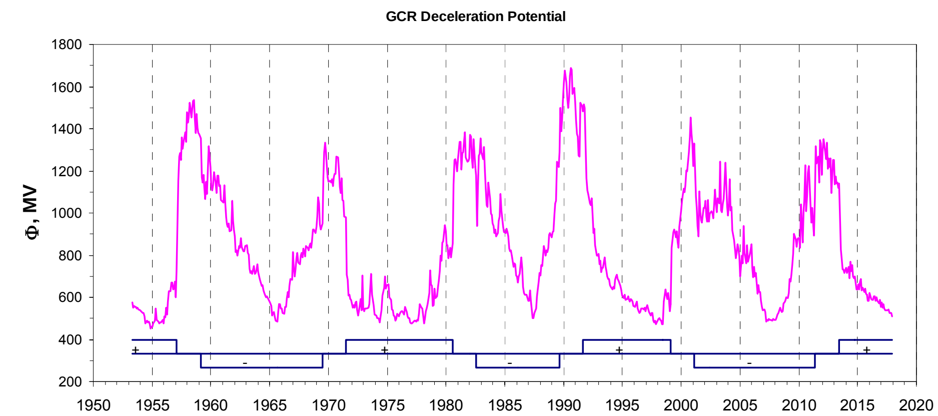
Example Solar Proton Event Data

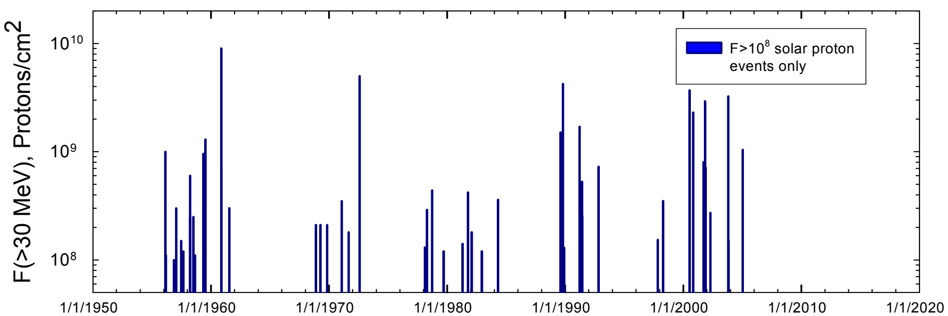
NASA JSC

August 30, 2006

M. Kim and F. Cucinotta

Times of Occurrence of Large SPE's





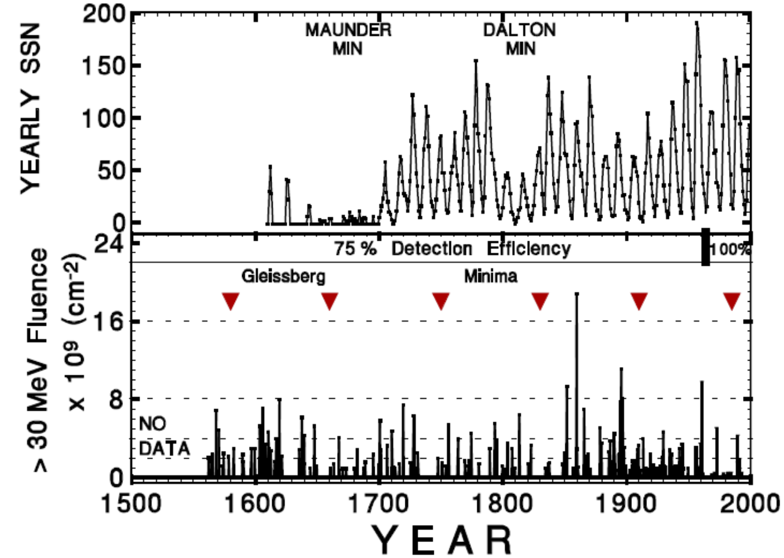


Fig. 1. The times of occurrence of >30 MeV solar proton events with fluence exceeding 1.0 x 10^9/cm^2, and the annual international sunspot numbers.

Modern Era (1956-2005)

Recent Era (1550-2000)
McKracken et al.

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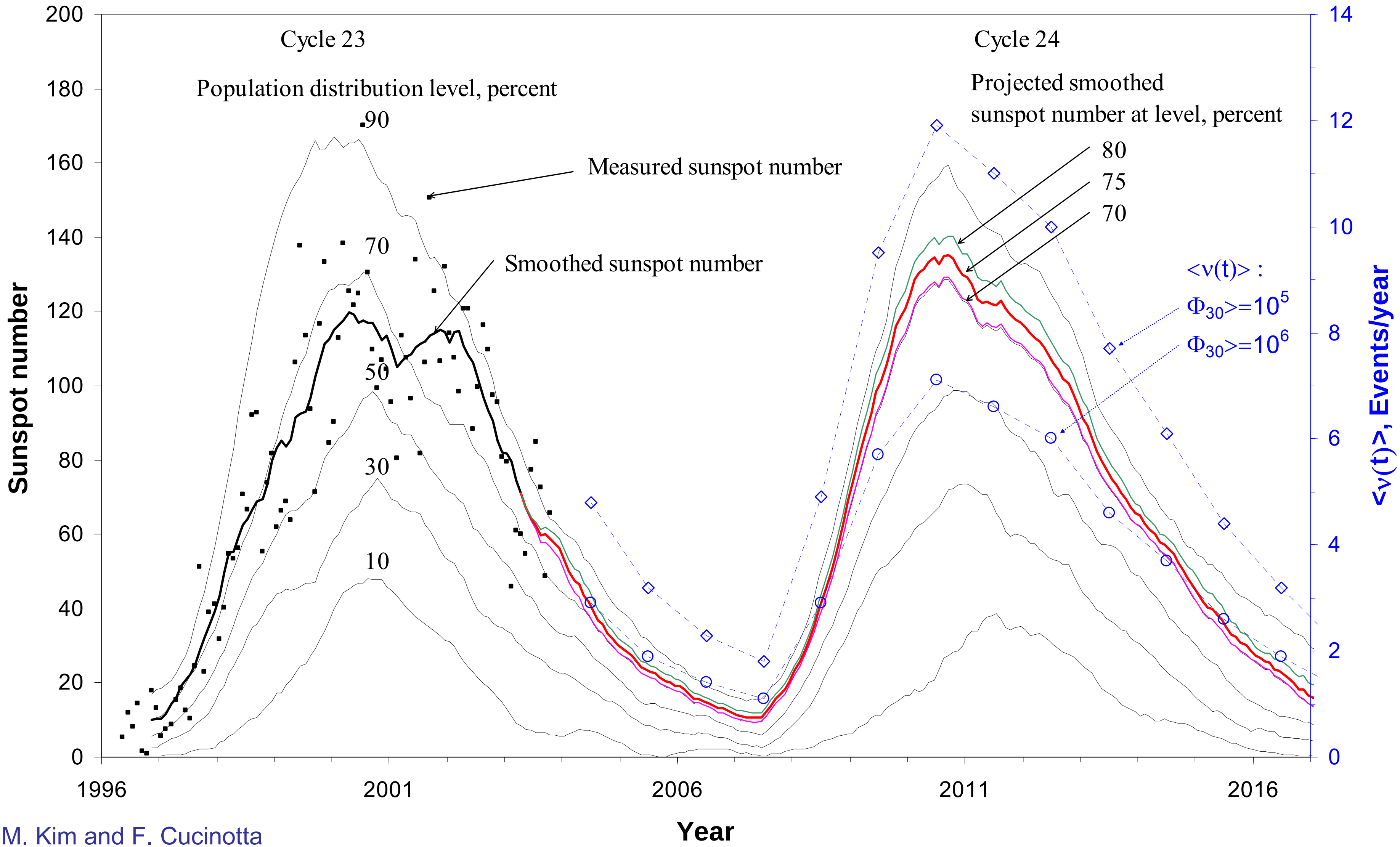
Projections of Cycles and Mean Occurrence Frequency of SPE



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Large Solar Proton Events during Solar Cycles 19-23 with $\Phi_{30} > 10^9$ protons/cm^2

Cycle	Onset Time	Φ_{30}, protons/cm^2	Time to Peak Flux, hr	Comment
19	**11/12/1960**	**9.00×10^9**	**14**	**(a), note 1**
20	**8/2/1972**	**5.00×10^9**	**69**	**(a)**
22	10/19/1989 13:05	4.23×10^9	26.9	(b)
23	7/14/2000 10:45	3.74×10^9	25.8	(b)
23	**10/26/2003 18:25**	**3.25×10^9**	**4.2**	**(b), note 2**
23	11/4/2001 17:05	2.92×10^9	33.2	(b)
19	7/10/1959	2.30×10^9	note 3	(a)
23	11/8/2000 23:50	2.27×10^9	16.1	(b)
22	3/23/1991 8:20	1.74×10^9	19.5	(b)
22	8/12/1989 16:00	1.51×10^9	15.2	(b)
22	9/29/1989 12:05	1.35×10^9	14.1	(b)
23	**1/16/2005 2:10**	**1.04×10^9**	**39.7**	**(b)**
19	**2/23/1956**	**1.00×10^9**	**note 4**	**(a)**

(a) Φ_{30} for solar cycle 19-21: data taken from Shea and Smart.
(b) Φ_{30} for solar cycle 22 and 23: calculated using corrected 5-min average proton flux of GOES measurements.
Note 1: There are large differences in the estimate of fluence in November 1960 SPE.
Data given by others are significantly smaller than this value (1.3 x 109 protons/cm2 by Freier and Webber).
Note 2: Φ_{30} for the combined 3 major peaks occurred during 10/26-11/6/2003: 3.42×10^9 protons/cm^2.
Note 3: one day later on July 11, 1959
Note 4: in the same day on February 23, 1956

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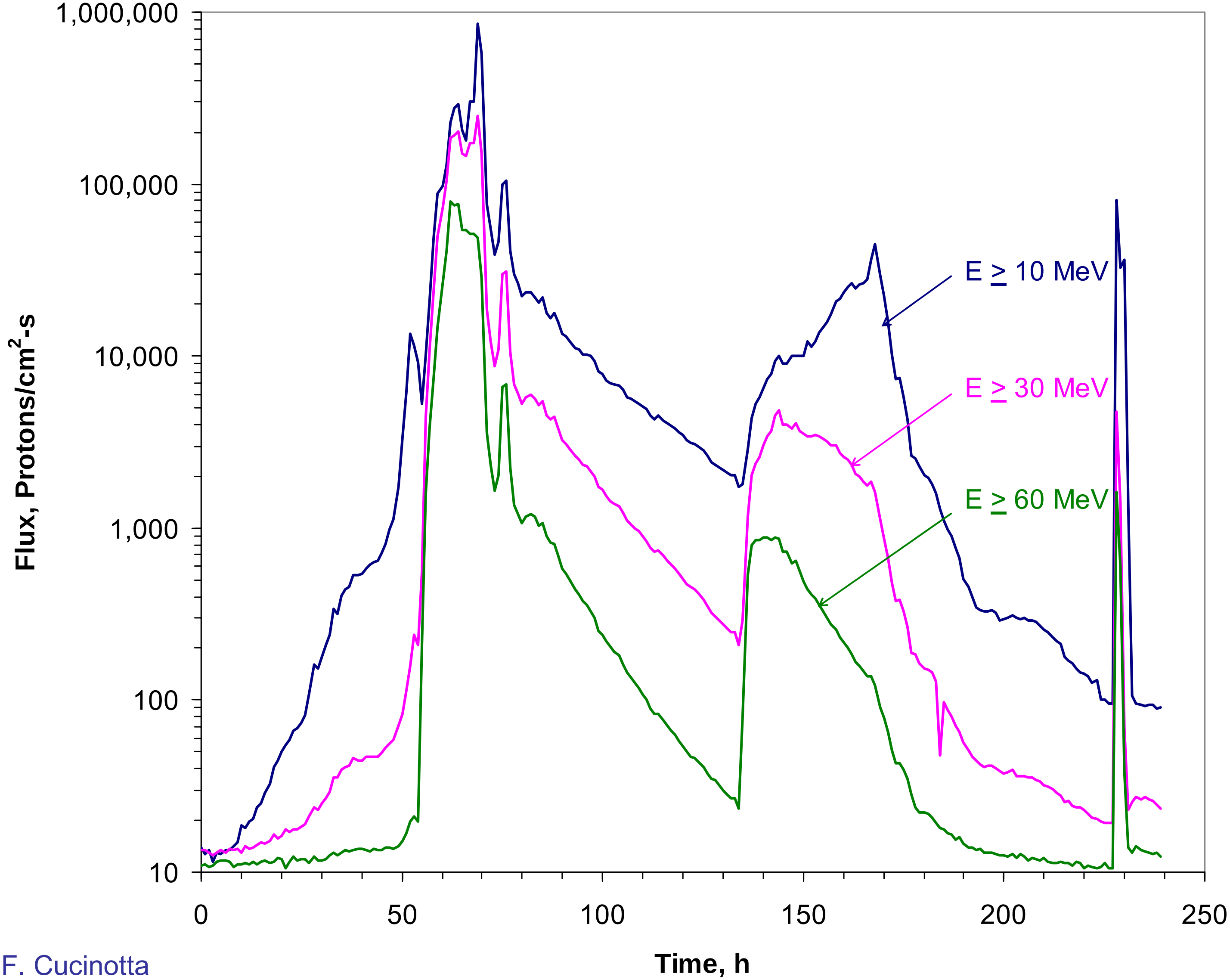
Proton Integral Flux
August 2-11, 1972 SPE



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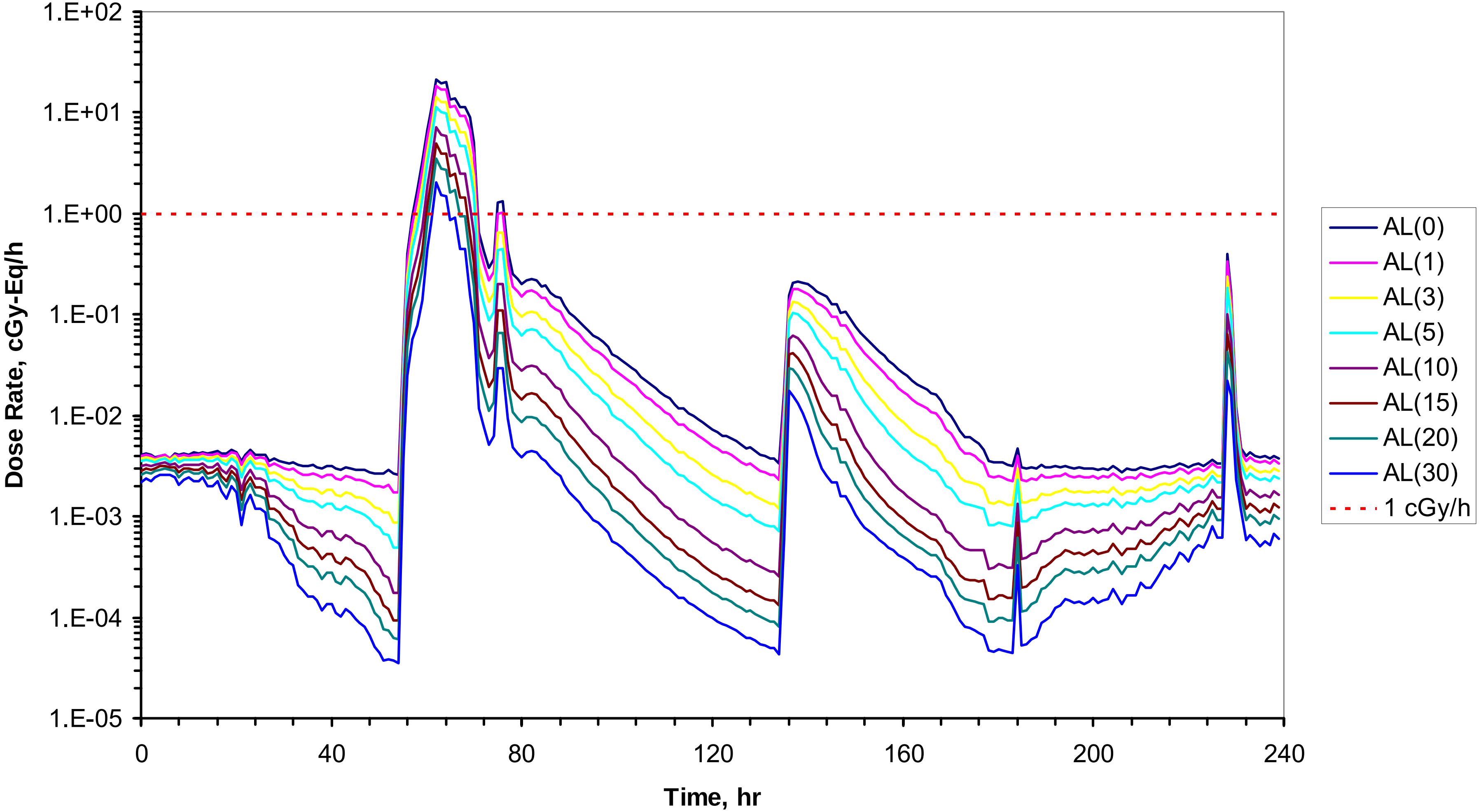
BFO Dose Rate
August 2-11, 1972 SPE



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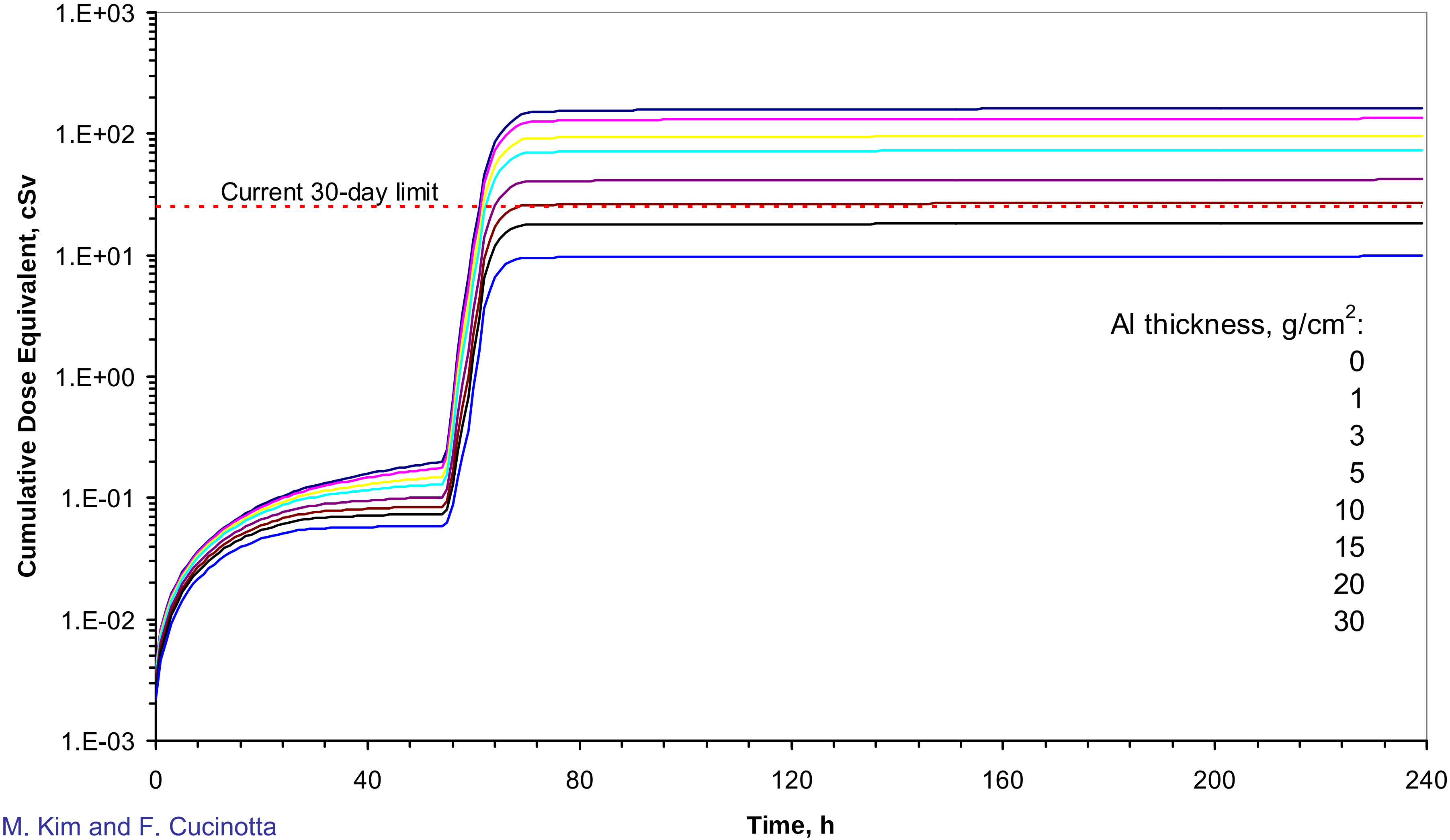
BFO Cumulative Dose
August 2-11, 1972 SPE



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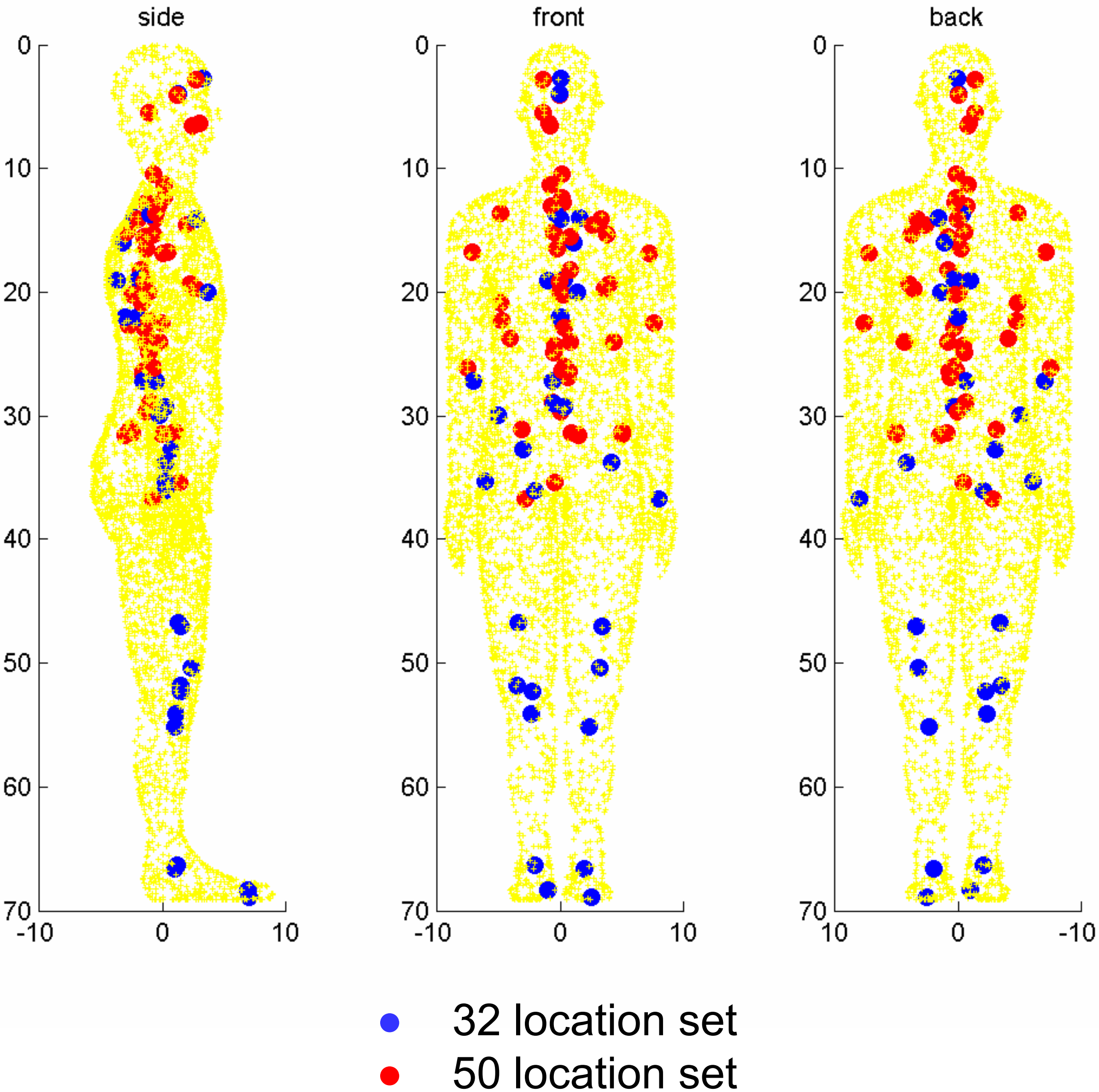
82 BFO Locations



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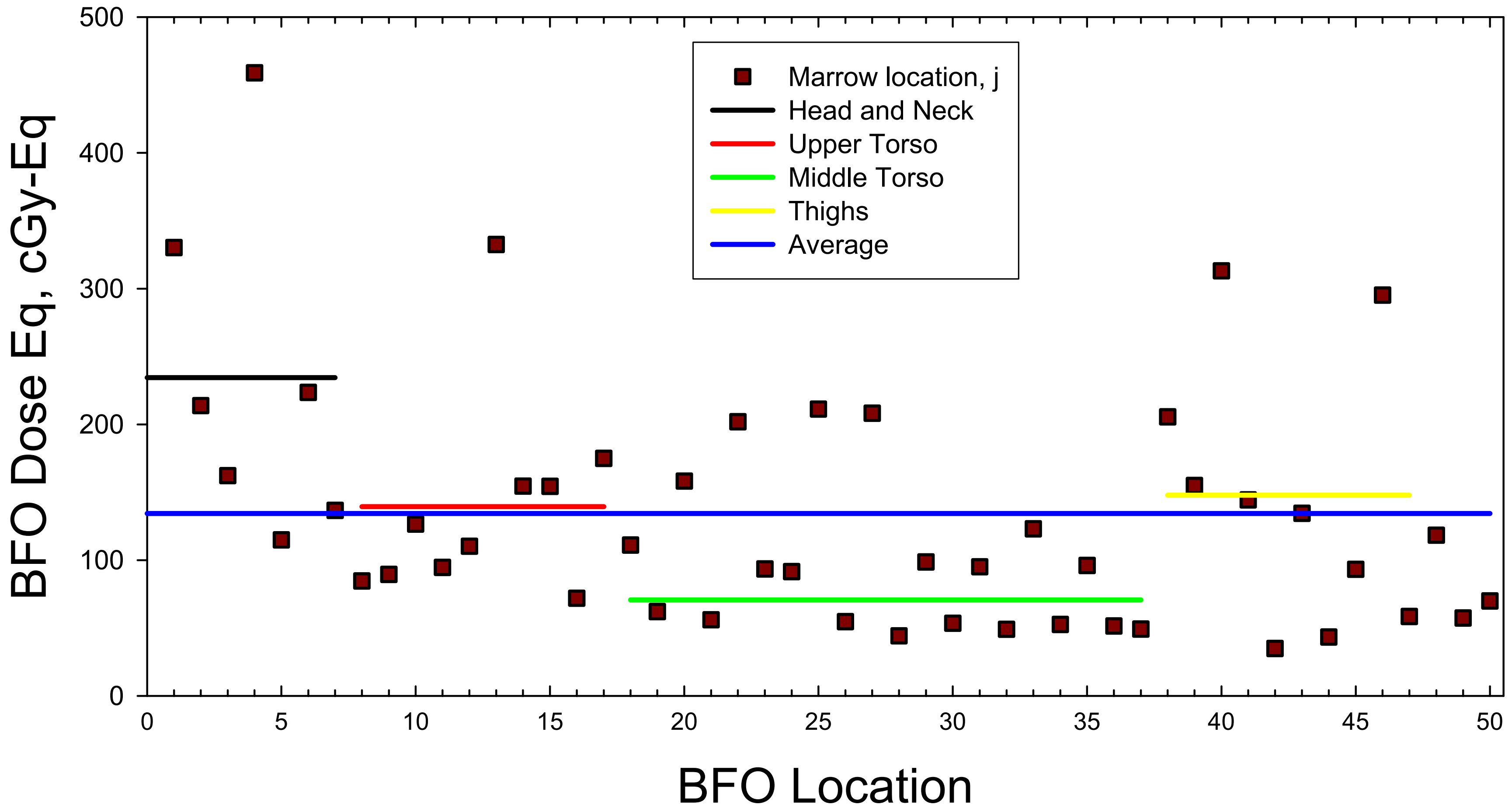
August 1972 SPE (1 g/cm^2 Al shield)



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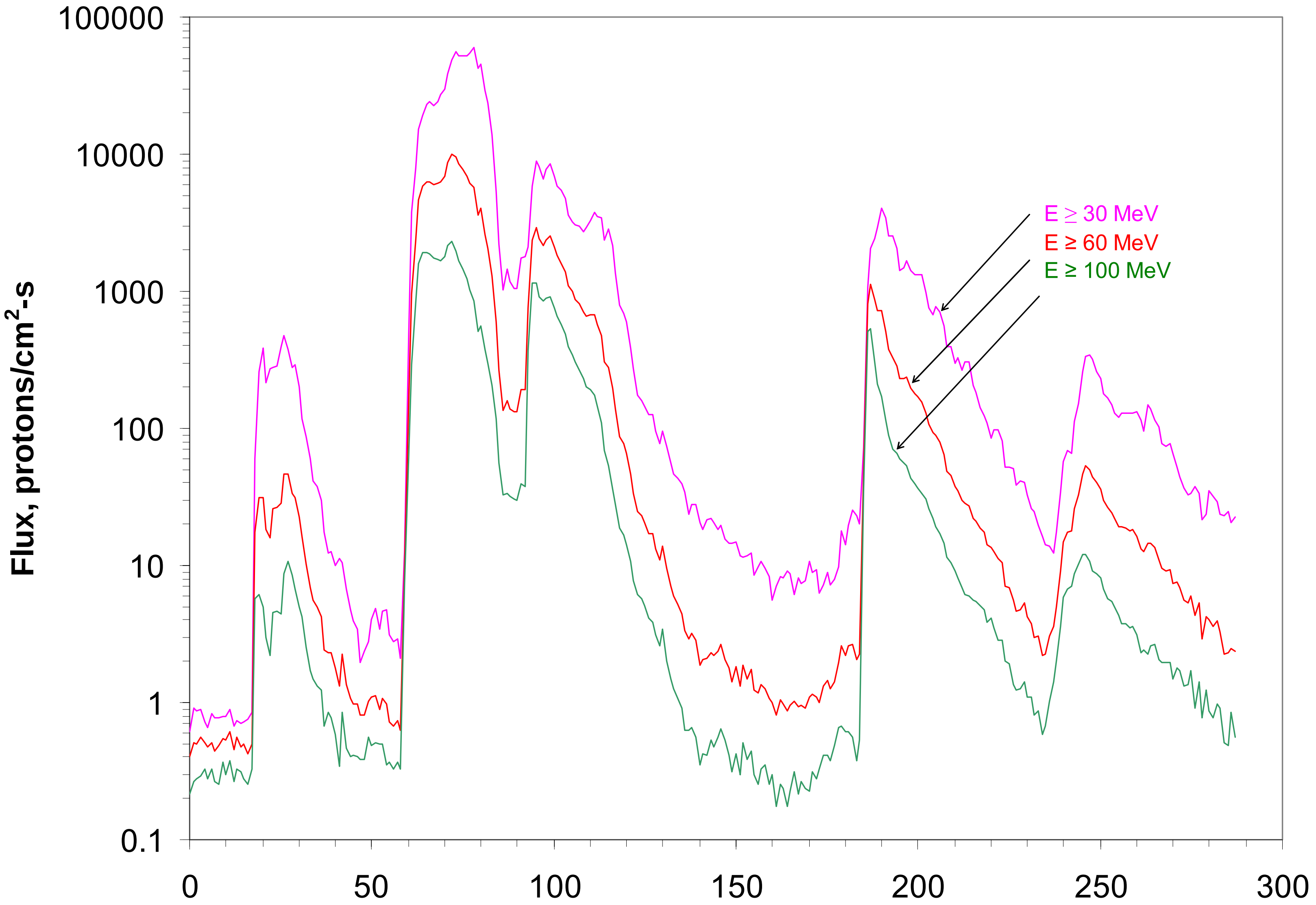
Hourly-Averaged Proton Integral Flux during Oct 26 - Nov 6, 2003 SPE



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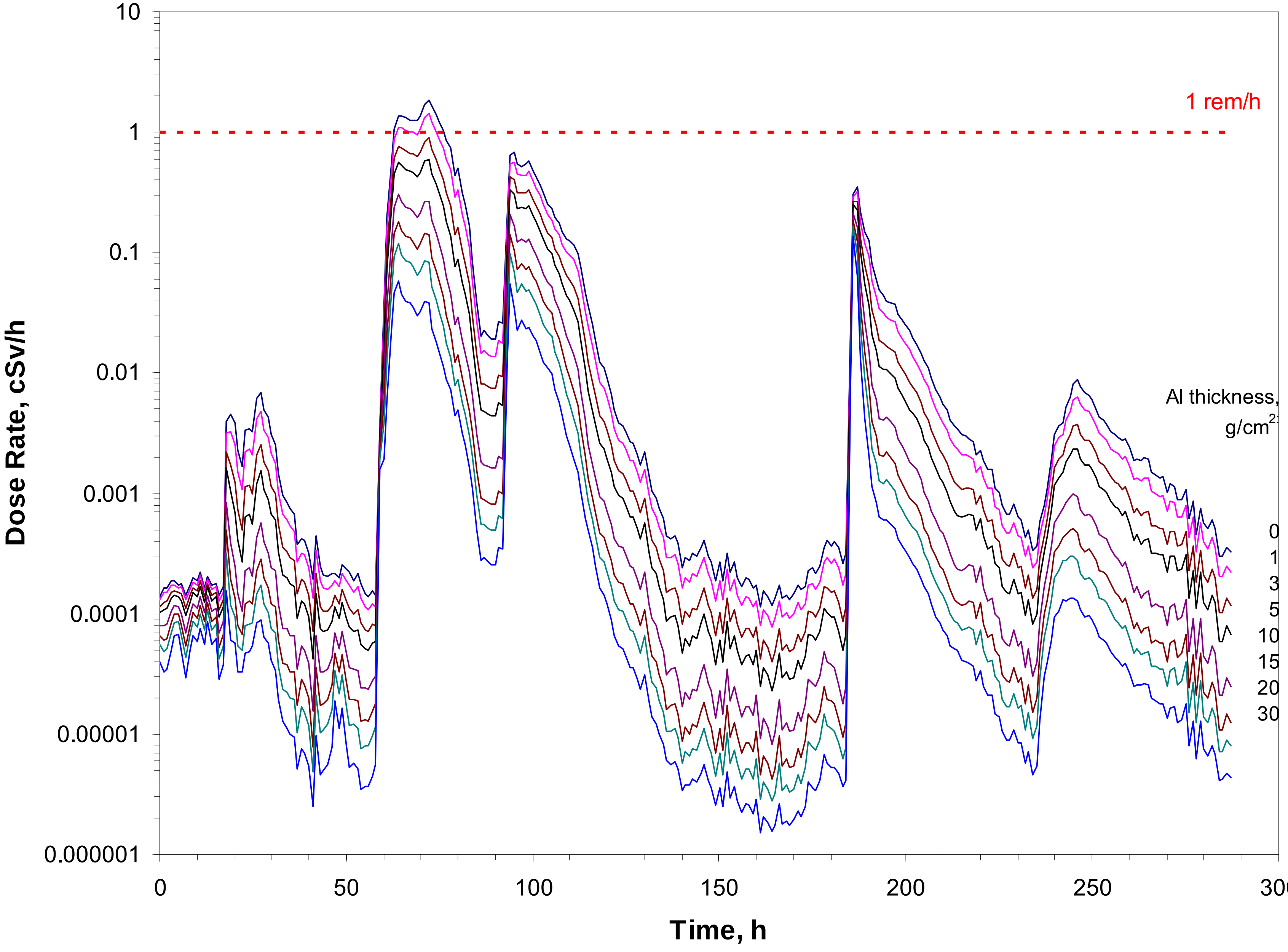
BFO Dose Rate during Oct 26 - Nov 6, 2003 SPE



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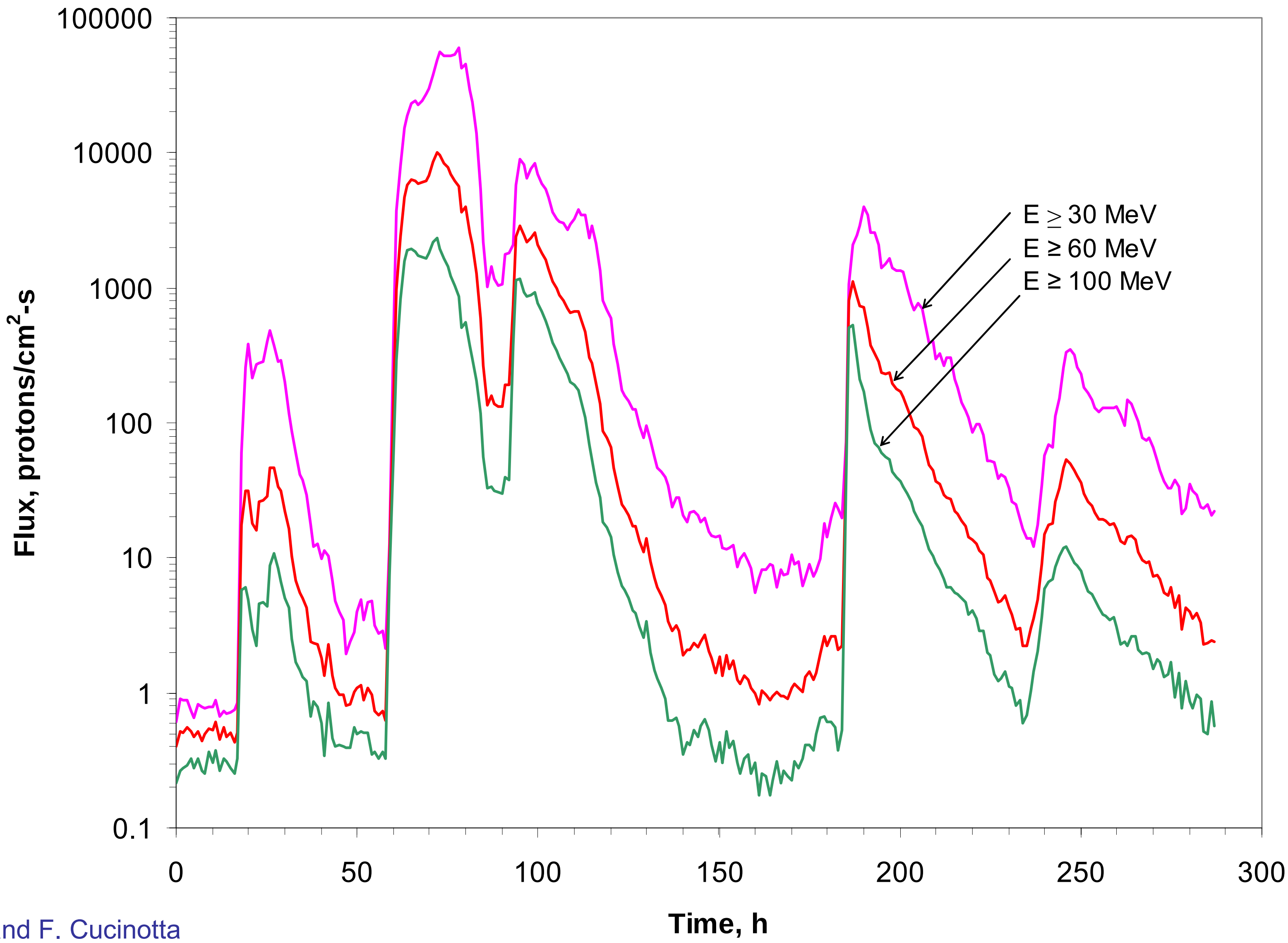
Hourly-Averaged Proton Integral Flux Oct 26 - Nov 6, 2003 SPE



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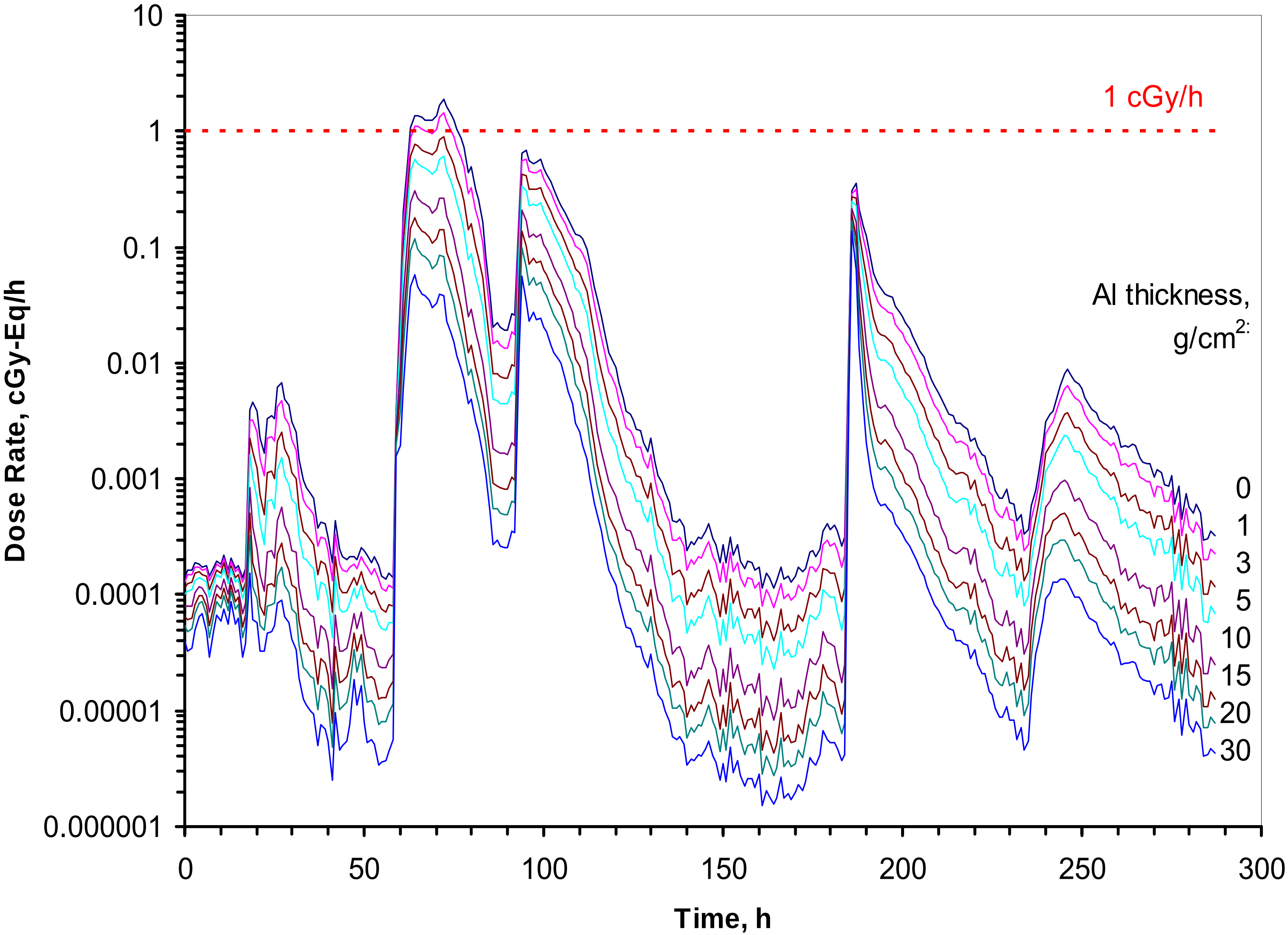
BFO Dose Rate
October 26- November 6, 2003 SPE



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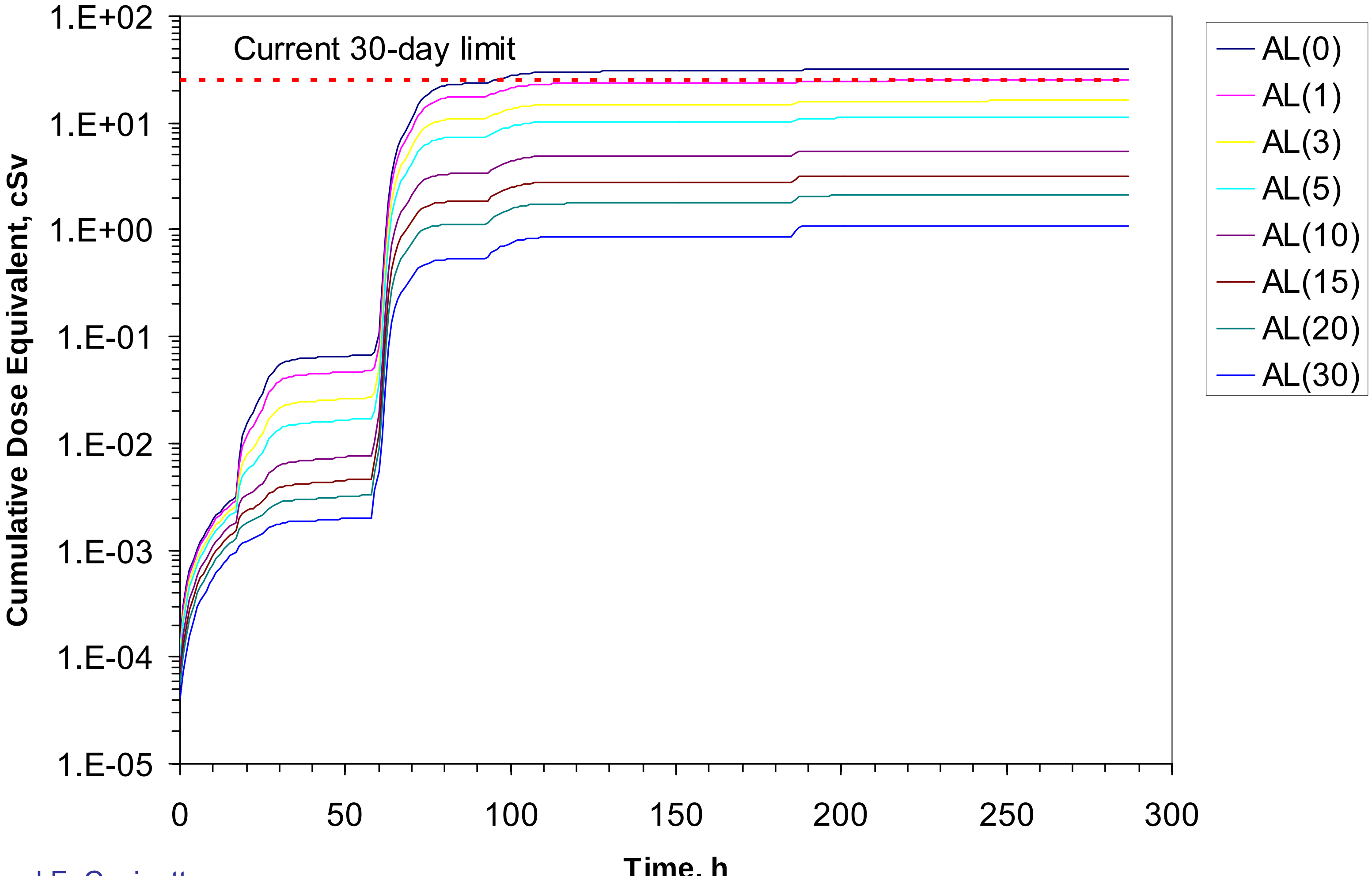
BFO Cumulative Dose
October 26- November 6, 2003 SPE



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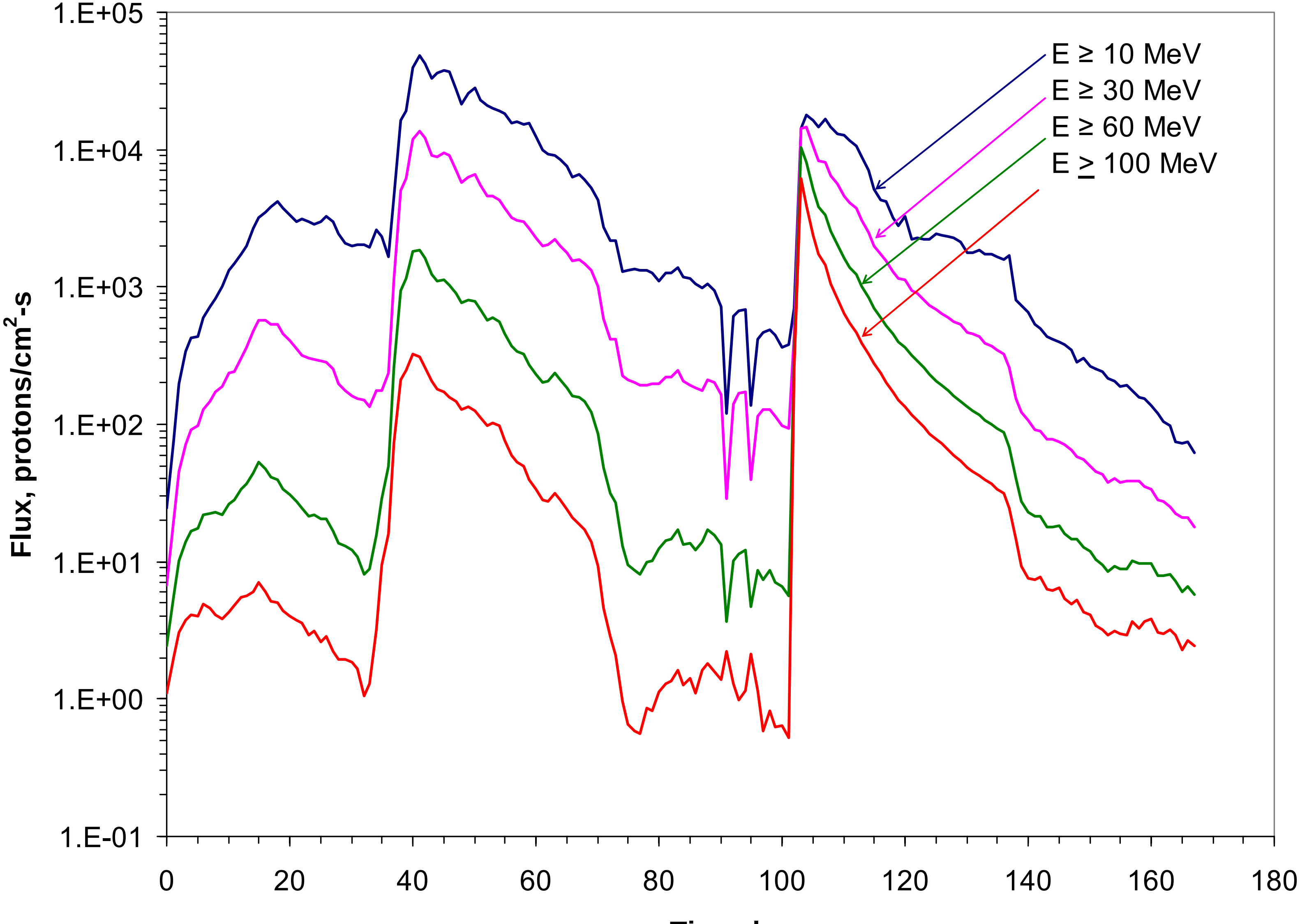
Hourly-Averaged Proton Integral Flux January 16-22, 2005 SPE



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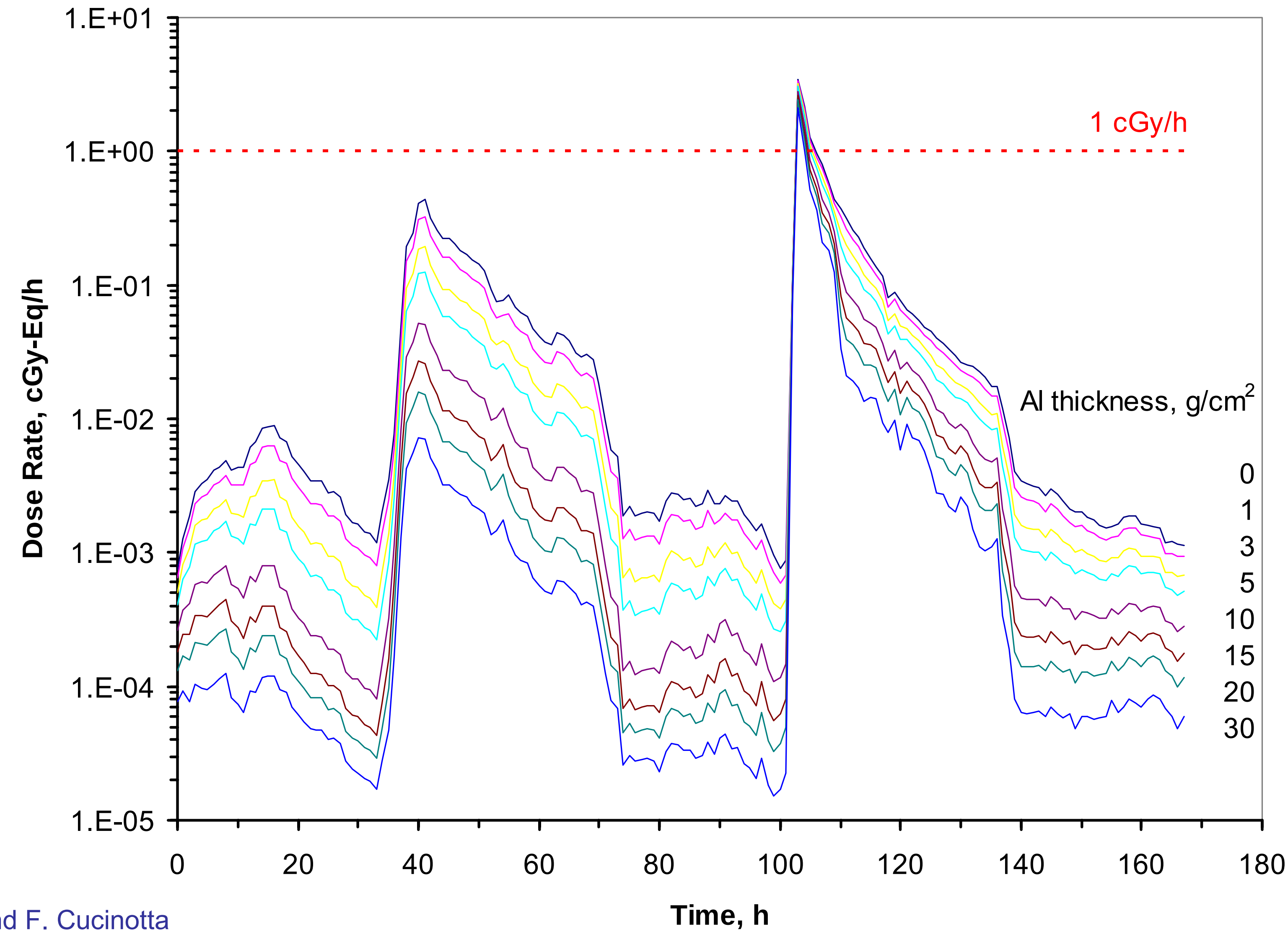
BFO Dose Rate
January 16-22, 2005 SPE



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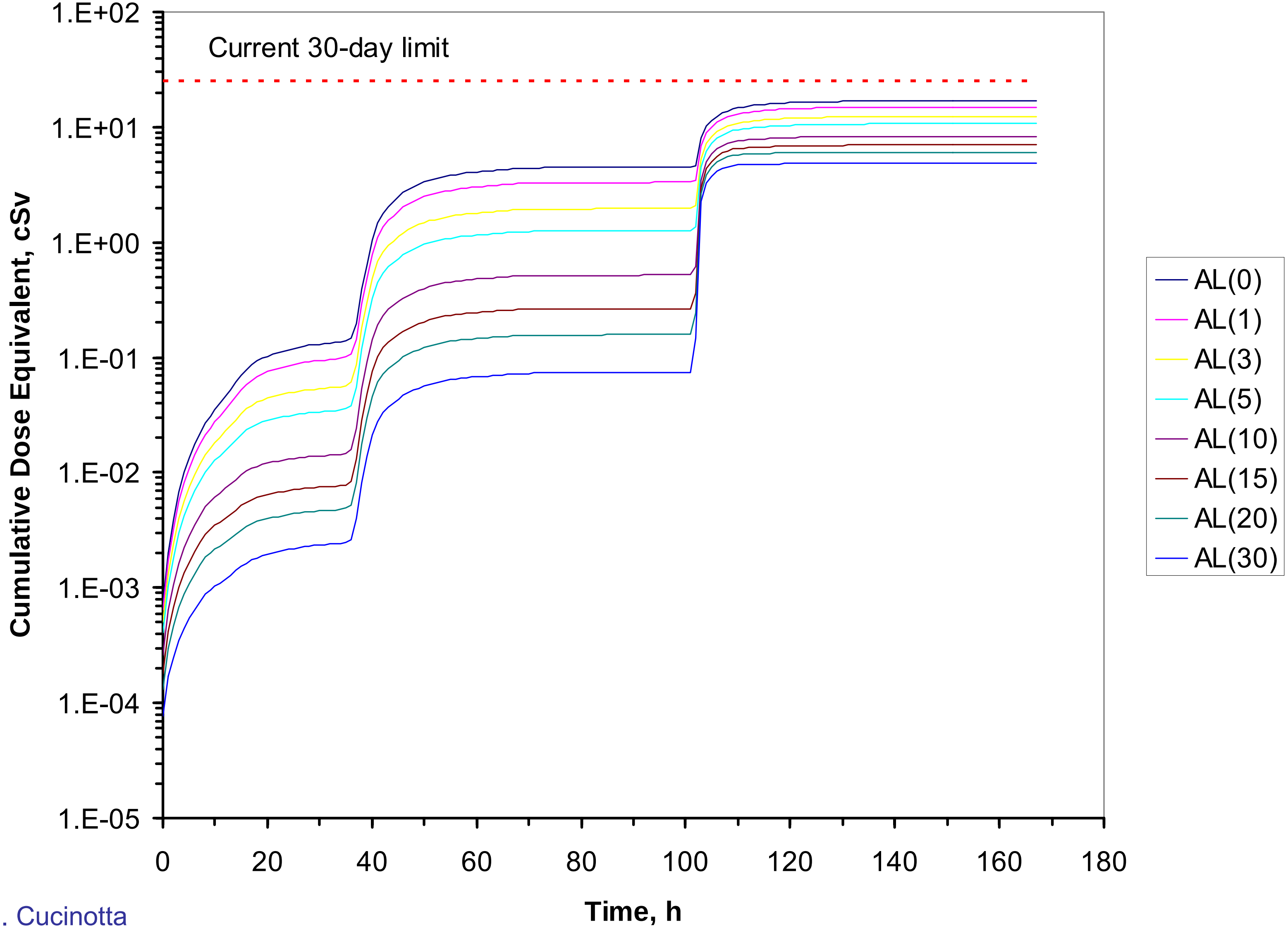
BFO Cumulative Dose
January 16-22, 2005 SPE



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Role of Dose-Rate and Shielding

- Shielding mitigates most SPE events
  - High-energy component (>100 MeV) often poorly known
- Proton biological damage is dependent on dose-rate
  - Effects increase above ~5 rad/hr

CAM ANALYSIS OF THE OCTOBER 1989 PROTON EVENT

EVA Today (Y/N?)

IVA (time to storm shelter)

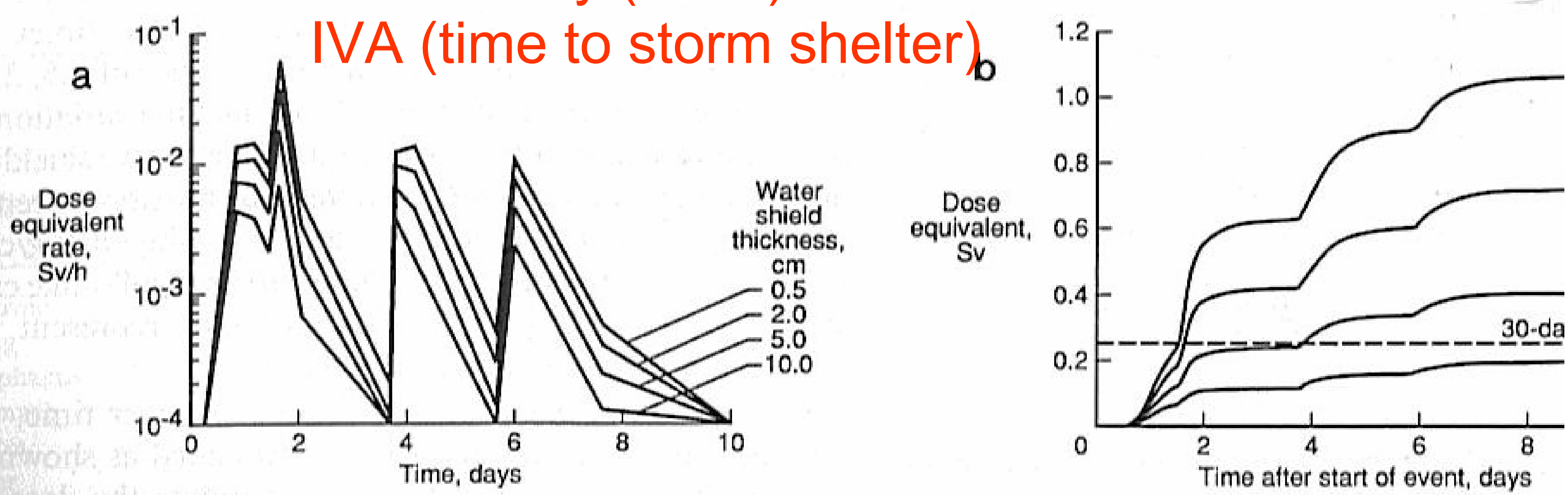
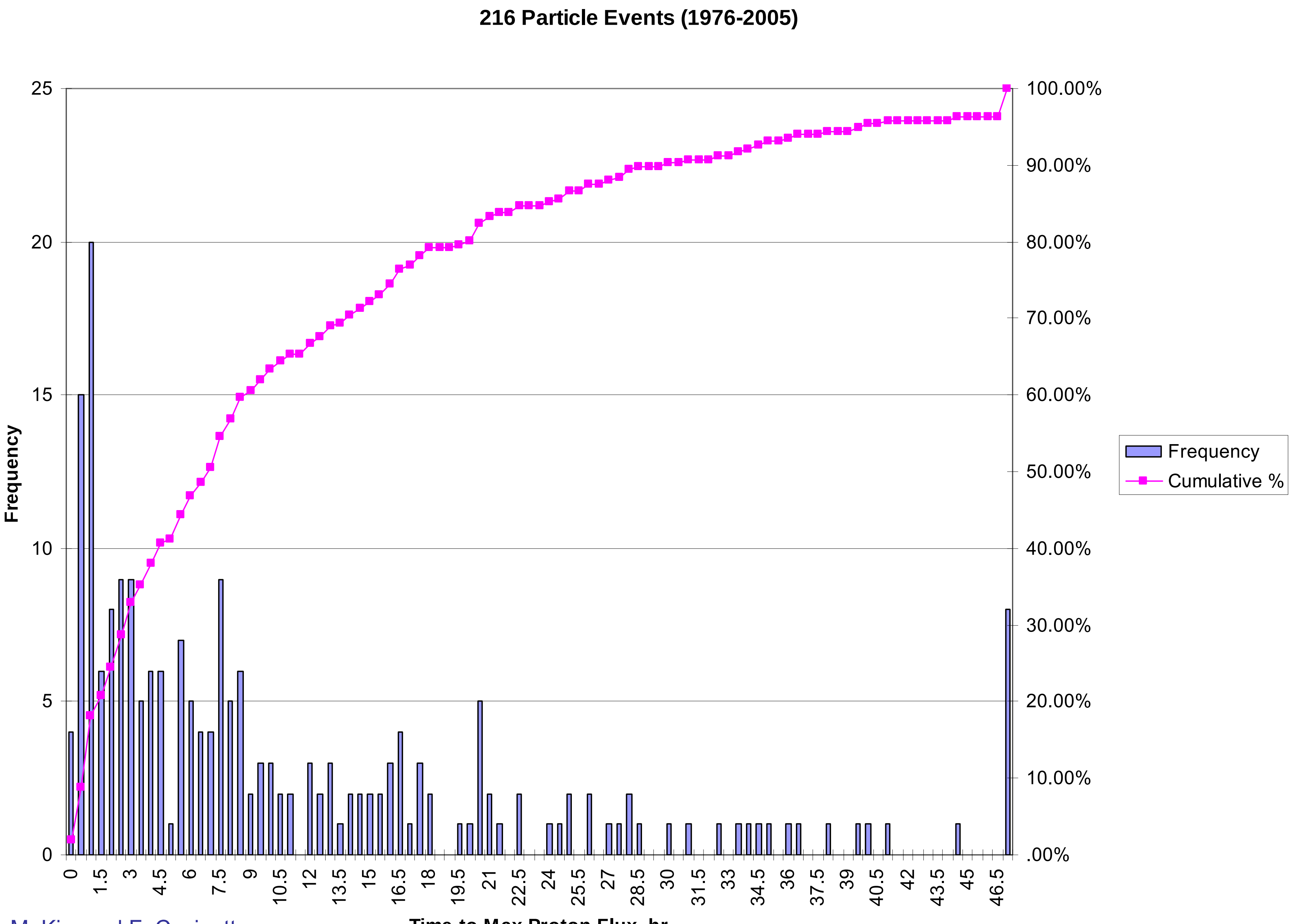


FIG. 9. Predicted BFO dose-rate variation and cumulative dose during the October 1989 event with 0.5, 2.0, 5.0, and 10.0
ickness. (a) BFO dose equivalent rate; (b) cumulative BFO dose equivalent.



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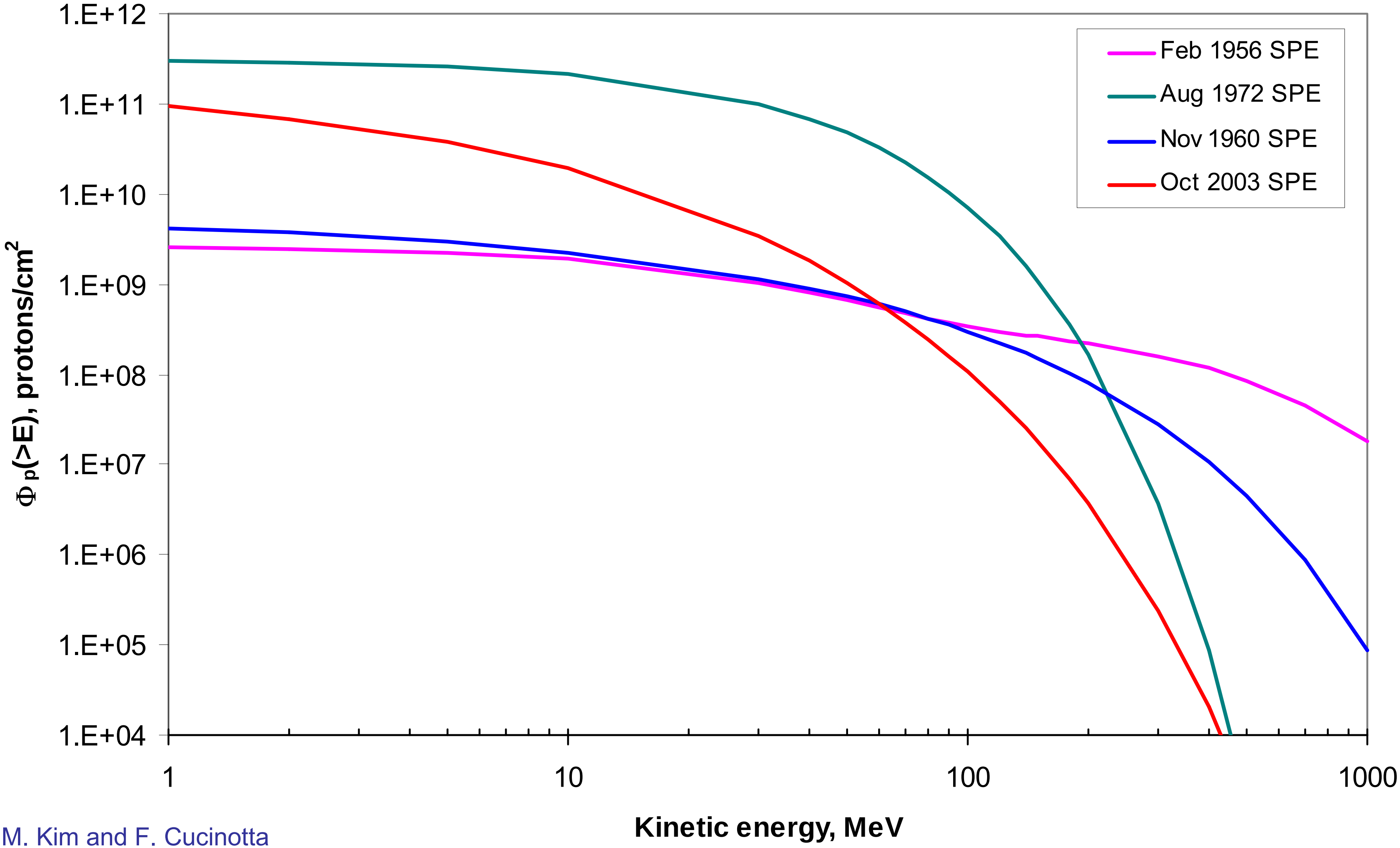
Large SPE Integral Fluence Spectra at 1AU



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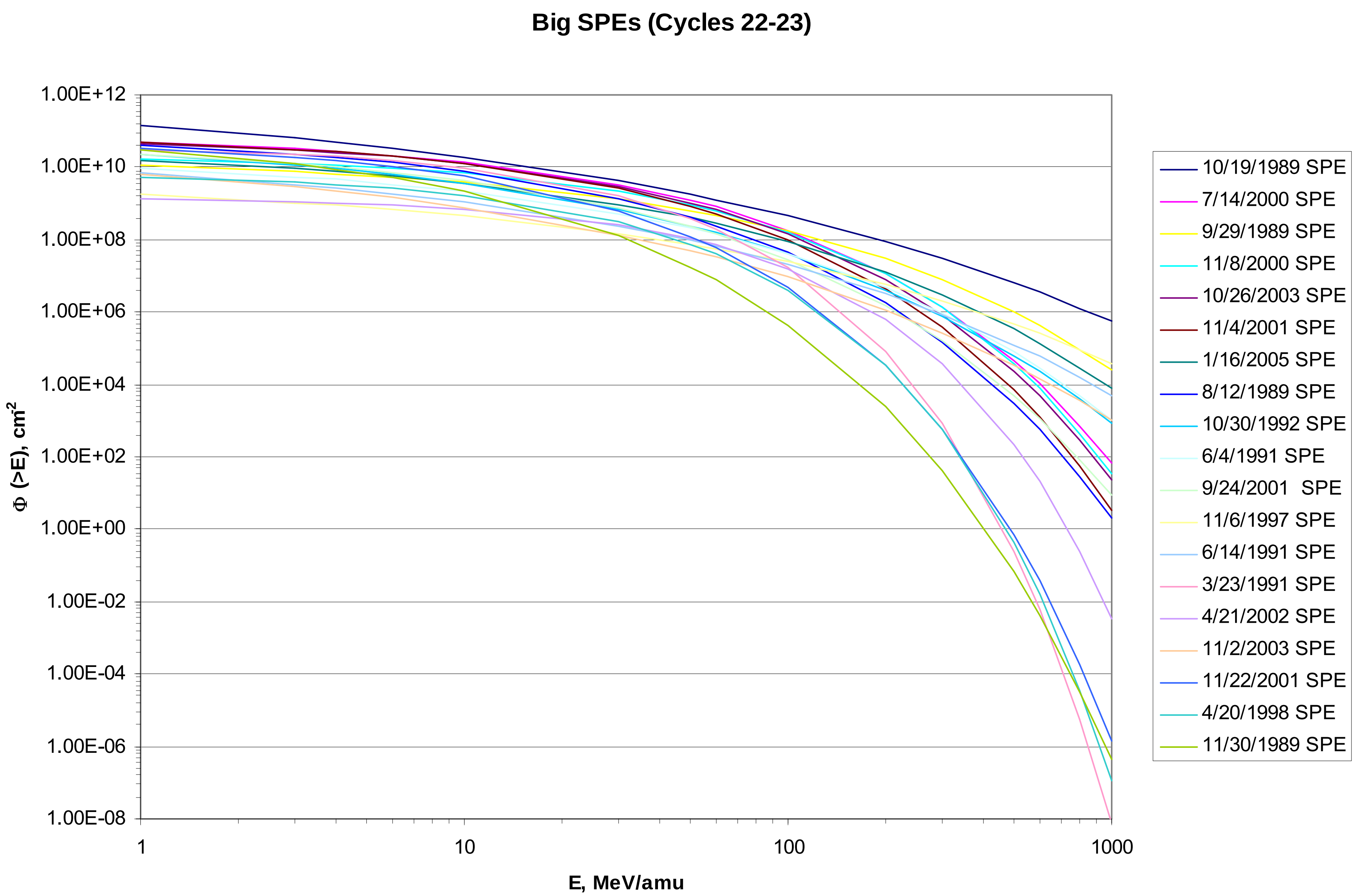

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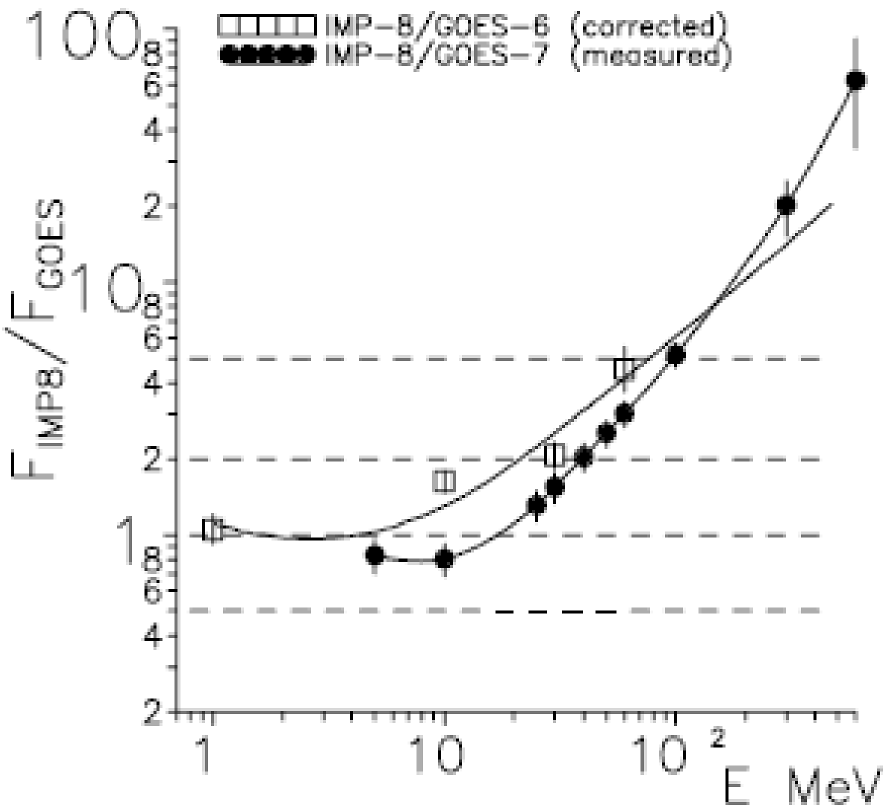

From Nymik- COSPAR

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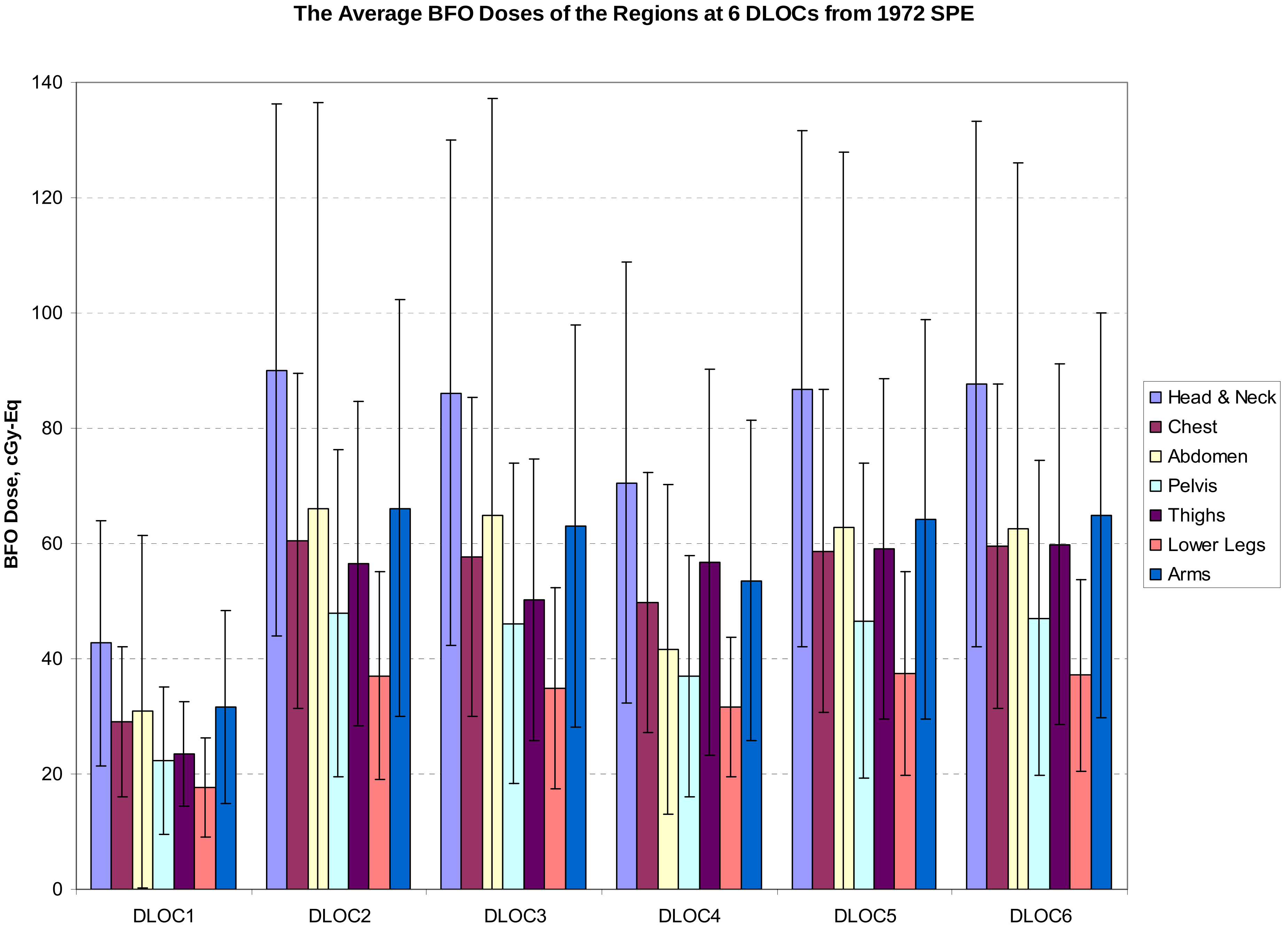

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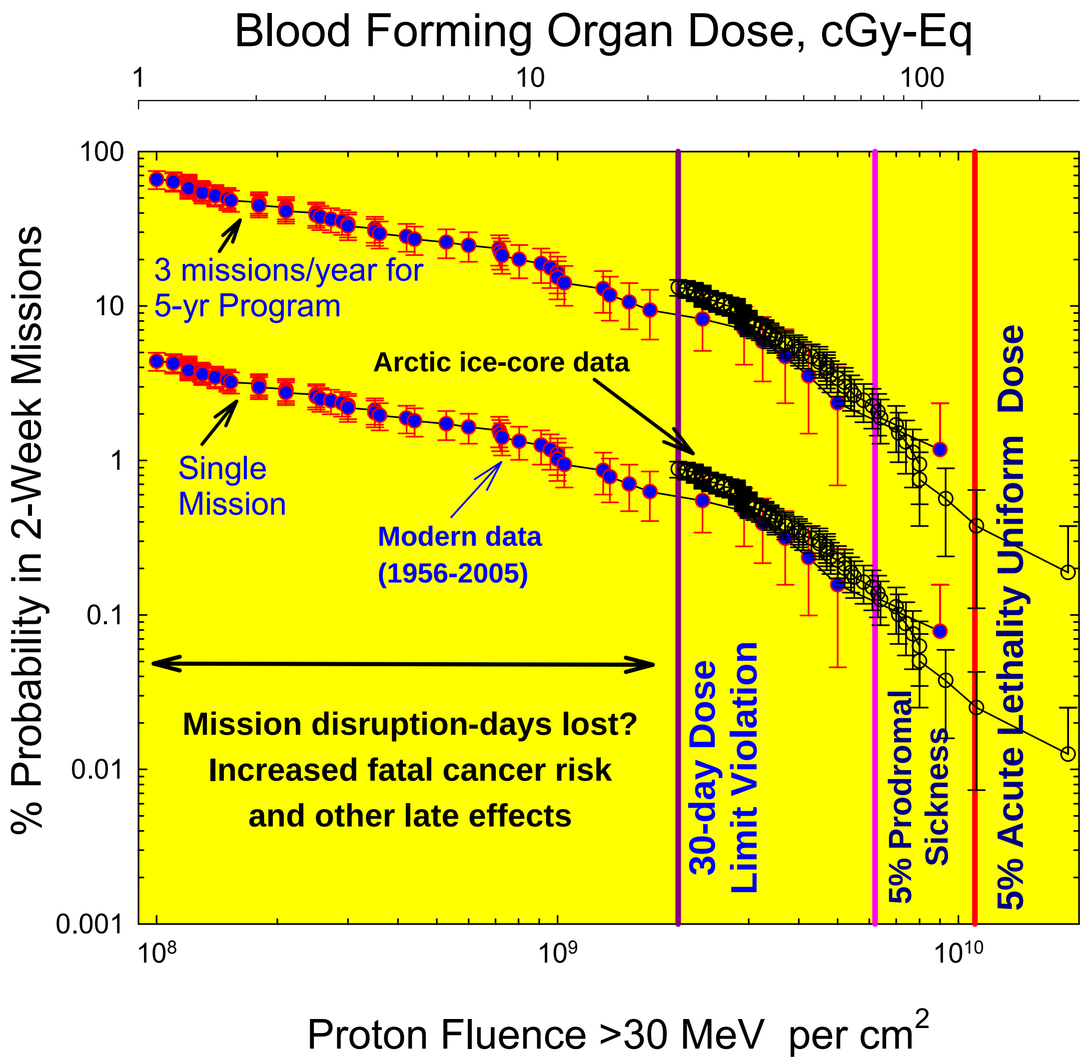
Was Carrington Event (1859) Lethal?

1859 event has largest F>30 Flux known



Conditions under Apollo Spacecraft -type shielding

Ice-Core data -$F_{>30MeV}$ flux from 1450-1990

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Large SPE's

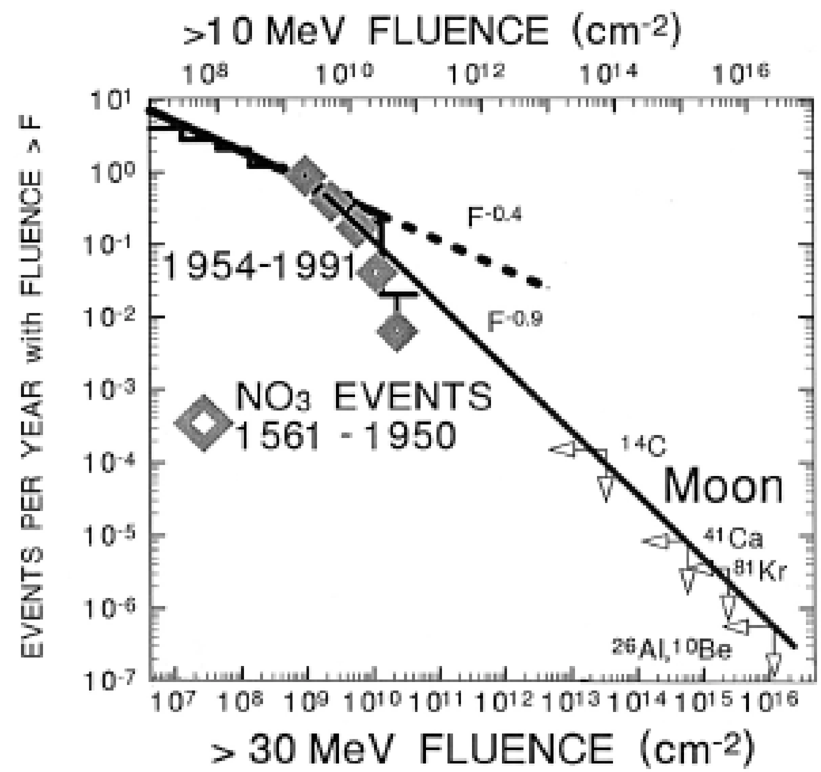

Fig.4. Cumulative probabilities of the SPEs observed by satellite, and derived from the nitrate data. The diamond shaped symbols refer to the nitrate data; the histogram and lines to the satellite data and fluence limits derived from cosmogenic isotopes in moon rocks.

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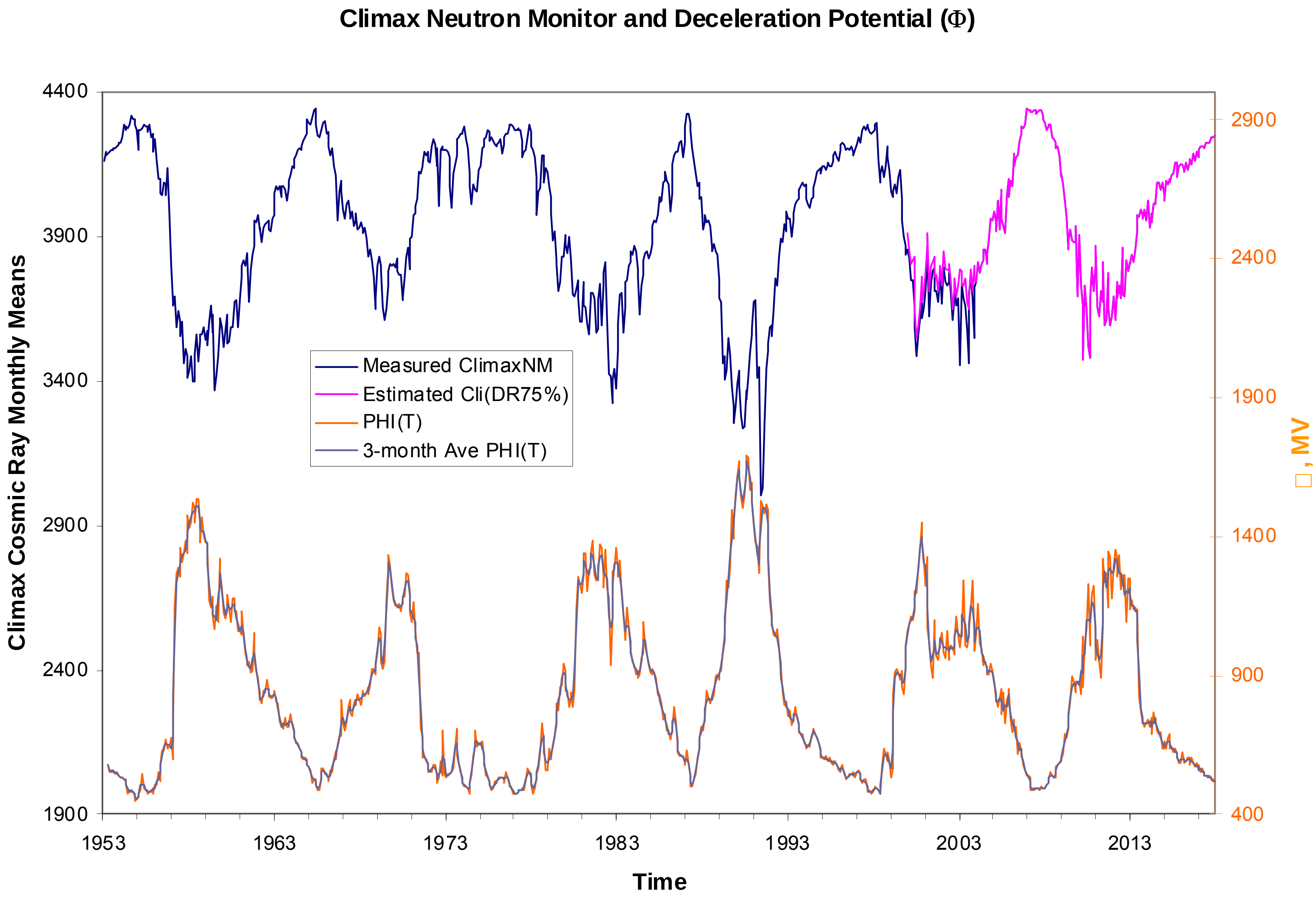
Long-Term Forecasting



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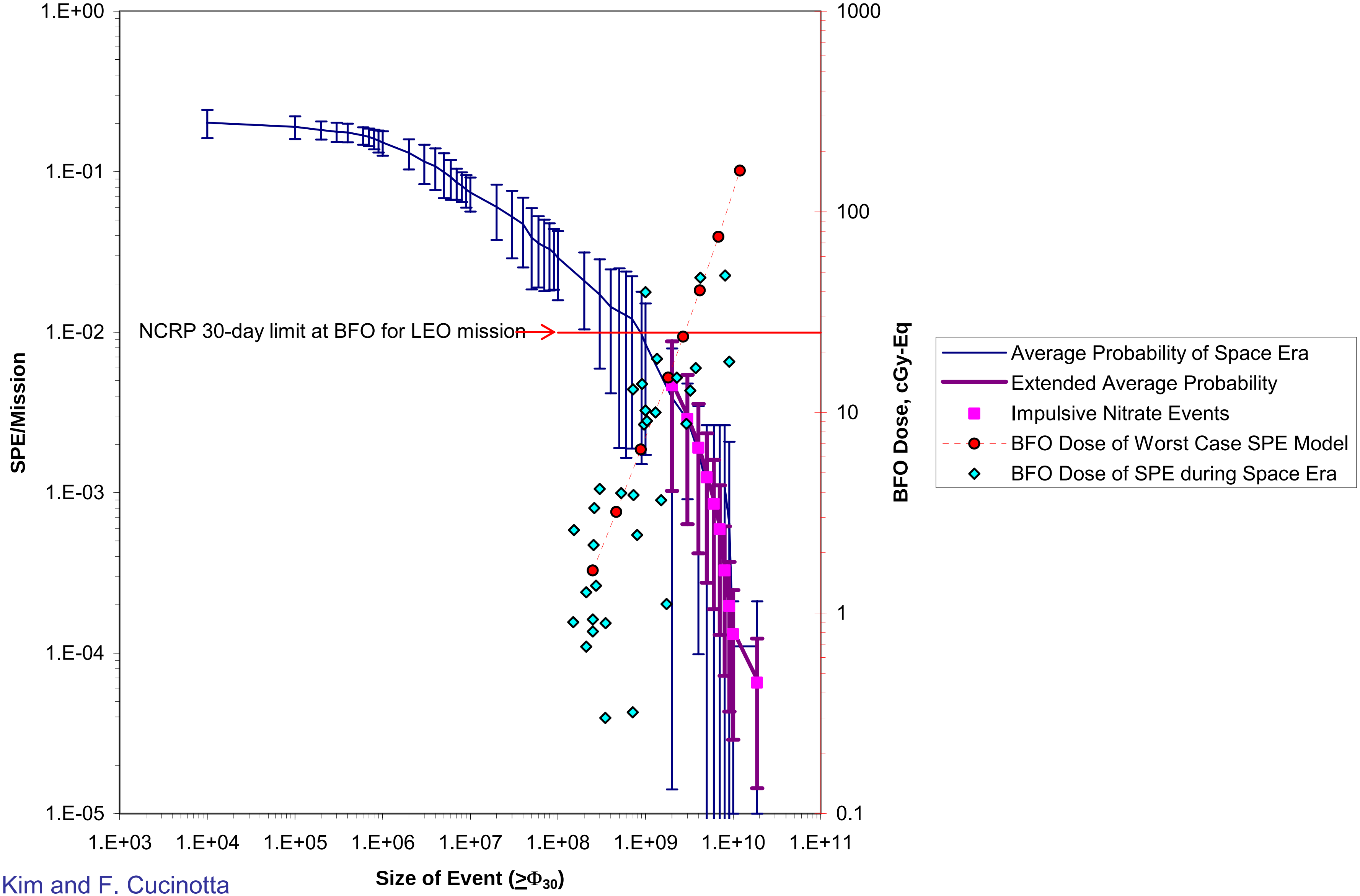
SPE Probability in 1-Week Mission
and
BFO Exposure Level inside a Typical Equipment Room in Free Space



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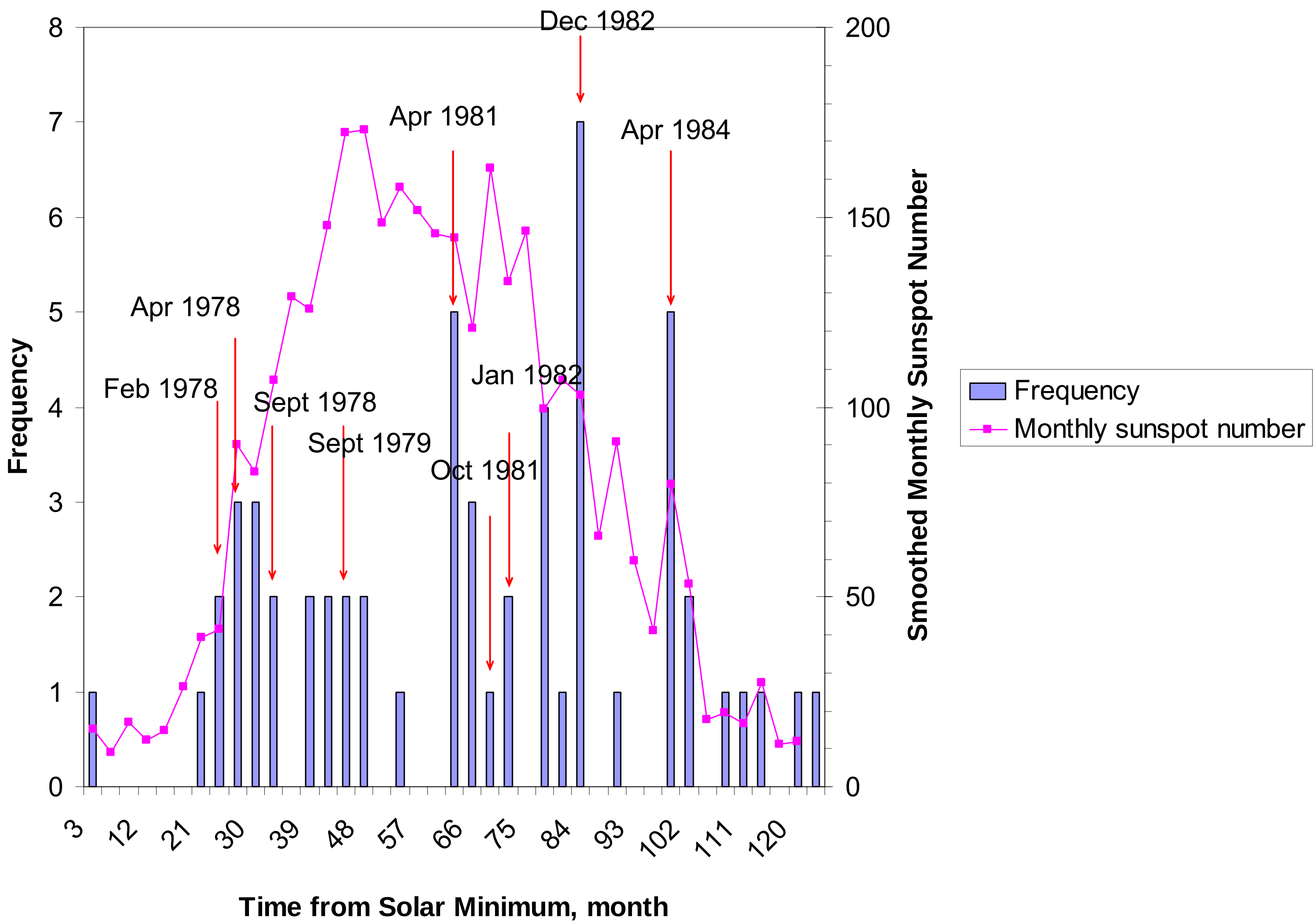
Frequency of SPE Occurrence in 3-Month Periods

$\Phi_{30} > 10^8$ protons/cm^2 for Solar Cycle 21.



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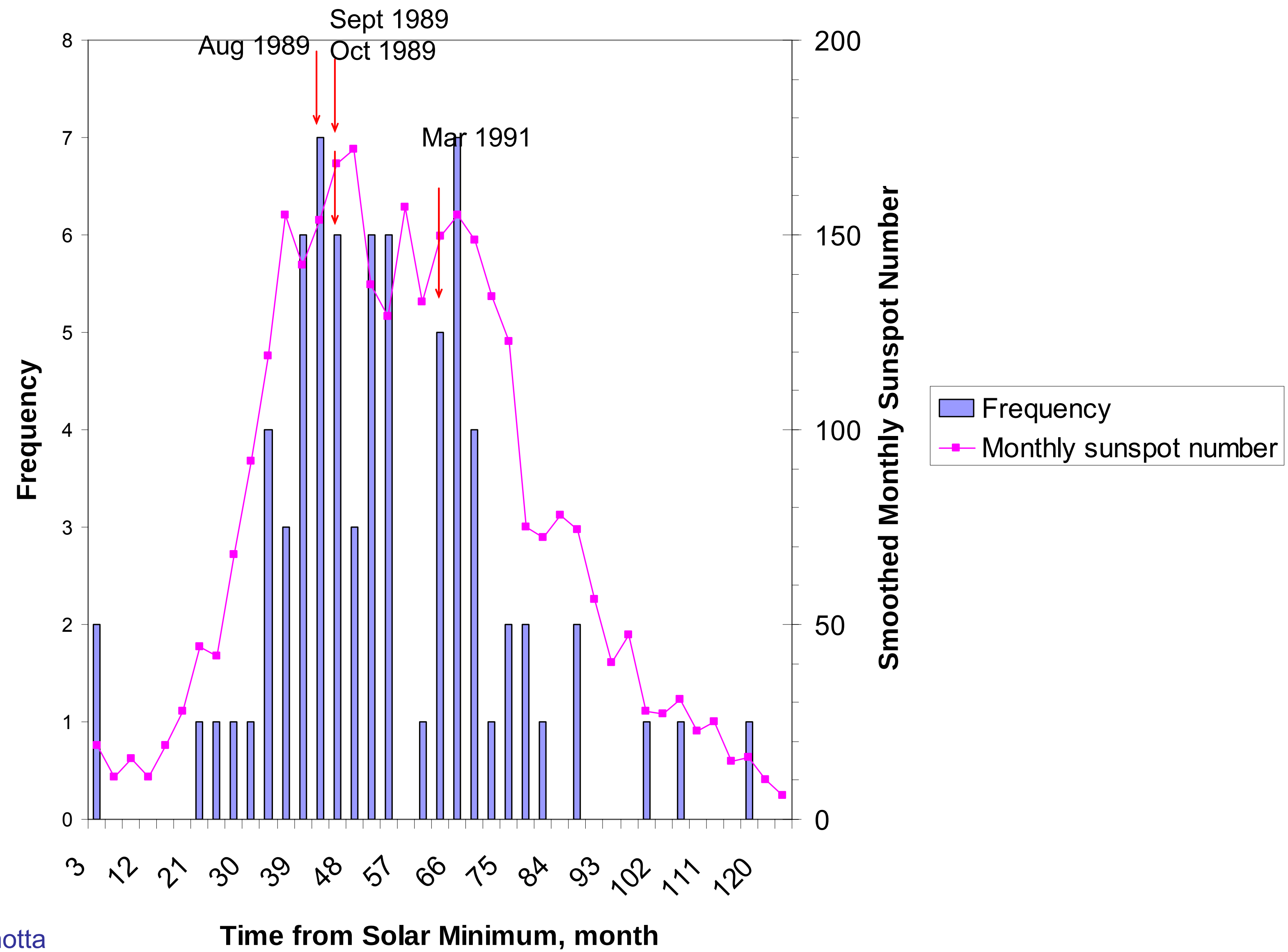
Frequency of SPE Occurrence in 3-Month Periods

$\Phi_{30} > 10^9$ protons/cm^2 for Solar Cycle 22.



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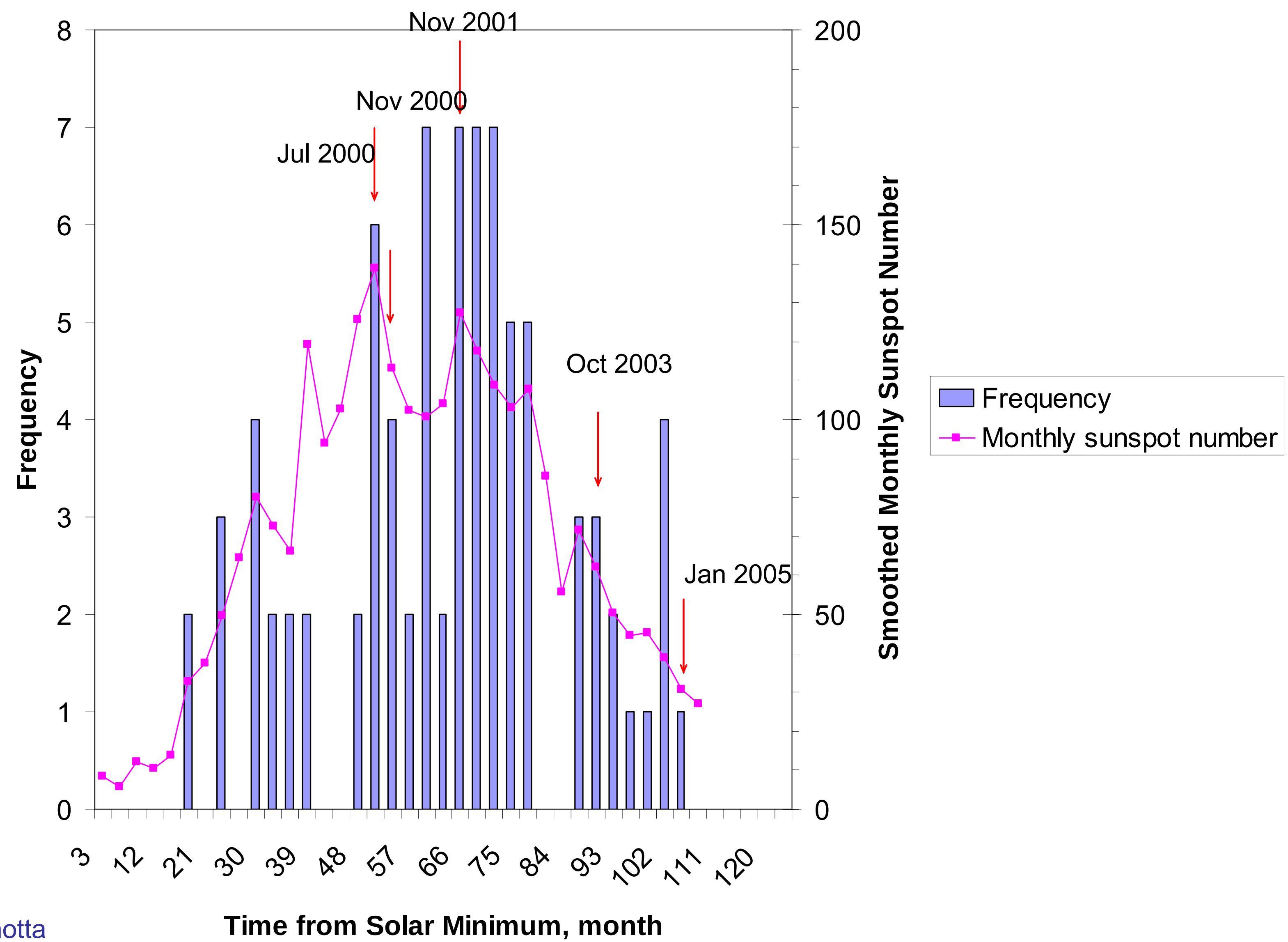
Frequency of SPE Occurrence in 3-Month Periods

$\Phi_{30} > 10^9$ protons/cm^2 for Solar Cycle 23.



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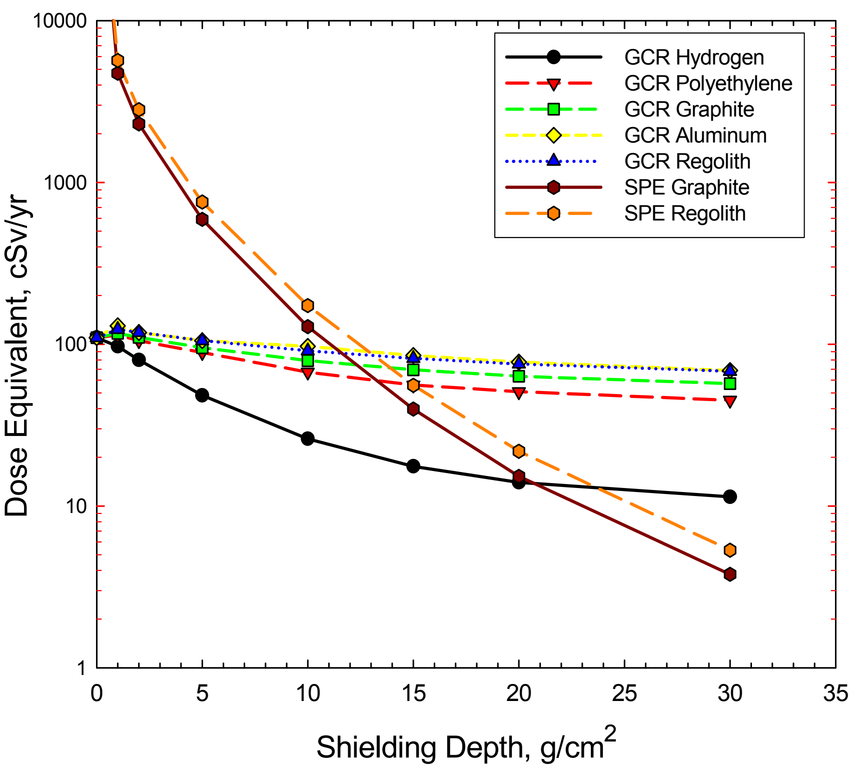
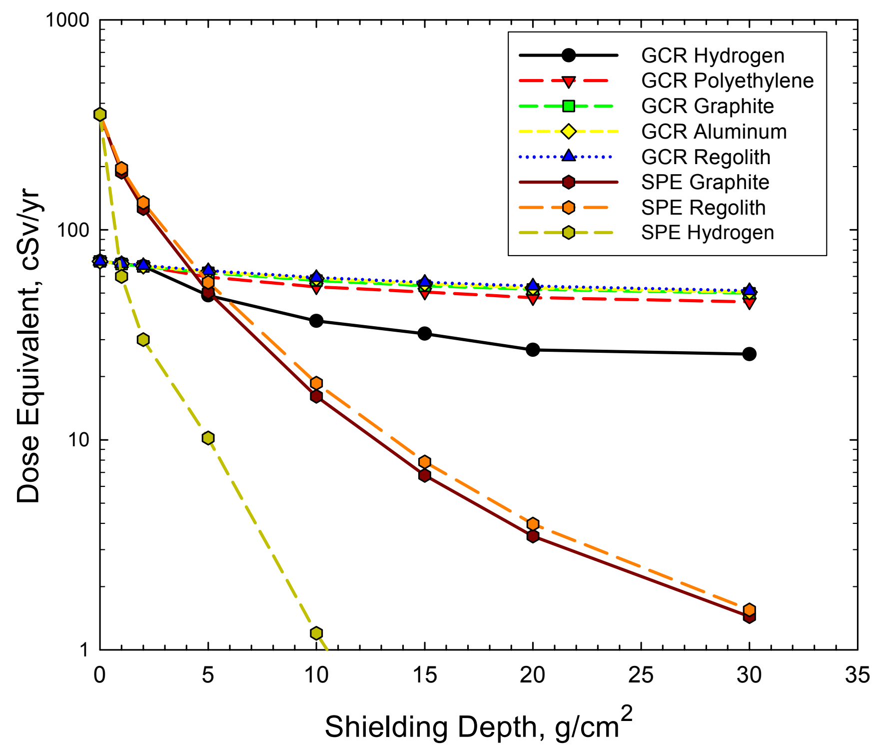
GCR and SPE Dose: Materials & Tissue
GCR higher energy >> secondary radiation

No Tissue Shielding



With Tissue Shielding



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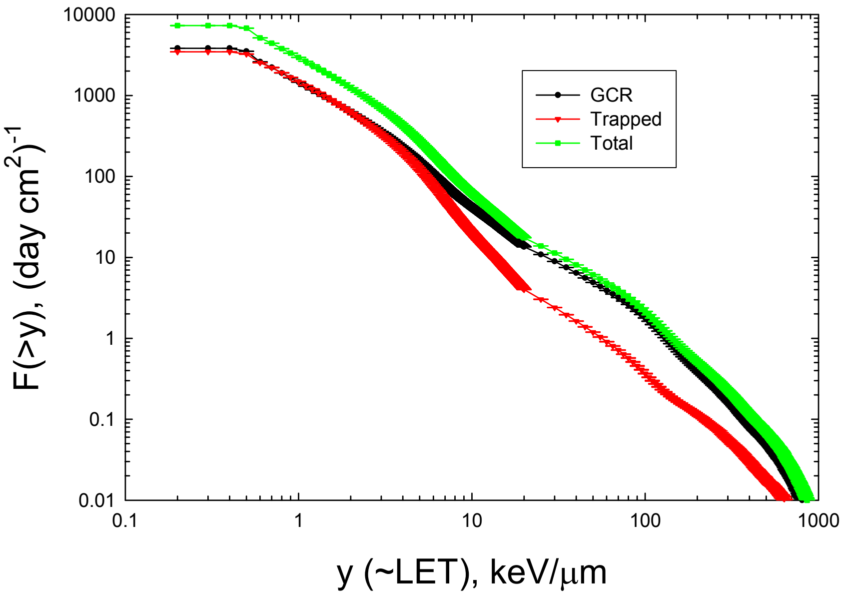
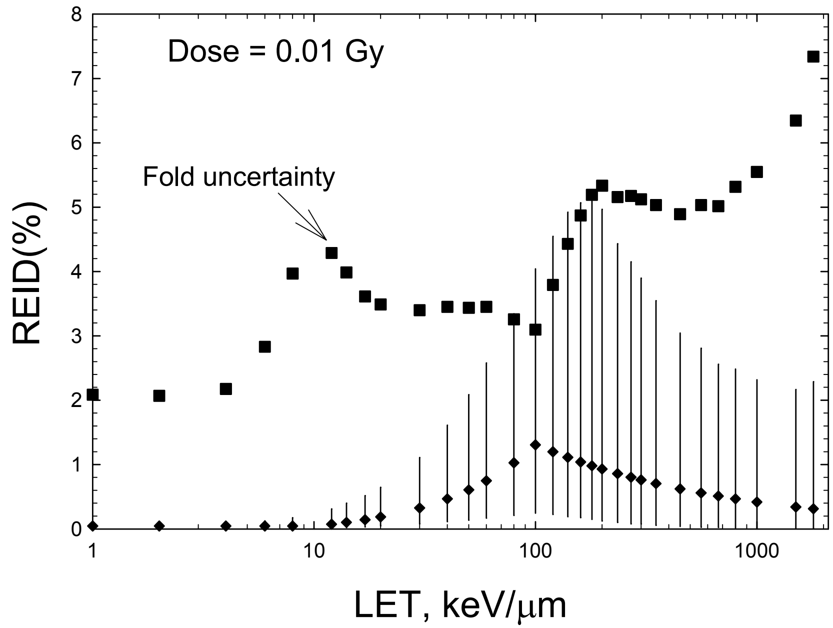
Risk and Uncertainties increase with Linear Energy Transfer (LET)

TEPC Data on NASA-MIR 7 (1/21/1998 to 5/28/1998)



95% CL of Risk Model



Dose = Flux x LET

Biological Dose H = Dose X Q(L)

REID = Risk of exposure induced death = H x R_0(sex,age)

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Accuracy of Space Radiation Transport Models

Absolute Predictions from HZETRN and Flight Measurements

Mission	DATE	Inclination	Altitude	Shielding	Dose, mGy/d			Dose Eq., mSv/d		
					Measured	Theory	%Difference	Measured	Theory	%Difference
STS-40	1991	39	293	Dloc2	0.052	0.048	7.7	0.13	0.16	-23.1
STS-49	1992	28.5	358	Dloc2	0.05	0.048	4.0	0.127	0.155	-22.0
STS-51	1993	28.5	296	Payload Bay	0.044	0.048	-9.1	0.144	0.154	-6.9
STS-57	1993	57	298	Payload Bay	0.113	0.109	3.5	0.422	0.434	-2.8
STS-57	1993	57	298	DLOC-2	0.138	0.11	20.3	0.414	0.37	10.6
Mir-18	1995	51.6	390	P	0.142	0.141	0.7	0.461	0.526	-14.1
STS-81	1997	51.6	400	0-sphere	0.147	0.135	8.2	0.479	0.521	-8.8
STS-81	1997	51.6	400	Poly 3-in	0.138	0.138	0.0	0.441	0.400	9.3
STS-81	1997	51.6	400	Poly 5-in	0.129	0.118	8.5	0.316	0.368	-16.5
STS-81	1997	51.6	400	Poly 8-in	0.128	0.113	11.7	0.371	0.323	12.9
STS-81	1997	51.6	400	Poly 12-in	0.116	0.111	4.3	0.290	0.298	-2.8
STS-89	1998	51.6	393	0-sphere	0.176	0.148	15.8	0.561	0.614	-9.4
STS-89	1998	51.6	393	Al 3-in	0.167	0.159	4.8	0.445	0.488	-9.7
STS-89	1998	51.6	393	Al 7-in	0.149	0.161	-8.1	0.529	0.617	-16.6
STS-89	1998	51.6	393	Al 9-in	0.171	0.162	5.3	0.492	0.541	-10.0

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Model vs. Phantom Expt. (STS and ISS)

Phantom Data on STS-91 for Trapped + GCR (51.6 x 390 km)

Organ	Measured (mGy)	Theory (mGy)	Theory* (mGy)	% Difference	% Difference*
Brain	2.23	2.42	2.26	-8.5	-1.4
Bone Surface	2.16	2.36	2.21	-9.3	-2.1
Esophagus	1.71	1.79	1.67	-4.7	2.2
Lung	1.92	1.81	1.69	5.7	11.9
Stomach	2.05	2.08	1.94	-1.5	5.2
Liver	1.88	2.15	2.01	-14.4	-6.9
Spinal Column	1.65	1.98	1.85	-20.0	-12.1
Bone Marrow	1.75	1.98	1.85	-13.1	-5.7
Colon	1.71	1.9	1.78	-11.1	-3.8
Bladder	1.58	1.87	1.75	-18.4	-10.6
Gonad	1.75	1.85	1.73	-5.7	1.2
Skin/Breast	2.46	2.58	2.41	-4.9	2.0
Skin/Abdomen	2.35	2.58	2.41	-9.8	-2.6

*Includes a correction to TLD efficiency vs. LET.

ISS Increment-2 results

CALCULATIONS & % DIFFERENCES

	TRAPPED (mGy/day)	GCR (mGy/day)	TOTAL (mGy/day)		% DIFF. (C-M)/M
BRAIN	0.066	0.077	0.143		13.3
THYROID	0.072	0.077	0.148		9.4
HEART	0.061	0.077	0.138		6.6
STOMACH	0.057	0.077	0.133		5.5
COLON	0.056	0.076	0.131		2.5
LIVER	0.053	0.077	0.130		-4.0

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HZETRN Comparisons to GCR Secondary Energy Spectra on STS 48
- Because of Earth Magnetic Cutoff predominantly secondary protons and deuterons are measured (Stringent test of HZETRN Code)

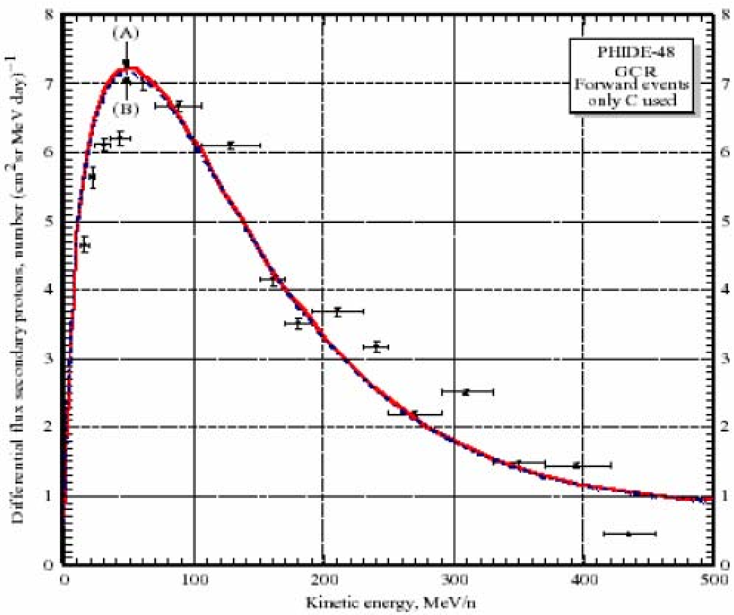

Figure 5. Comparison of observed and calculated secondary proton energy spectra.

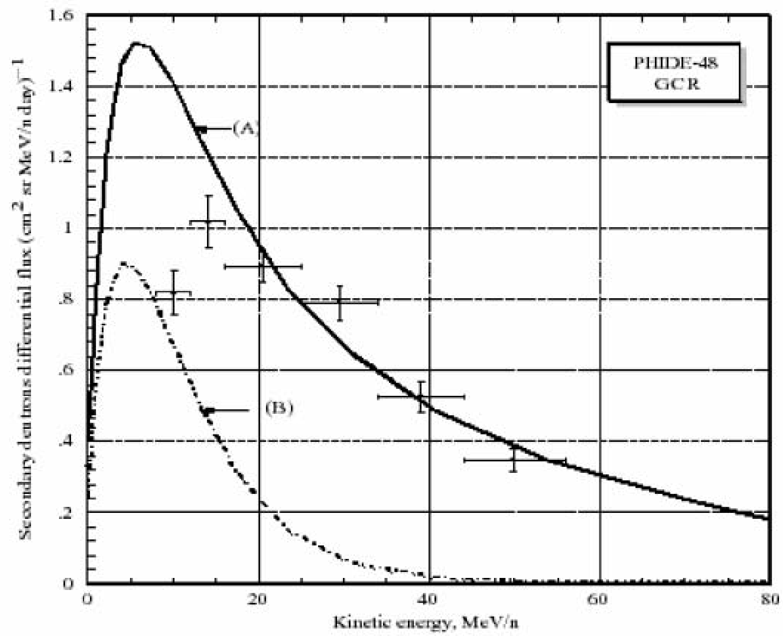

Figure 6. Comparison of observed and calculated secondary deuteron energy spectra.

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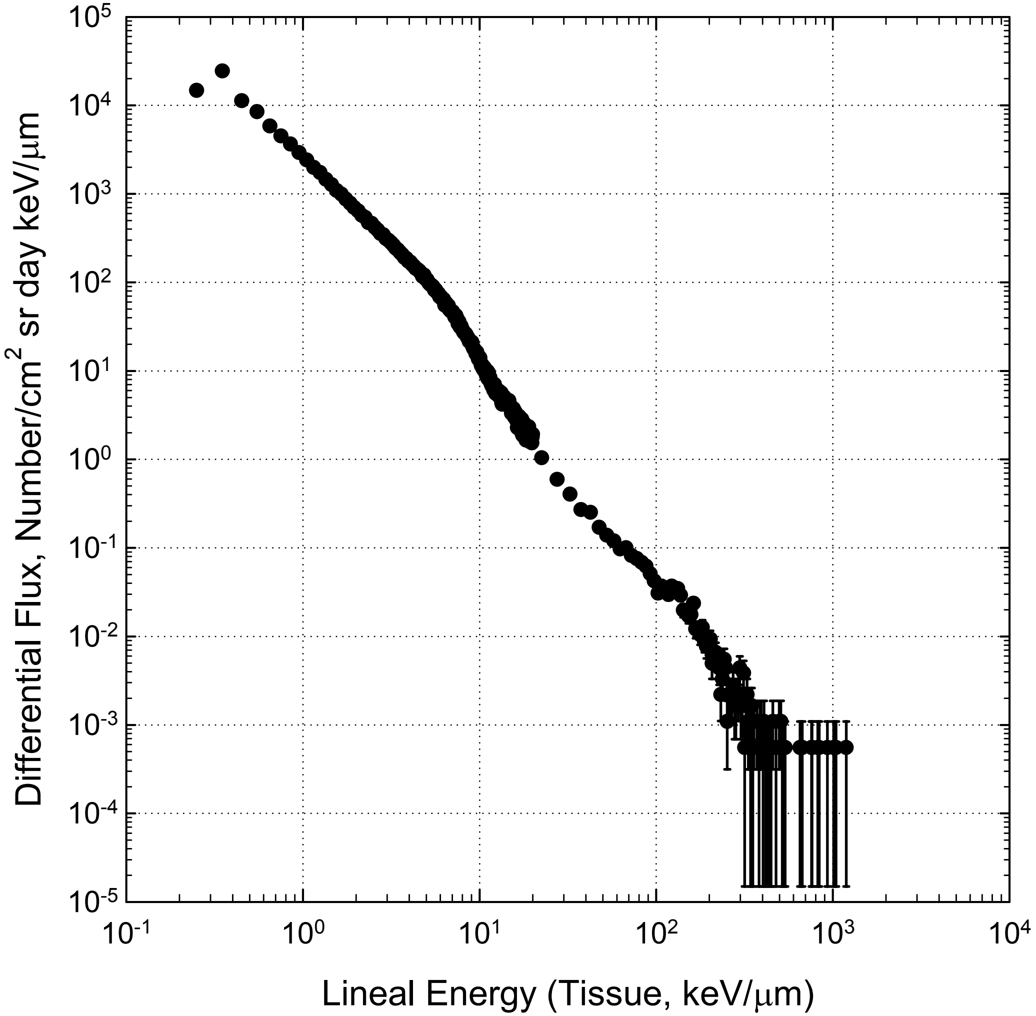
Phantom Torso TEPC Trapped + GCR Differential Flux
June 25 - July 3, 2001



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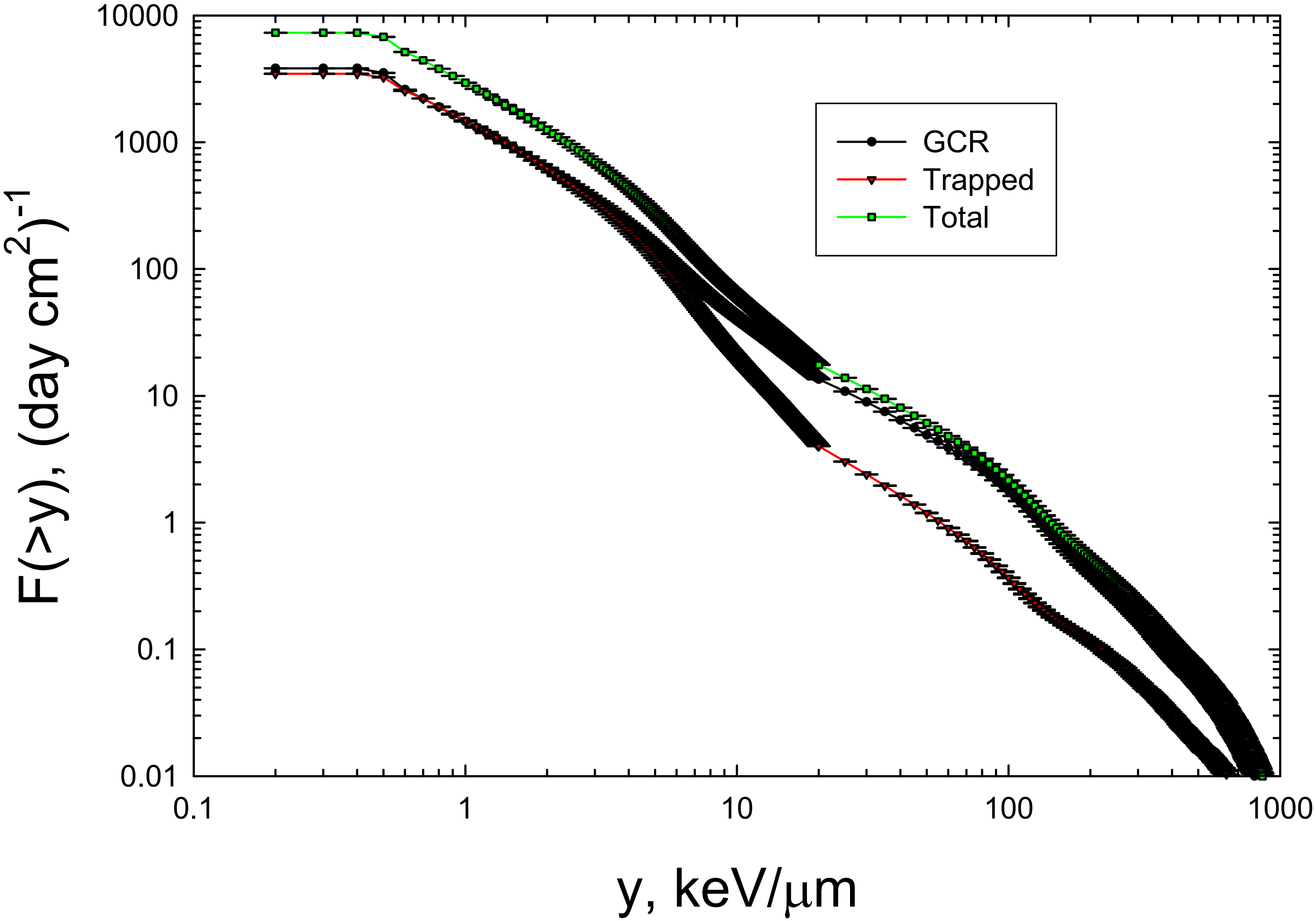
NASA-MIR 7 (1/21/1998 to 5/28/1998)



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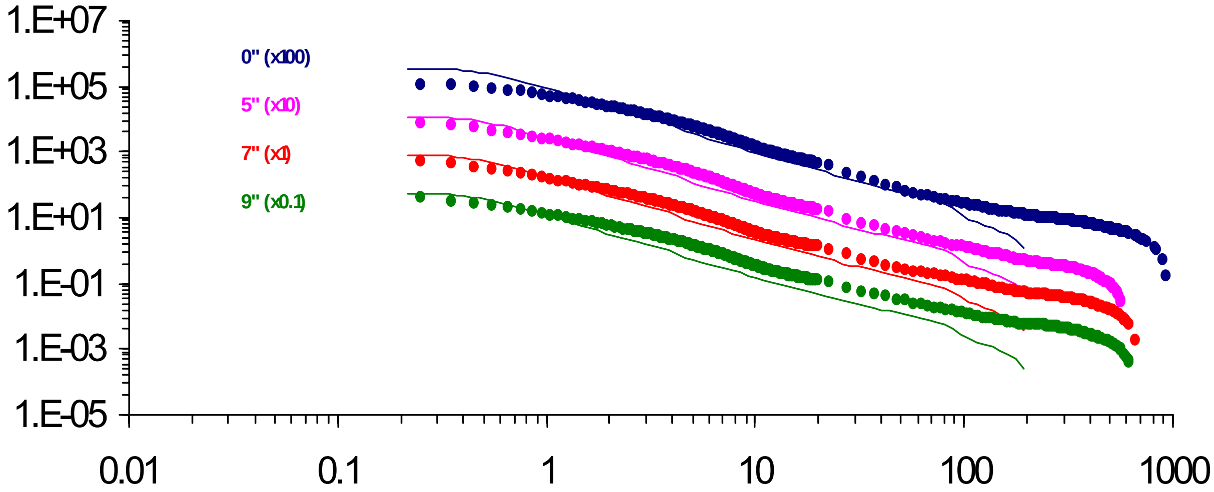
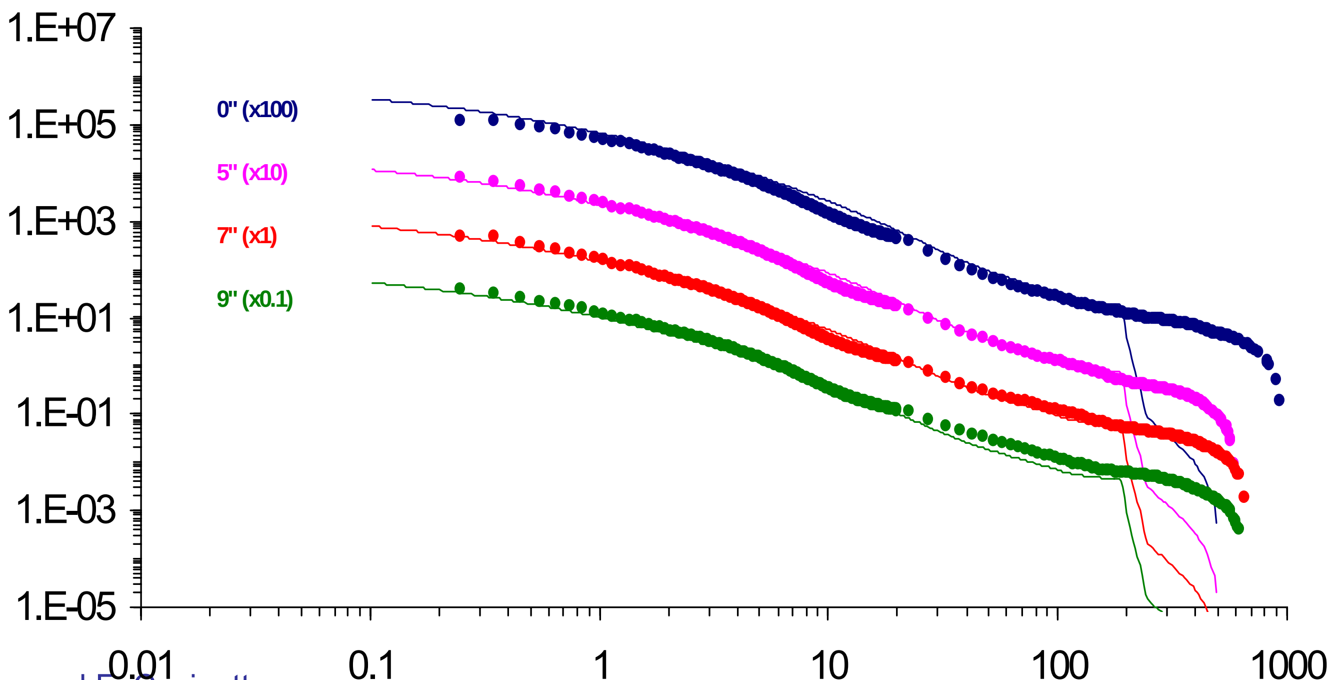


LET vs TEPC



TEPC model
Vs TEPC (no TF)

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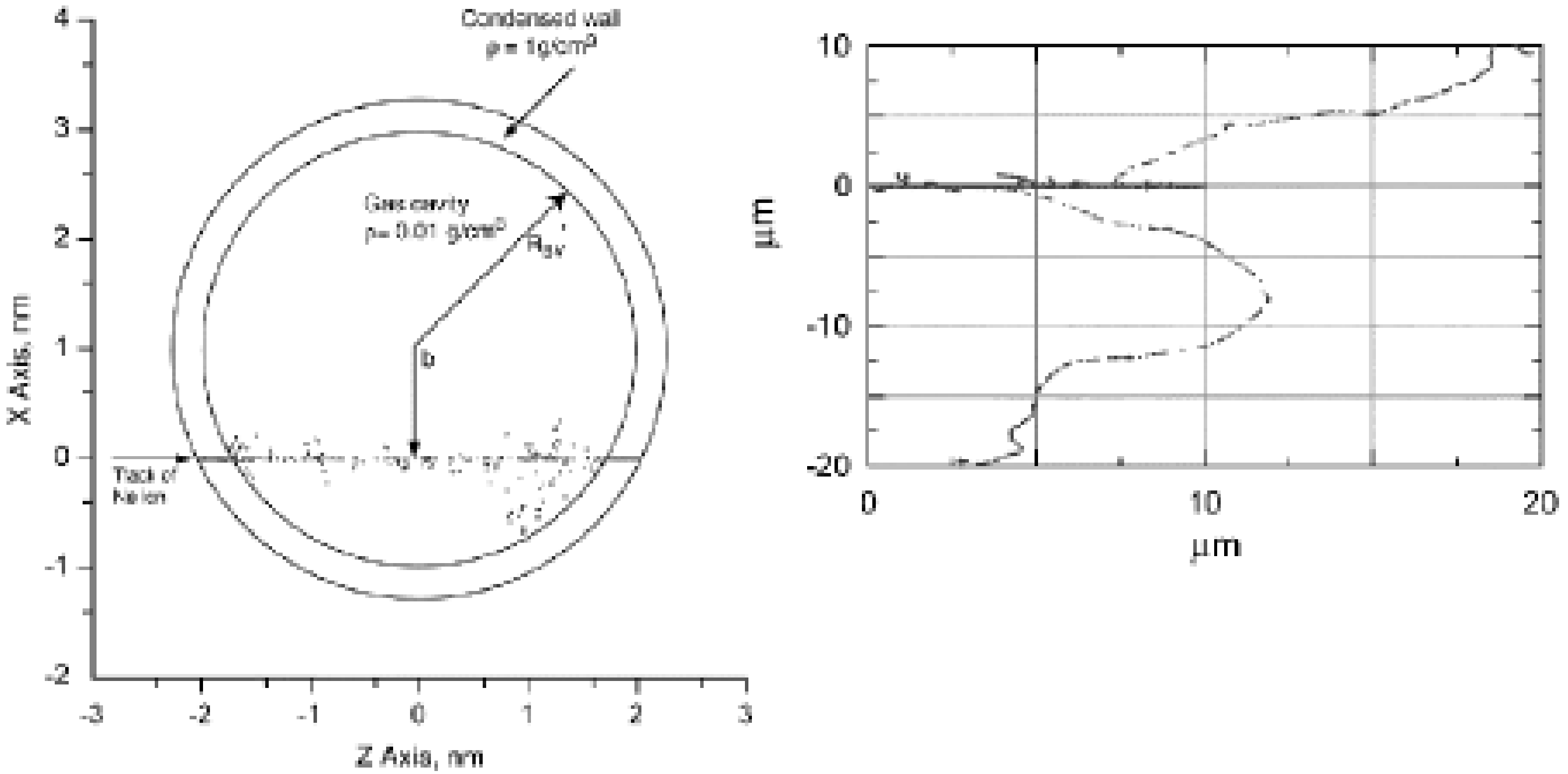

Figure 3. An example of the energy transfer points produced by the passage of a high-energy Ne ion through a walled proportional-counter chamber (left) and of the two-dimensional spatial distribution of two long-range δ-rays (electrons) originating from the primary track (right).