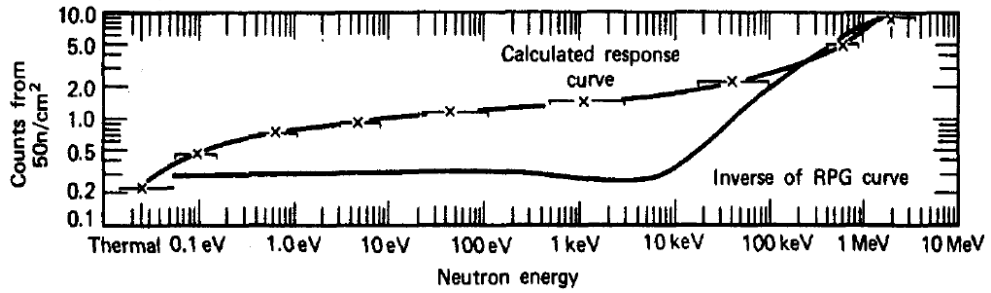
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2001

Motive



- Neutron dose meters
  - These detectors used for radiation protection purpose are commonly calibrated with ^{252}Cf and then are used in various workplaces.

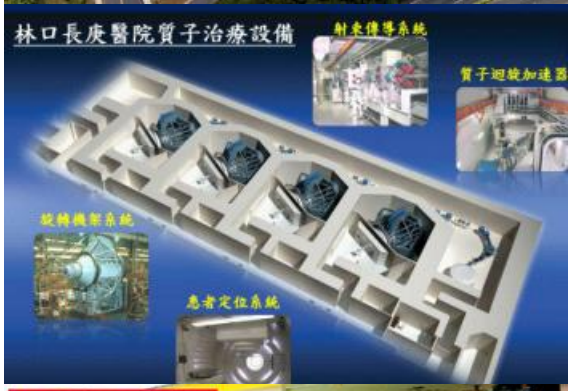




A workplace-specific correction factor is suggested to consider the effect of neutron spectrum.

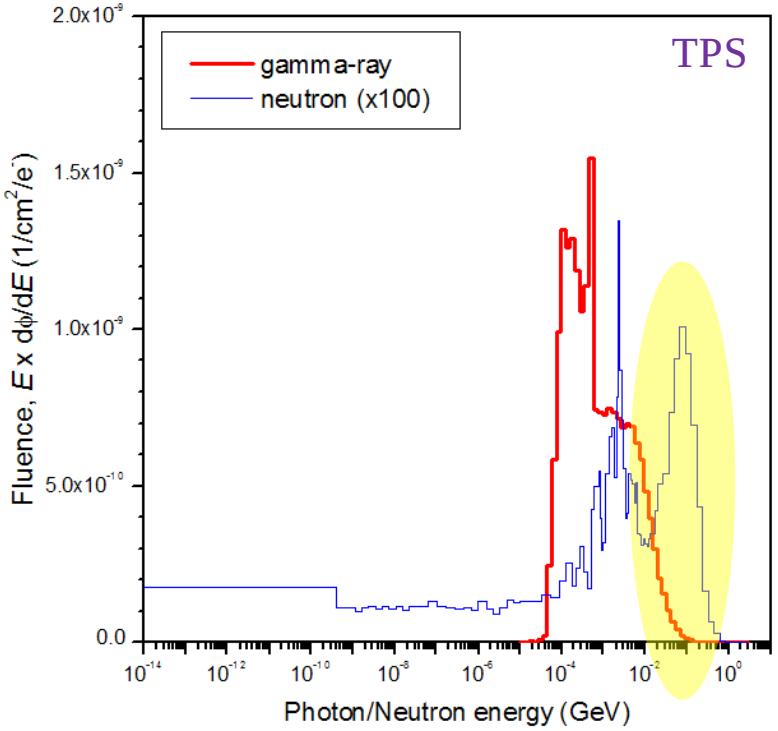
New accelerator facilities in Taiwan

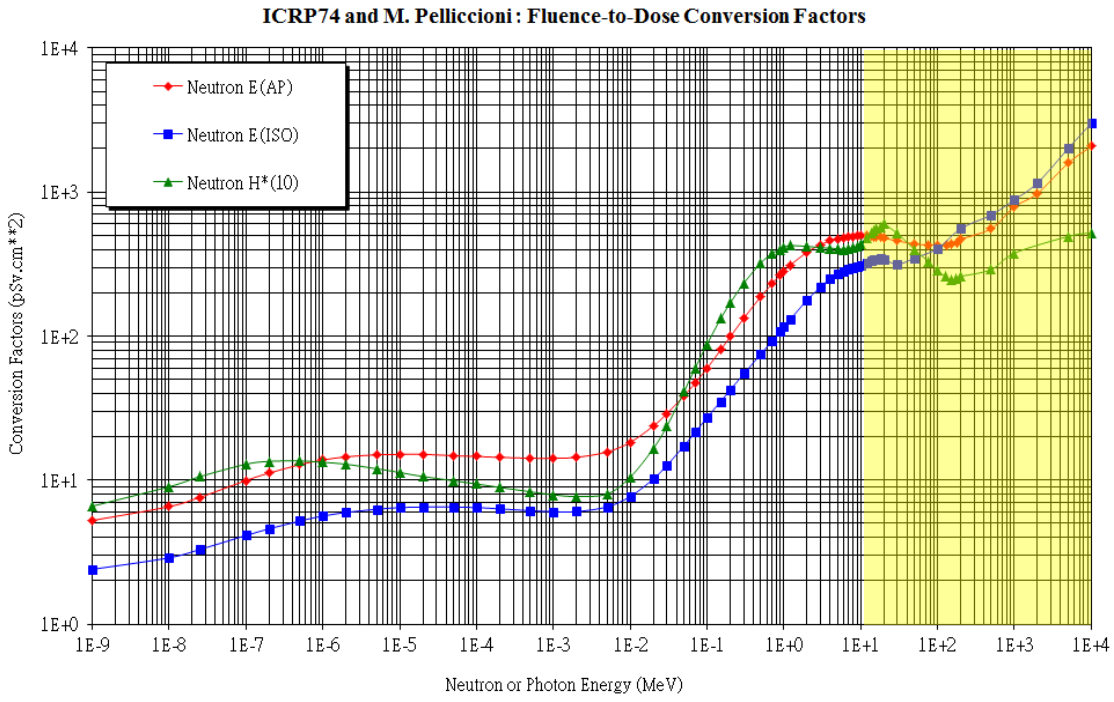
- Taiwan Photon Source
  - NSRRC, Hsinchu
  - 3 GeV electron synchrotron
  - Commissioning
- Proton therapy center
  - Chang Gung Memorial Hospital, Linkou
  - 235 MeV proton cyclotron
  - Clinical trials
- Heavy-ion therapy center
  - Veterans General Hospital, Taipei
  - 400 MeV/A carbon machine
  - Planning



High-energy neutrons (E_n>10 MeV)

- High-energy accelerators → high-energy neutrons
  - Even account for only a small fraction of total neutrons in workplaces, high-energy neutrons may contribute substantially to the total dose.

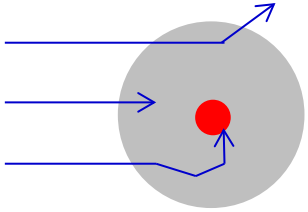




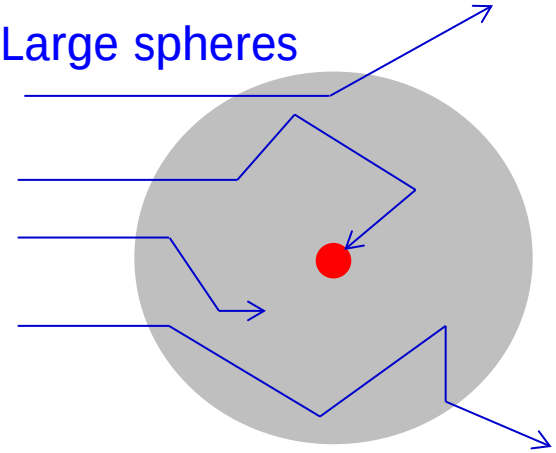
High-energy neutrons

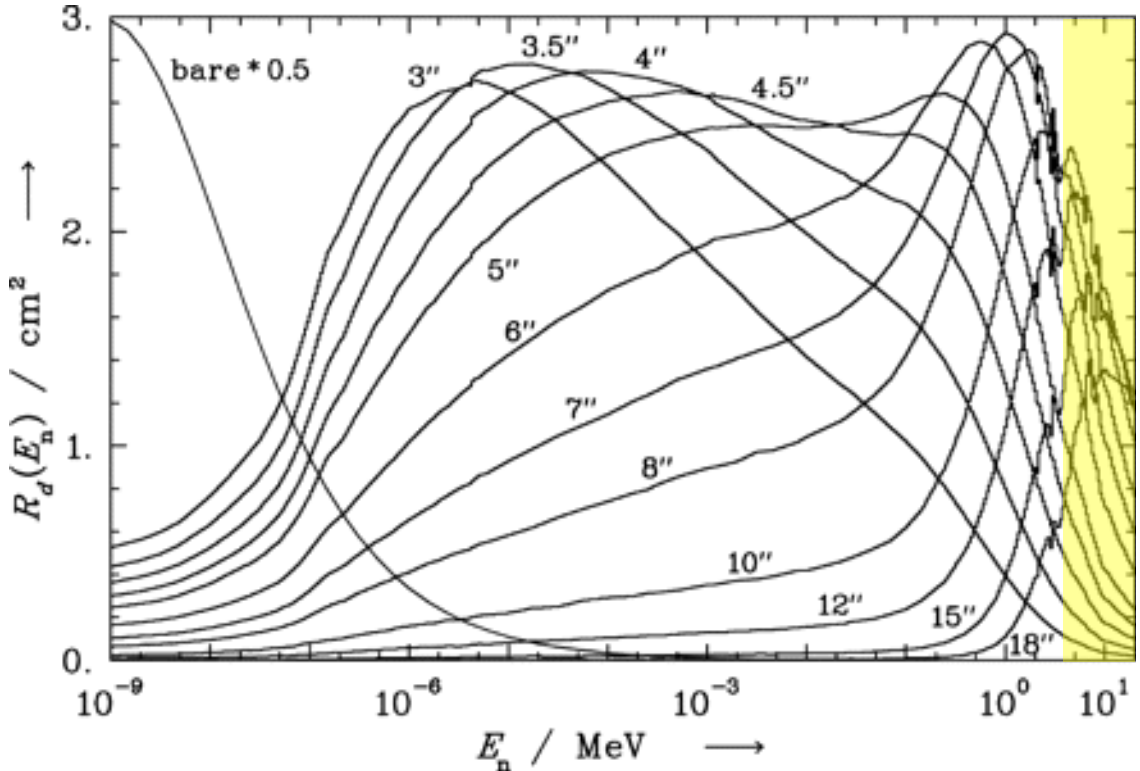
- A key issue in neutron dose meter's response
  - High-energy neutrons contribute substantially to the dose fraction but result in only a small or negligible response in most conventional moderated-type neutron detectors.

(A) Small spheres



(B) Large spheres

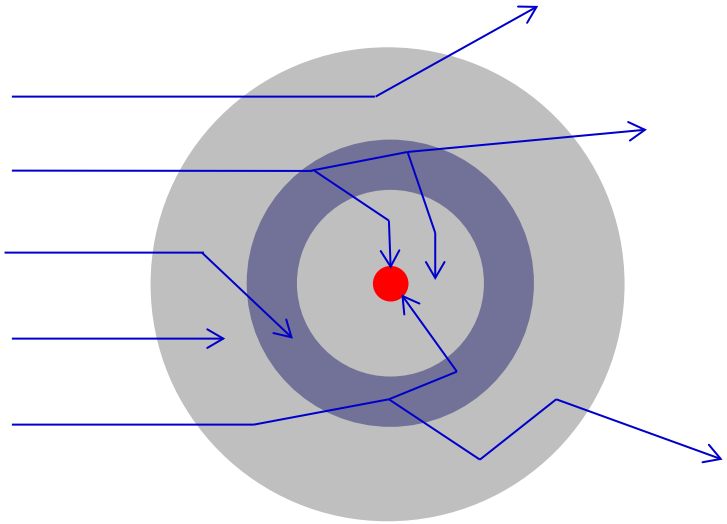


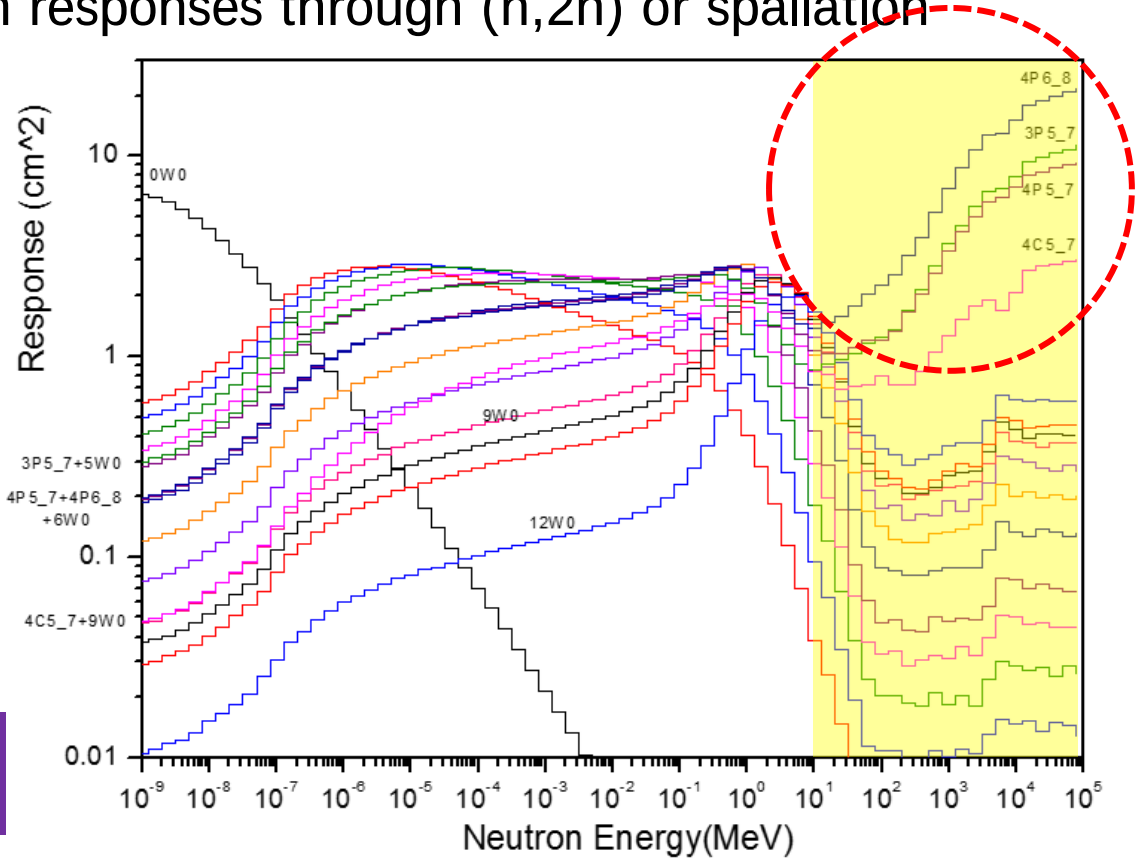


High-energy neutrons

- Extended-range neutron detectors
  - By embedding heavy metals in moderators to increase high-energy neutron responses through (n,2n) or spallation

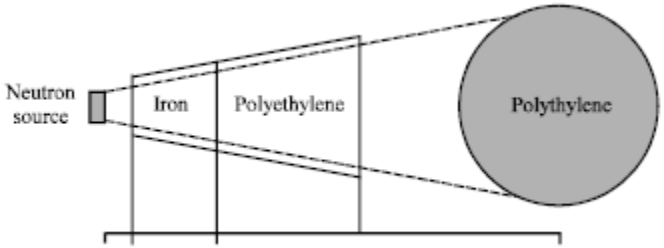
(C) Metal-embedded spheres





More expensive and heavier than conventional neutron dose meters!

Analysis methods



Neutron detector calibration (^{252}Cf) & workplace-specific correction factors

Neutron calibration room

Cf-252 spectrum

Detector response, net CR (cps)

Known DR: H*(10) (μSv/h)

DCF_{cf252} (μSv/h/cps)

Neutron field at workplace

Spectrum of concern

Det response function $\Re(E)$ (cm^2)

Conversion H*(10) (μSv·cm^2)

Predicted CR (cps)

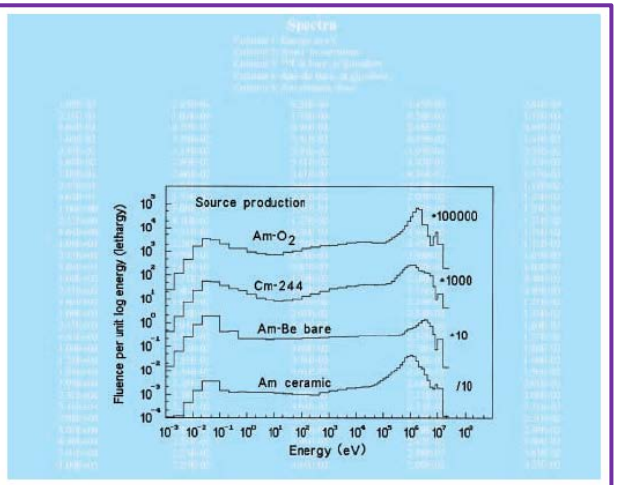
$H^*(10)_{cf252}$ (μSv/h)

$H^*(10)_{spe}$ (μSv/h)

Spectral correction factor: $H^*(10)_{spe}$ / $H^*(10)_{cf252}$

Note:

- DR: dose rate
- CR: counting rate
- DCF: dose calibration factor



TECHNICAL REPORTS SERIES No. 403

Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes

Supplement to Technical Reports Series No. 318

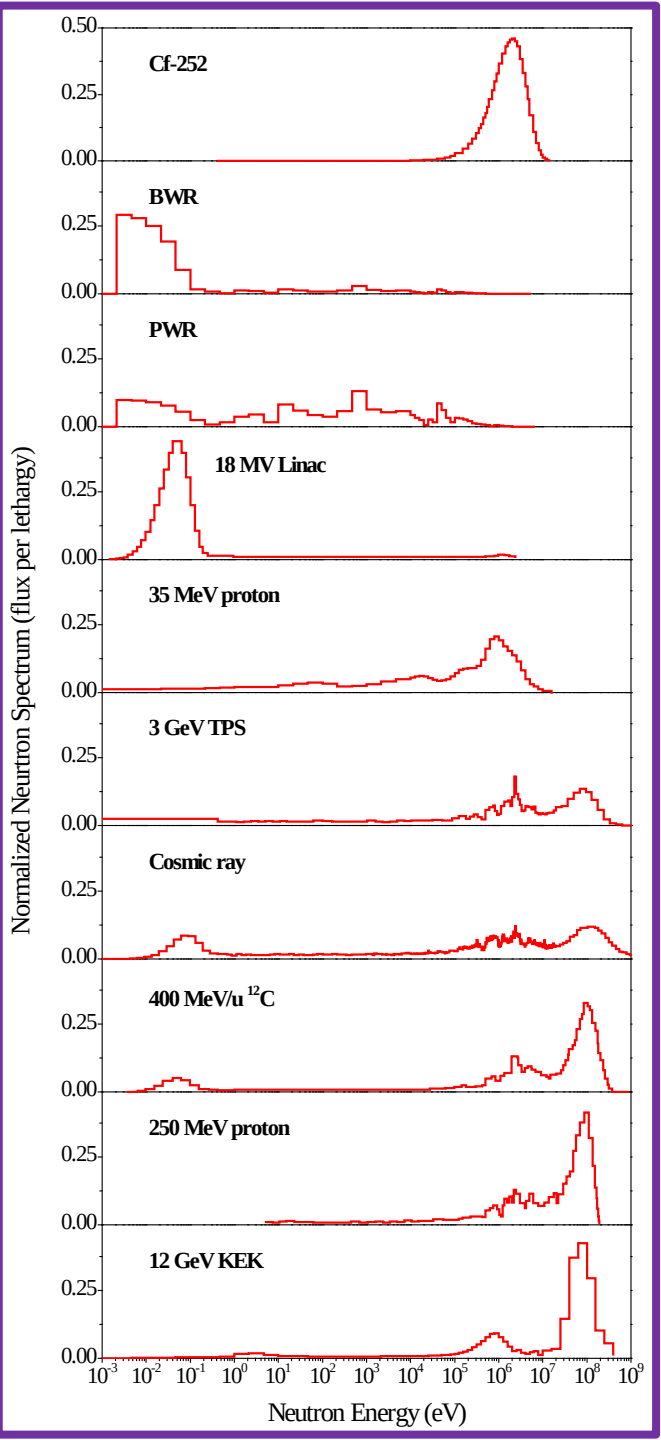
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2001

243 neut. spectra (123 spectra with neutrons E_n > 10 MeV)

Neutron spectra in workplaces

- How to characterize high-energy neutrons in workplaces?
- If the neutron spectrum is known, either by calculations or measurements, then the percentage of high-energy neutrons in the spectrum is a good index.
- RHS shows 10 neutron spectra covering a wide range of neutron fields, presented in the order of increasing percentages of high-energy neutrons in the spectra.
- High-energy neutrons expected to cause varying degrees of dose underestimation in conventional neutron dose meters
- Quantitatively evaluate the effect of neutron spectrum on the responses of neutron dose meters calibrated with ^{252}Cf

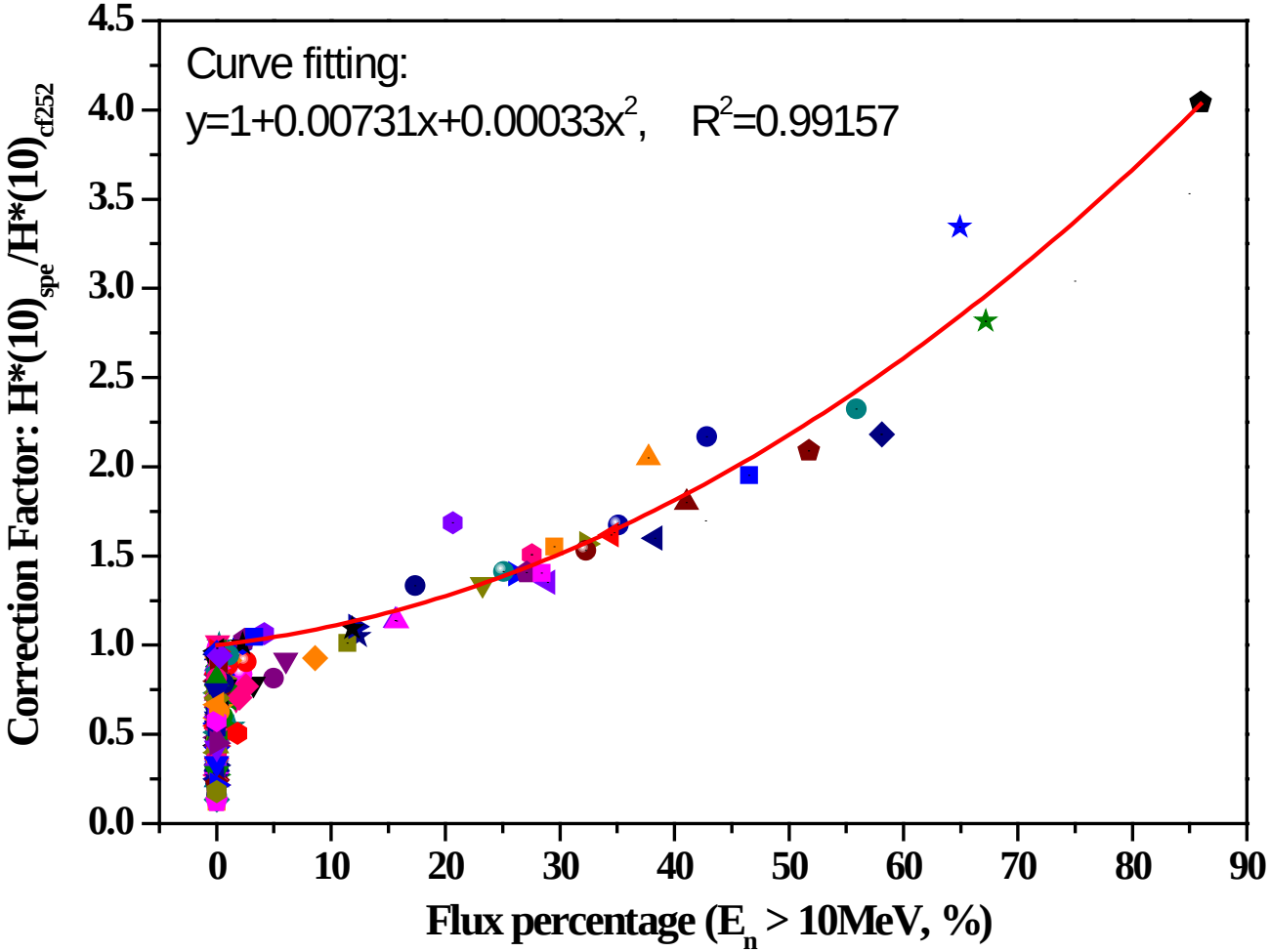
Neutron spectra at workplaces	Thermal neutrons $E_n < 1$ eV	Epithermal neutrons 1 eV $< E_n <$ 10 keV	Fast neutrons 10 keV $< E_n <$ 10 MeV	High-energy neutrons $E_n >$ 10 MeV
^{252}Cf	0.0%	0.1%	99.9%	0.0%
BWR	86.7%	11.3%	2.0%	0.0%
PWR	36.4%	52.8%	10.8%	0.0%
18 MV Linac	84.8%	9.1%	6.1%	0.0%
35 MeV proton	10.3%	28.4%	61.1%	0.2%
3 GeV TPS	27.0%	14.0%	31.4%	27.6%
Cosmic ray	19.1%	15.2%	33.4%	32.3%
400 MeV/u ^{12}C	11.0%	7.4%	29.9%	51.7%
250 MeV proton	0.0%	8.1%	33.8%	58.1%
12 GeV KEK	2.3%	8.4%	22.1%	67.2%



Spectral correction factors

as a function of the percentage of high-energy neutrons in the spectrum

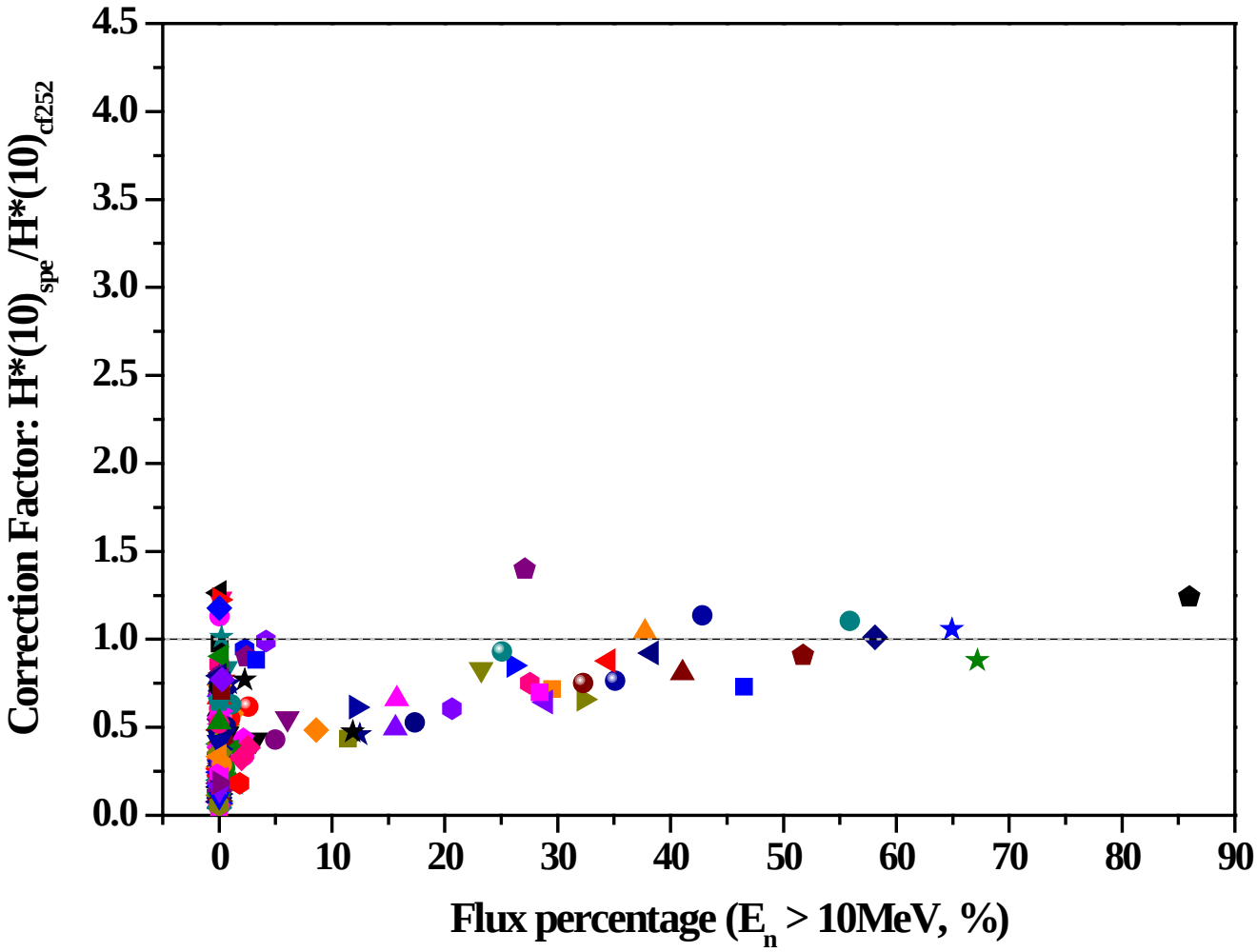
9” Bonner sphere



Spectral correction factors

as a function of the percentage of high-energy neutrons in the spectrum

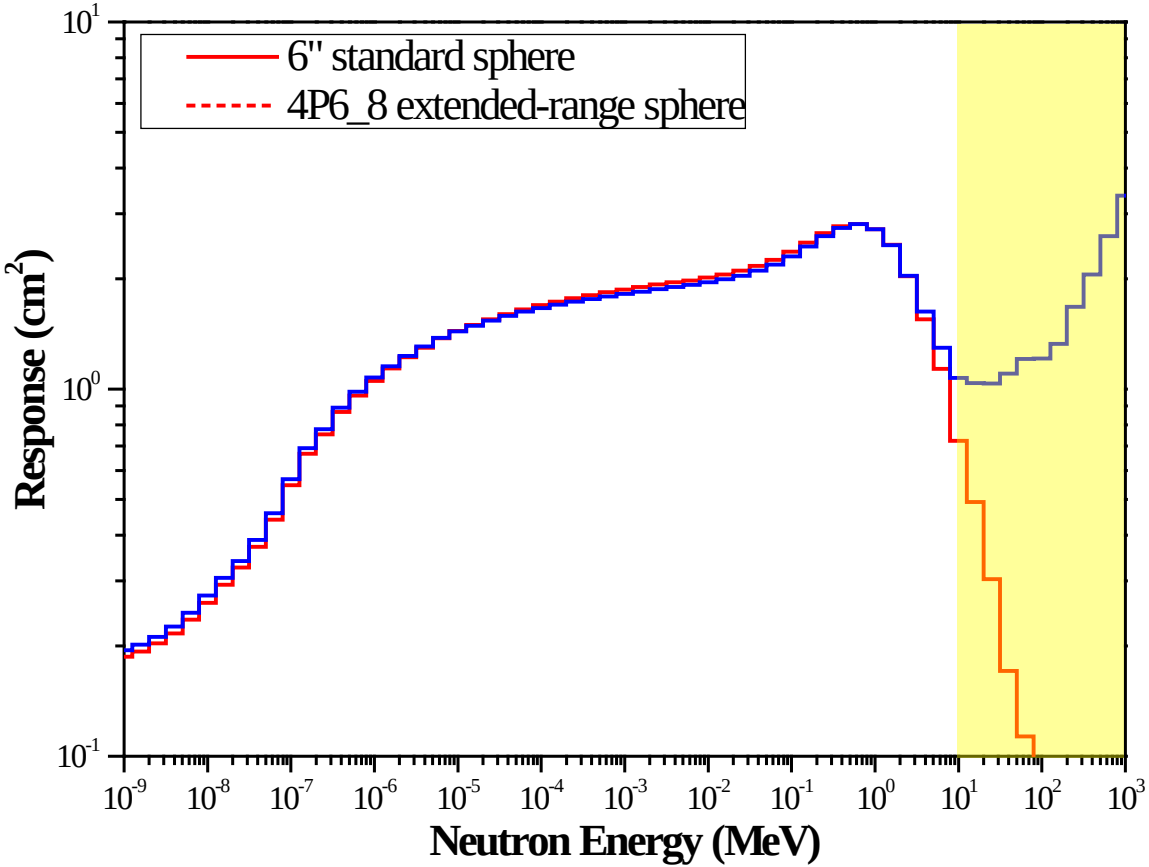
4P6_8 lead-embedded sphere



Neutron spectra in workplaces

- What if the percentage of high-energy neutrons at the location of interest is not known?

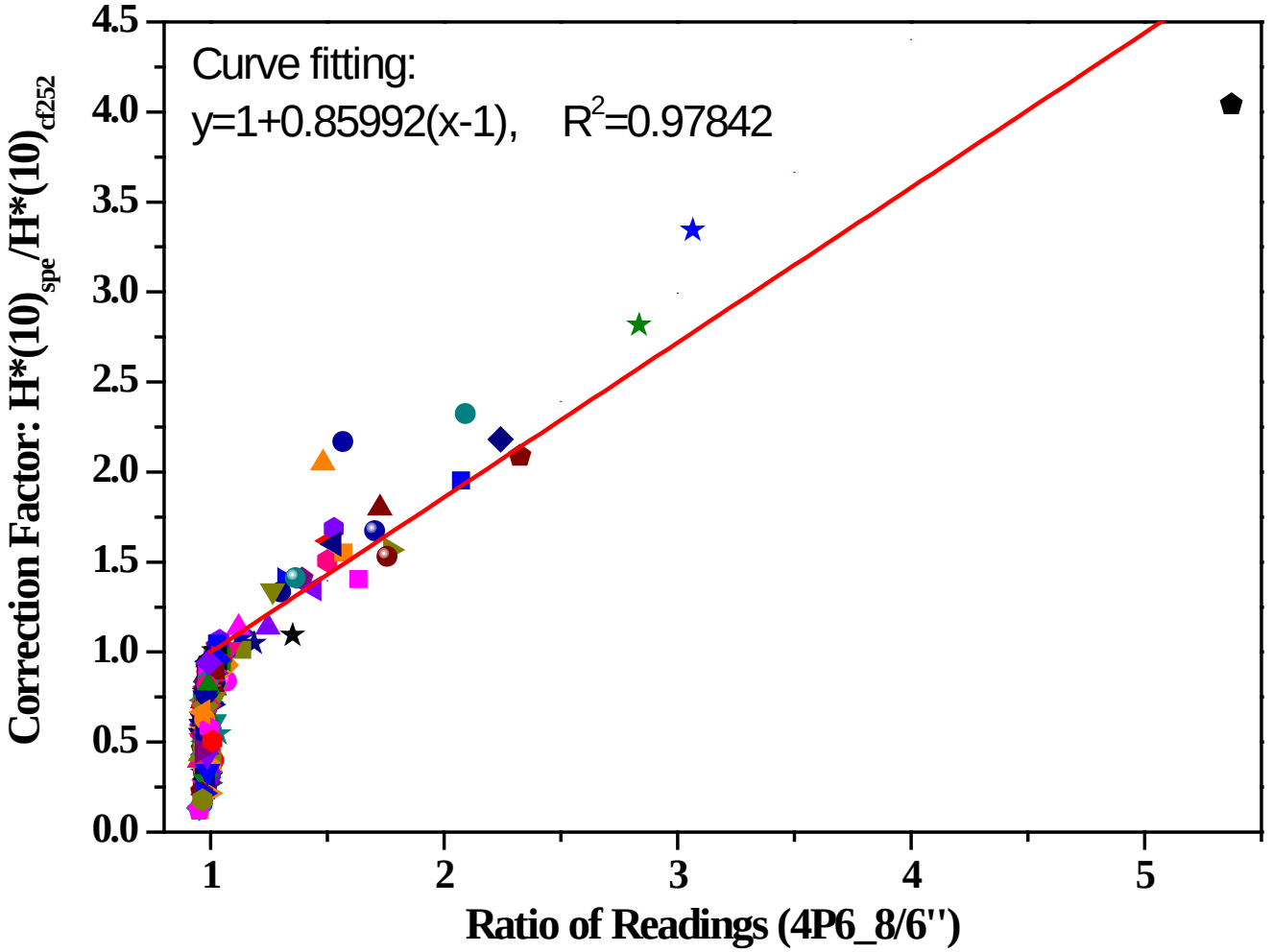
- Determining the entire span of neutron spectra in workplaces through measurements or high-fidelity calculations is time-consuming and needs expertise.
- We proposes another practical approach as an alternative to estimate the spectral correction factor based on the ratio of the measured responses of two Bonner spheres (a conventional sphere and an extended-range sphere). Best choice is the ratio (4P6_8/6”), a good indicator of the significance of high-energy neutrons in workplaces.



Spectral correction factors

as a function of the ratio between 2 measured responses (4P6_8 vs. 6”)

9” Bonner sphere



Conclusions

- Neutron dose meters are commonly calibrated with ^{252}Cf and then used in various workplaces. A workplace-specific correction factor is suggested, especially for high-energy neutrons.
- Hundreds of neutron spectra in IAEA-TRS-403 representing various neutron environments was used to study the effect of the neutron spectrum on the accuracy of dose measurements.
- The extended-range neutron detectors perform well in dose measurements in high-energy neutron environments, while appropriate spectral correction factors (~1 to 4) are necessary for conventional neutron dose meters, depending on the extent to which high-energy neutrons are present in radiation fields.
- Fitting curves of the spectral correction factors as a function of the percentage of high-energy neutrons or as a function of the ratio between the measured responses of two Bonner spheres (4P6_8 versus 6") were given.
- These results provide useful information to improve the accuracy of dosimetric evaluations for conventional neutron dose meters used in environments with high-energy neutrons.