Results from Passive Detector Intercomparisons made during the ICCHIBAN-2 Experiment and Current Status of the ICCHIBAN-4 and Proton ICCHIBAN Experiments

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Overview of ICCHIBAN Experiments for Passive Detectors

ICCHIBAN-2, May 2002:	150 MeV/n He 400 MeV/n C 490 MeV/n Si 500 MeV/n Fe
ICCHIBAN-4, May 2003:	150 MeV/n He 400 MeV/n C 400 MeV/n Ne 500 MeV/n Fe
Proton ICCHIBAN, Sept. 2003:	70-250 MeV protons

ICCHIBAN-2: Participants

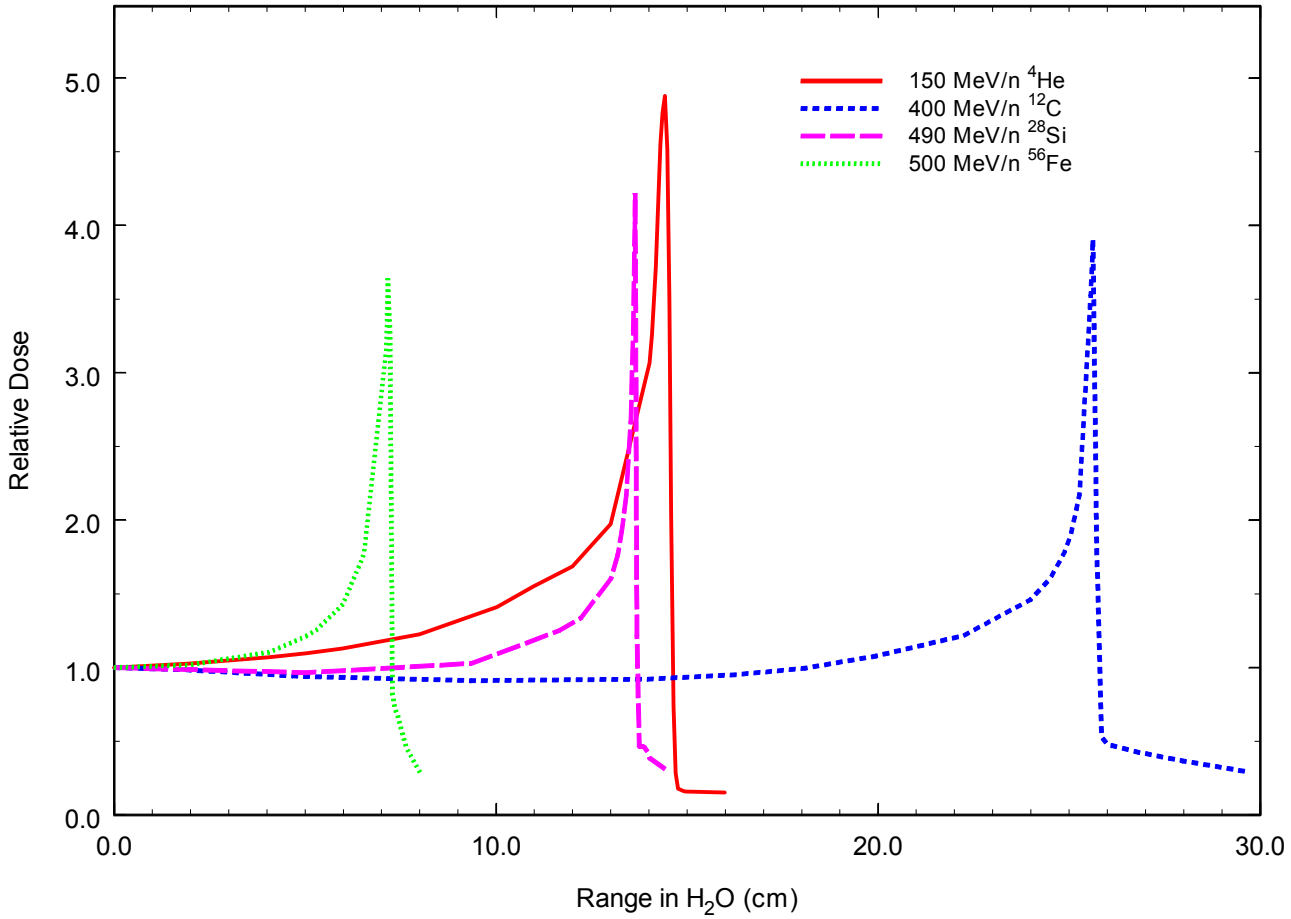
Institution	Investigators	Country	Detectors
ATI	T. Berger*, M. Hajek & N. Vana	Austria	TLD-600 (^{6}LiF:Mg, Ti), TLD-700 (^{7}LiF:Mg, Ti) CR-39 PNTD
DLR	G. Reitz	Germany	TLD-100 (LiF:Mg,Ti)
ERI	E. R. Benton*, A. L. Frank & E. V. Benton	USA	CR-39 PNTD, TLD-700 (^{7}LiF:Mg, Ti)
IMBP	Yu. Akatov* & V. Shurshakov	Russia	TLD-100 (LiF:Mg,Ti), CR-39 PNTD, Biomarker Seeds
KFKI AEKI	S. Deme, I. Apathy & T. Pazmandi	Hungary	Pille TLD System ($CaSO_4$:Dy)
INP	P. Bilski & T. Horwacik	Poland	TLD-100 (LiF:Mg,Ti), LiF:Mg,Cu,P TLD, LiF:Mg,Ti, CR-39 PNTD
NASA JSC	E. Semones	USA	TLD-100 (LiF:Mg,Ti), TLD-300 (CaF_2:Tm), TLD-600 (^{6}LiF:Mg, Ti), TLD-700 (^{7}LiF:Mg, Ti)
NIRS	Y. Uchihori*, H. Kitamura* & N. Yasuda	Japan	Luilin-4J MDU
NRPB	D. Bartlett * L. Hager	UK	PADC PNTD
NASDA/KEK	H. Tawara, A. Nagamatsu* & M. Masukawa	Japan	MSO TLD (Mg_2SiO_4:Tb), CR-39 PNTD
NPI	F. Spurny & K. Turek	Czech Rep.	CR-39 PNTD, Melinex/Bi PNTD, Al_2O_3:C TLD, Al-P Glass
OSU	S.W.S. McKeever, R. Gaza, & E. G. Yukihara	USA	Al_2O_3:C OSL, Luxel Al_2O_3 OSL, Al_2O_3:C TLD, TLD-100 (LiF:Mg,Ti)

*Present at HIMAC

ICCHIBAN-2: Passive Detectors

- 12 Labaratories from 9 countries
- Two basic types of detectors (with a few exceptions): TLDs (including OSL) and CR-39 PNTDs
- Much variation within each detector type
  - TLDs: LiF most common, but all three forms of LiF (TLD-100, TLD-600, TLD-700) were used. Other types of TLD also used included CaF_2:Tm, Mg_2SiO_4:Tb, $CaSO_4$:Dy & Al_2O_3:C.
  - CR-39 PNTDs included both standard chemical etch and electrochemical etch.
- Other detectors included Biomarker Seeds (IMBP) and Alumino-Phosphate glass (NPI).

ICCHIBAN-2: Heavy Ion Bragg Curves



ICCHIBAN-2: Heavy Ions

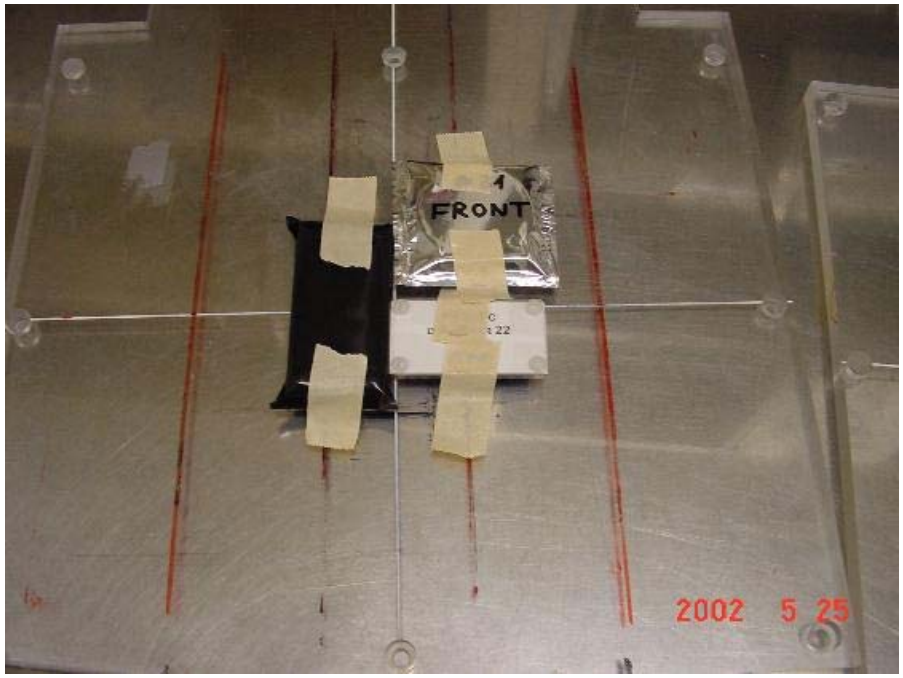
Date	Ion	Nominal Energy (MeV/n)	Actual Energy (MeV/n)	Range in H_2O (cm)	$LET_{\infty}H_2O$ (keV/μm)	IC* $LET_{\infty}H_2O$ (keV/μm)
24/05/02	^{4}He	150	143.5	14.2	2.29	2.24
25/05/02	^{12}C	400	396.9	26.6	11.19	10.96
23/05/02	^{28}Si	490	446.6	13.74	57.55	55.05
28/05/02	^{56}Fe	500	420.6	7.26	204.2	200.8

*Ion chamber measurement

ICCHIBAN-2: Exposures

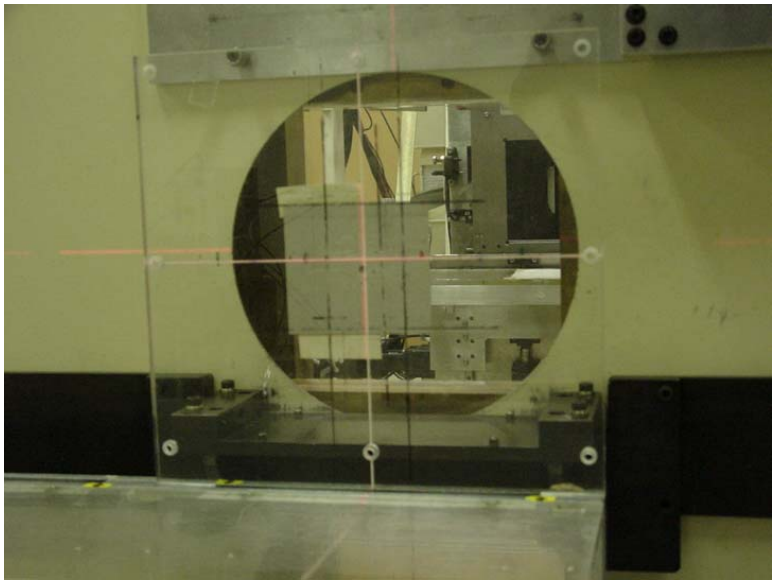
- Linearity/LET Efficiency Exposures:
  - 4 doses (1, 10, 50, 100 mGy)
  - 4 monoenergetic beams
- Fragmentation: 5 g/cm^2 layer of acrylic (PMMA)
- Blind Exposures:
  - 8 detectors exposed
  - participants not given any *a priori* knowledge of exposure composition.

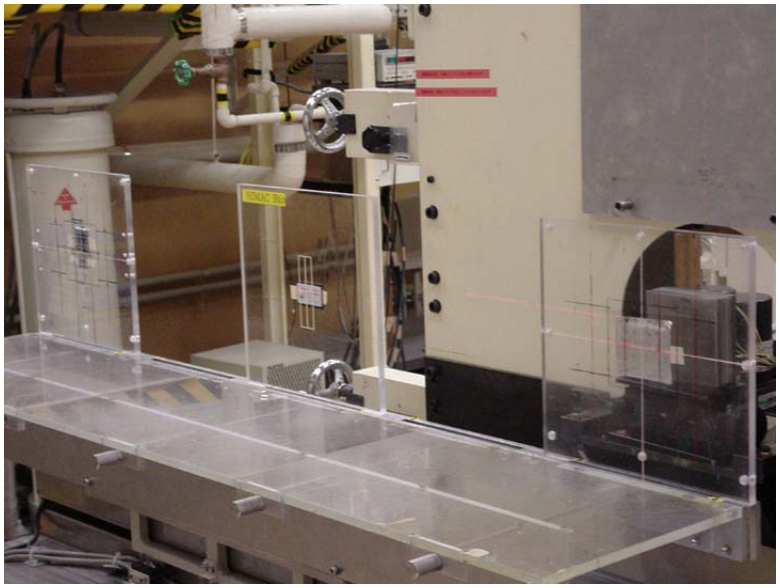
ICCHIBAN-2: Preparation of Detectors



- All Exposures carried out in HIMAC “BIO” room.
- Beam spot: ~10 cm diameter
- Passive detector packages taped onto acrylic plates.
- Each group used on labeling conventions, leading to confusion.

ICCHIBAN-2: Preparation of Detectors





The plates placed in left, center and right positions of 5-place sample chamber.

ICCHIBAN-2: Reporting of Results

- Each participant was asked to submit a written report documenting their results.
- Reports ranged from none at all to highly detailed (grad. students) along a smooth gradient.
- Not all labs participated in all exposures (usually due to limitations of their detectors).
- Not all labs provided identical dosimeter packages for each exposure.
- Not all labs provided results from all exposures.
- Not all labs provided values of standard deviation or uncertainty with their results.
- Often results were not directly comparable, requiring conversion.

ICCHIBAN-2: Linearity/Efficiency Exposures

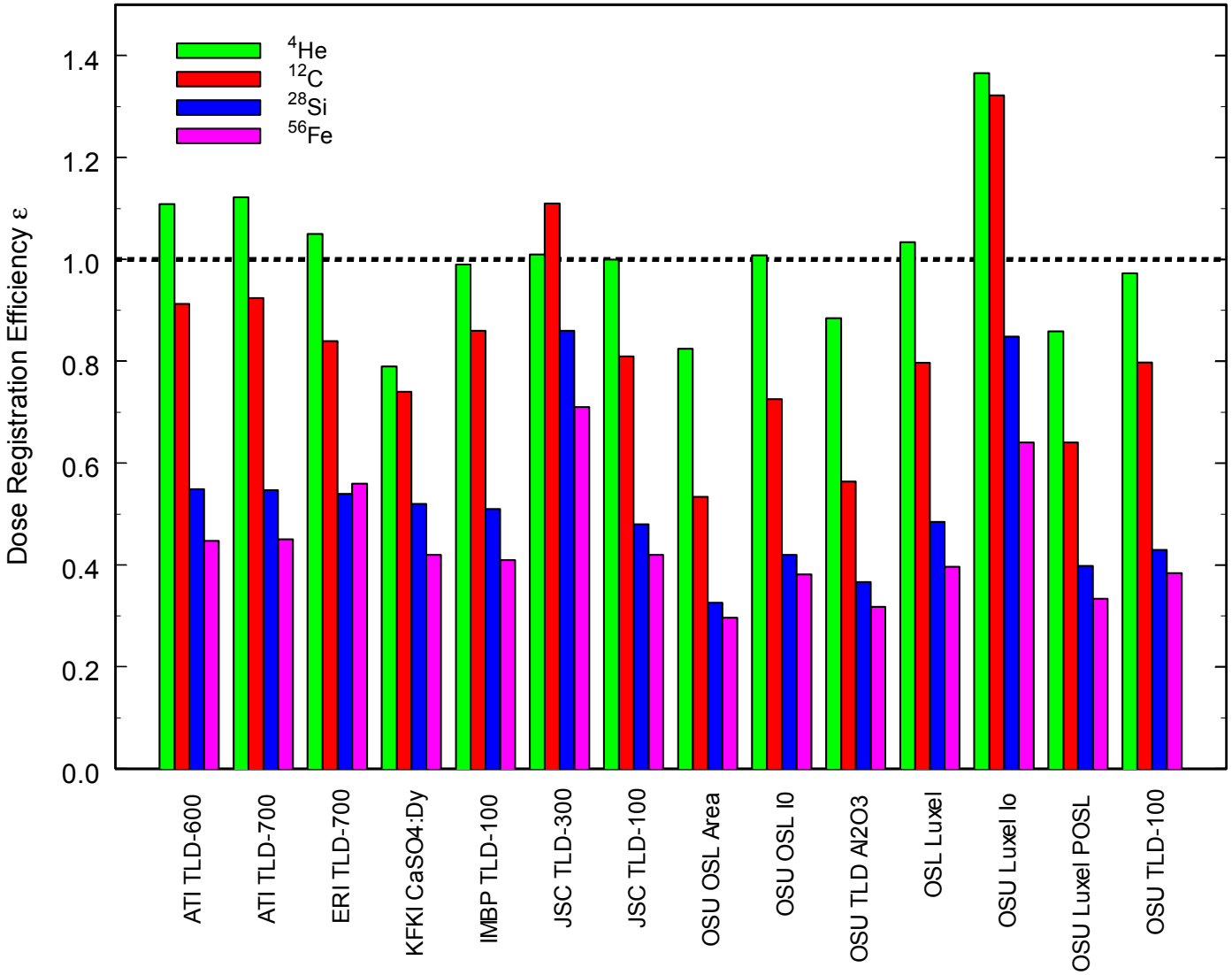
- All detectors (both TLDs and CR-39 PNTDs) demonstrated linearity as a function of dose.

- Not all groups measured Dose Registration Efficiency as a function of LET.

- Those groups that did measure Dose Registration Efficiency didn't define efficiency in the same way.

$$\varepsilon = \frac{D_{TLD}}{D_{IC}} \qquad \varepsilon = \frac{D_{TLD_H} / D_{IC}}{D_{TLD_\gamma} / D_\gamma}$$

ICCHIBAN-2: High-LET TLD Efficiency



ICCHIBAN-2: TLD Performance

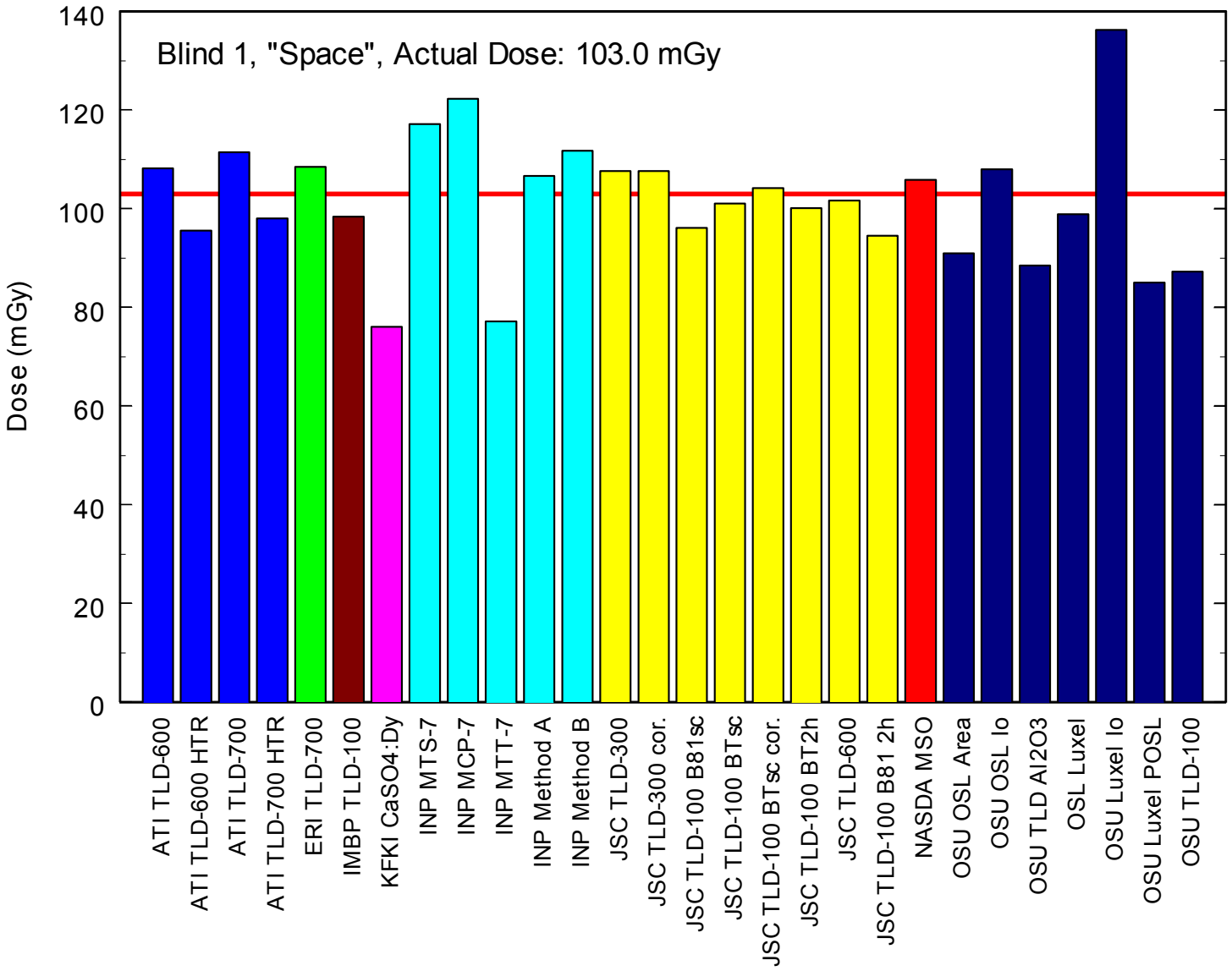
Many assumptions about how TLD analysis was carried out by different participants left undefined.

- Efficiency for LiF TLD (-100, -600, -700) nearly same for all groups.
- Assumed results were in tissue dose, not dose in air.
- In most cases, not specified in report how TLDs were calibrated (i.e. with ^{137}Cs γ-rays, ^{60}Co γ-rays or other).
- Pille $CaSO_4$:Dy results probably low because this was dose in air, not dose in water.
- Issue of tissue dose vs. air dose brought up at several WRMISS meetings, need to establish “Space Dosimetry Standard”.

ICCHIBAN-2: Blind Exposures

	^{4}He	^{12}C	^{28}Si	^{56}Fe
1. Space	100 mGy	1 mGy	1 mGy	1 mGy
2. Equal Dose No. 1	2 mGy	2 mGy	2 mGy	2 mGy
3. Equal Dose No. 2	5 mGy	5 mGy	5 mGy	5 mGy
4. Equal Fluence	1000 cm^{-2}	1000 cm^{-2}	1000 cm^{-2}	1000 cm^{-2}
5. “Magic”	1 mGy	3 mGy	7 mGy	12 mGy
6. 10 g/cm^2 Al (Si), 5.4 g/cm^2 Al (Fe)			5 mGy	1 mGy
7. 10 g/cm^2 Al + 5.4 g/cm^2 PMMA			2 mGy	
8. Spread Out Bragg Peak				5000 cm^{-2}

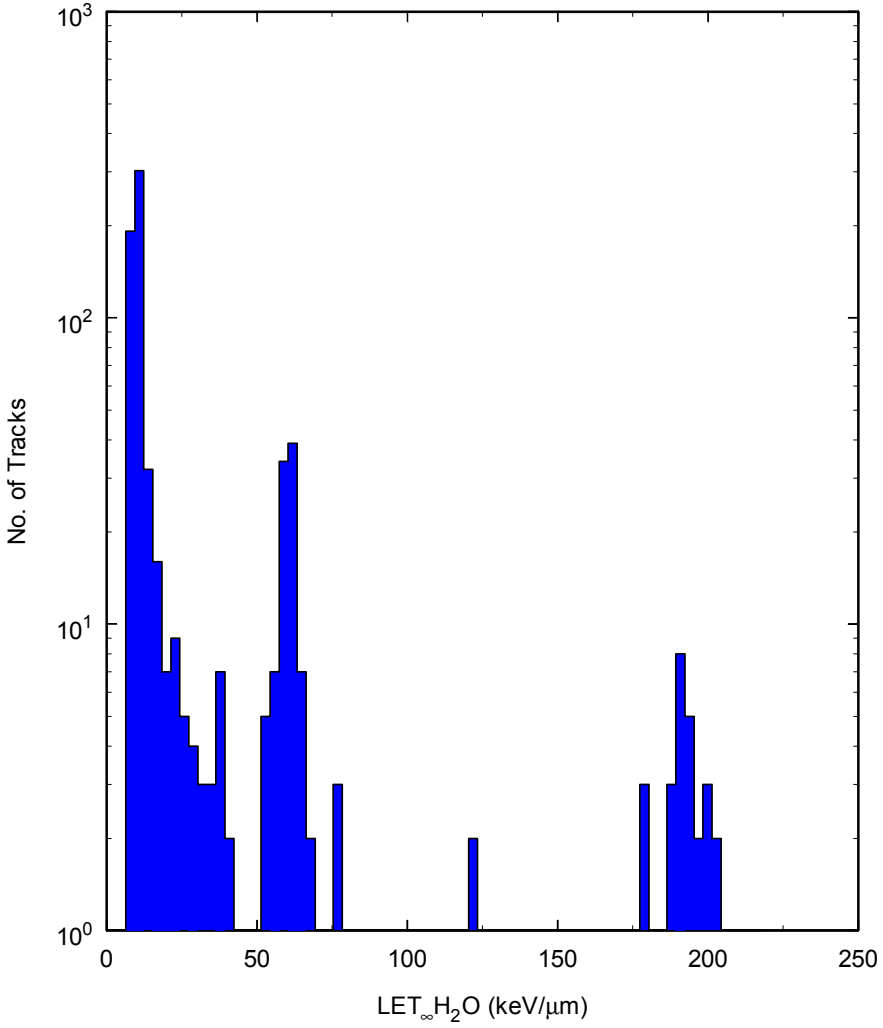
ICCHIBAN-2: Blind No. 1 TLD/OSL

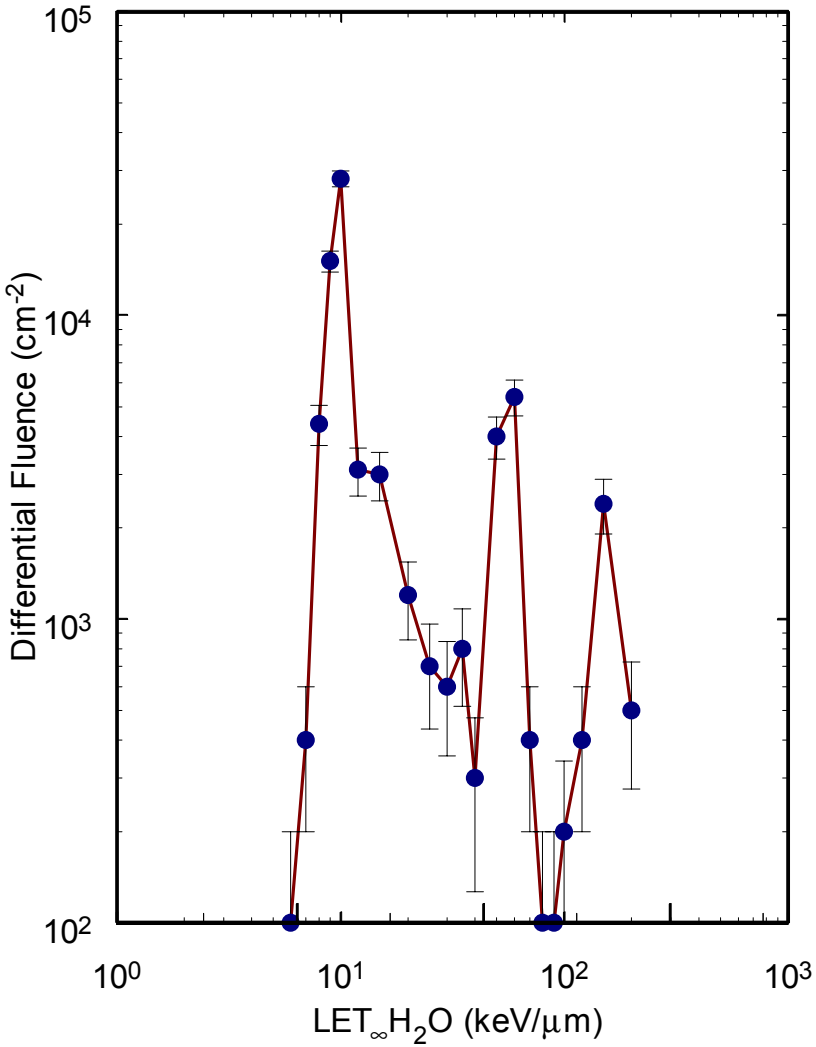


ICCHIBAN-2: Blind 1 TLD Results

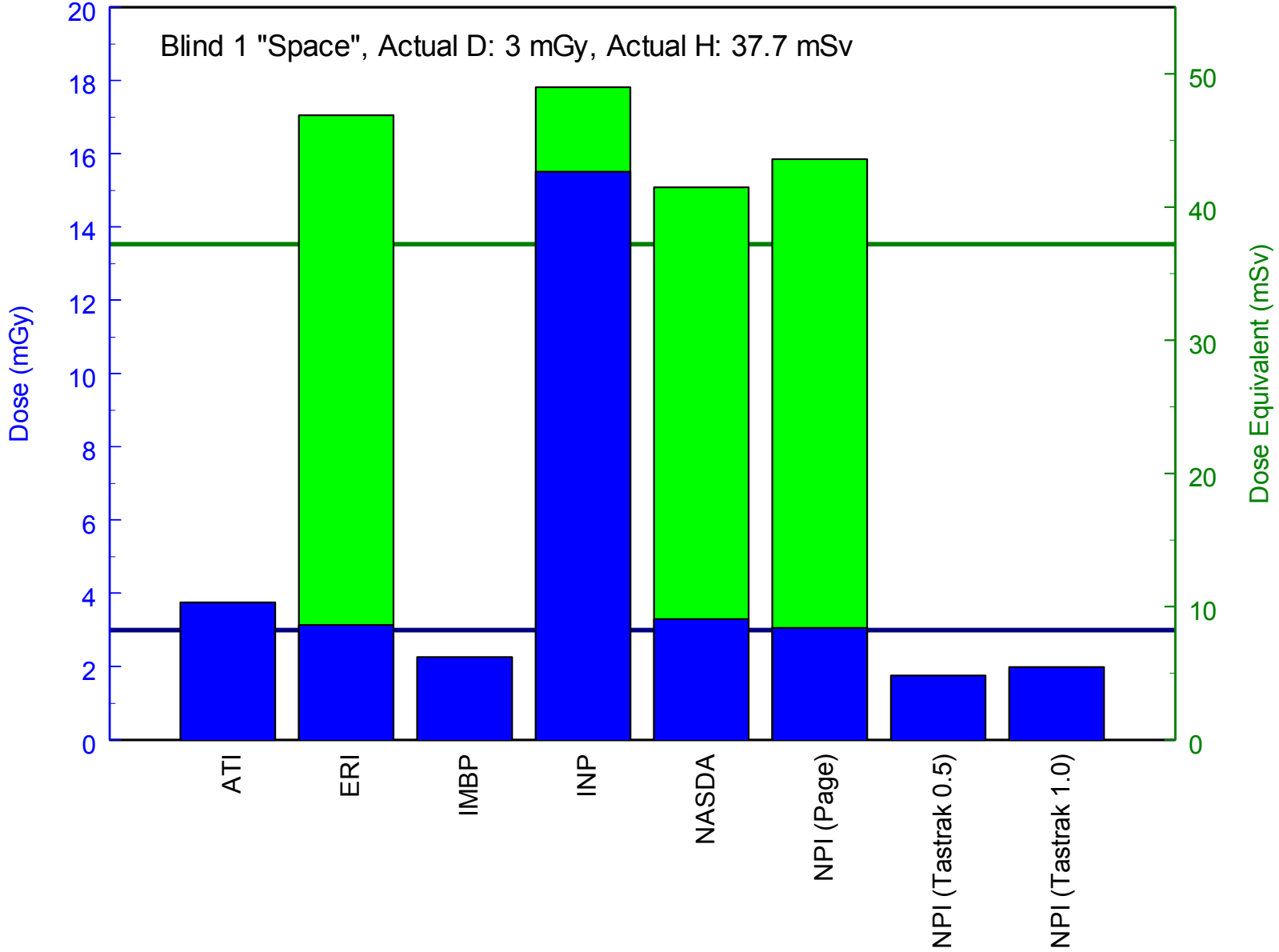
- Most like space exposure because dominated by low-LET charged particles (He instead of protons)
- Gave best results for TLDs because of large low-LET component. Reduced efficiency of high-LET particles did have major influence on result.
- Dose measured by TLD was fairly close to actual dose delivered by HIMAC and measured by HIMAC ion chamber.

ICCHIBAN-2: Blind No. 1 LET Spectrum

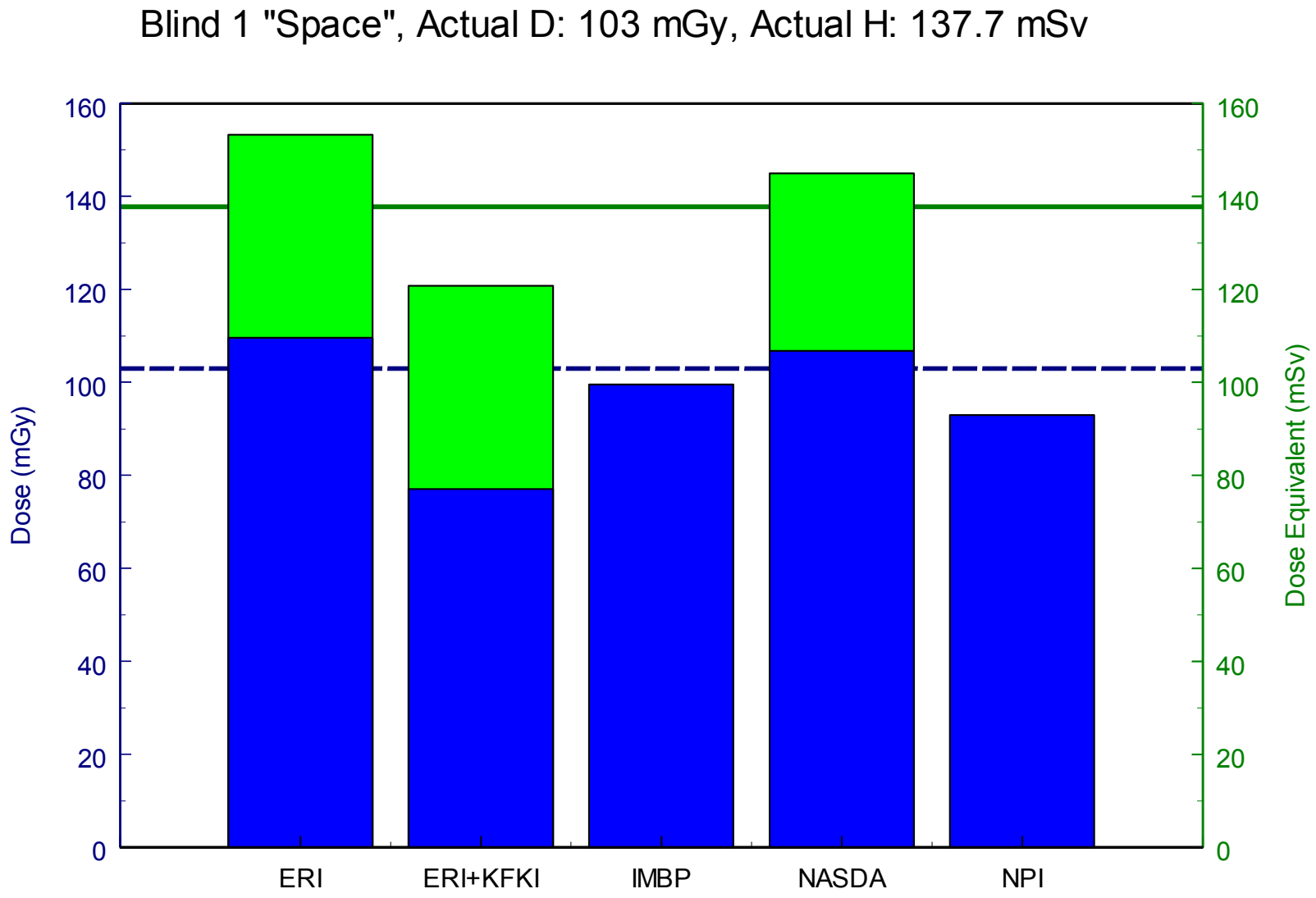




ICCHIBAN-2: Blind No. 1 CR-39 PNTDs



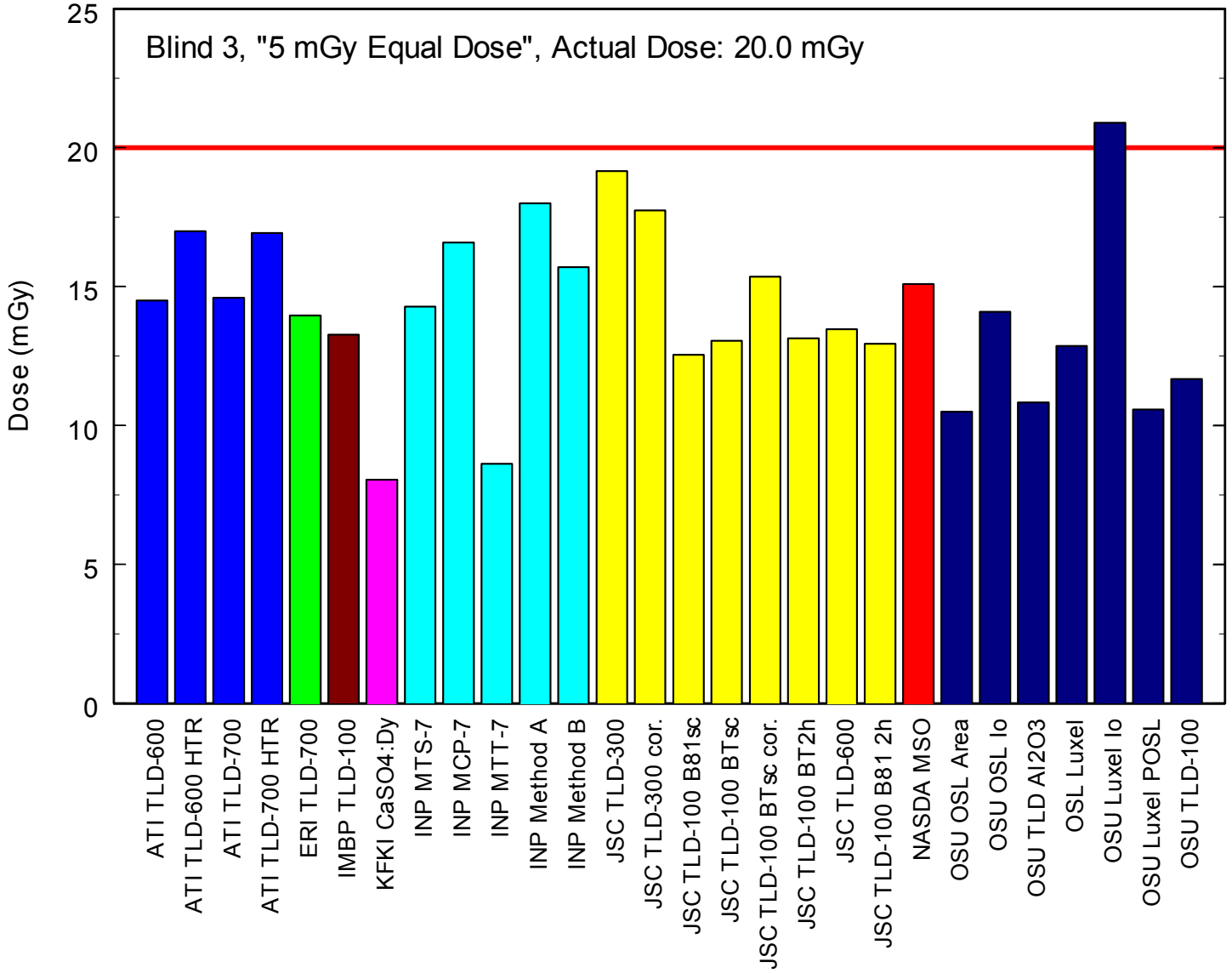
ICCHIBAN-2: Blind No. 1 TLD+PNTD



ICCHIBAN-2: Blind No. 1 PNTD Results

- No participant (except ERI) provided LET spectrum.
- Although 6 groups exposed CR-39 for Blind 1, only 4 groups provided dose equivalent from CR-39.
- Only 2 groups provided Dose and Dose Equivalent from combined TLD+CR-39.
- Appears that groups using CR-39 “reversed engineered” the blind exposure by deducing how exposure was made rather than measuring dose and dose equivalent as if this were a space-exposed dosimeter.

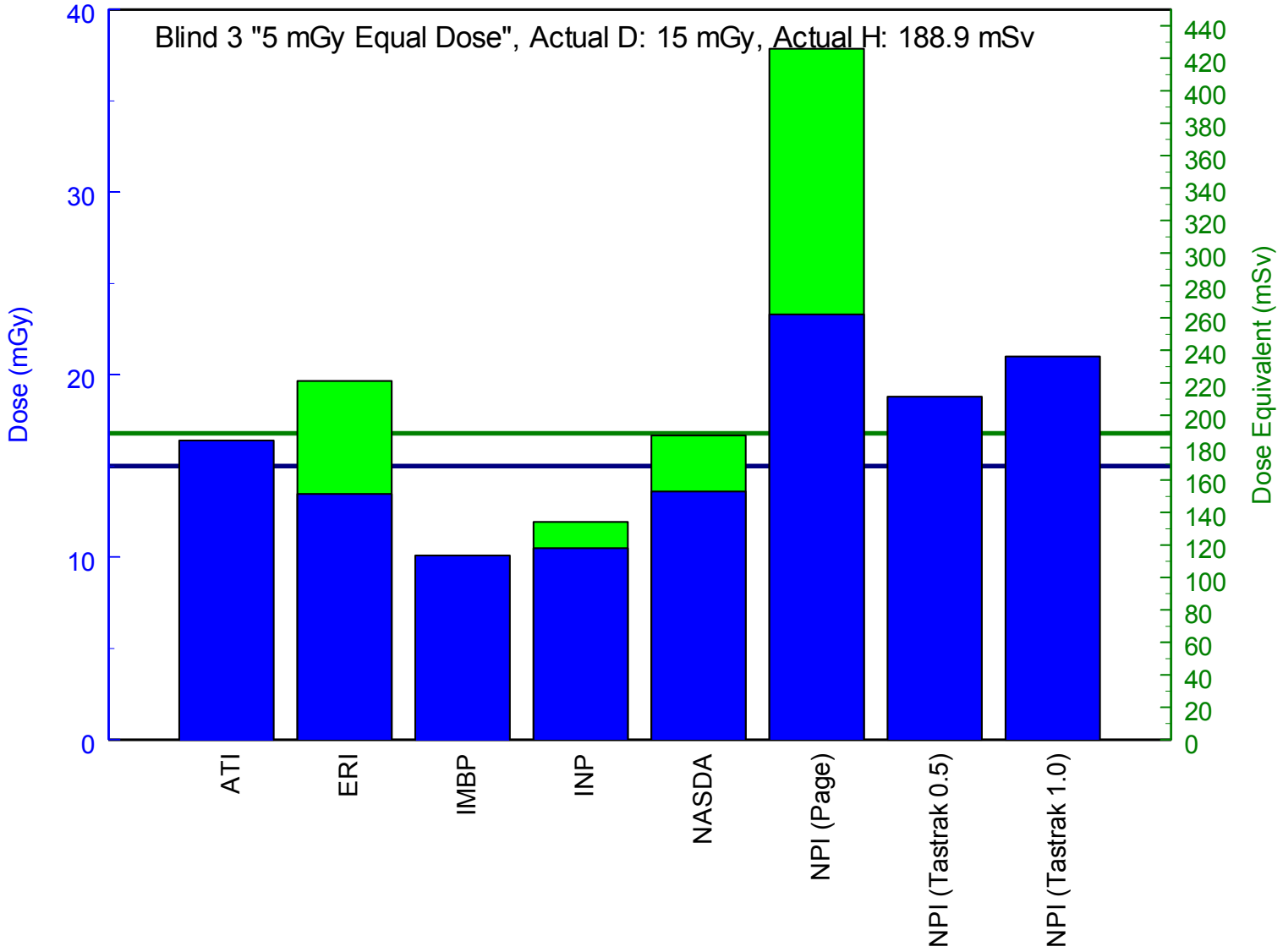
ICCHIBAN-2: Blind No. 3 TLD/OSLD



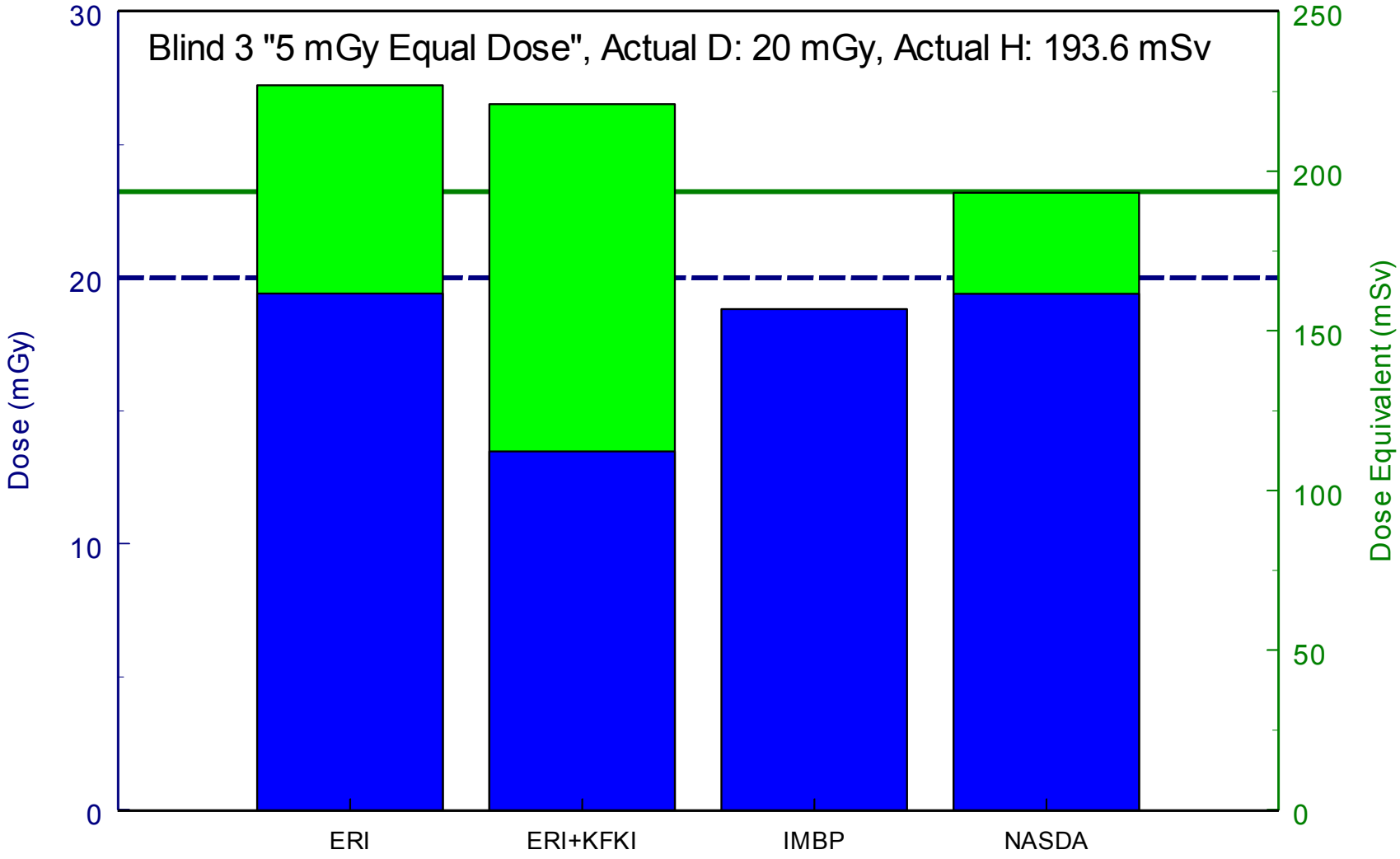
ICCHIBAN-2: Blind No. 3 TLD Results

- Large fraction of total dose from heavy ions resulted in under-measurement by TLDs due to reduced dose registration effiency of high-LET particles in TLD.
- OSU Luxel I_0 OSL was closest to actual dose, followed by JSC TLD-300.
- High-LET corrections such as HTR (ATI) and method of NPI resulted in significant improvement of dose value.

ICCHIBAN-2: Blind No. 3 CR-39 PNTDs



ICCHIBAN-2: Blind No. 3 TLD+PNTD

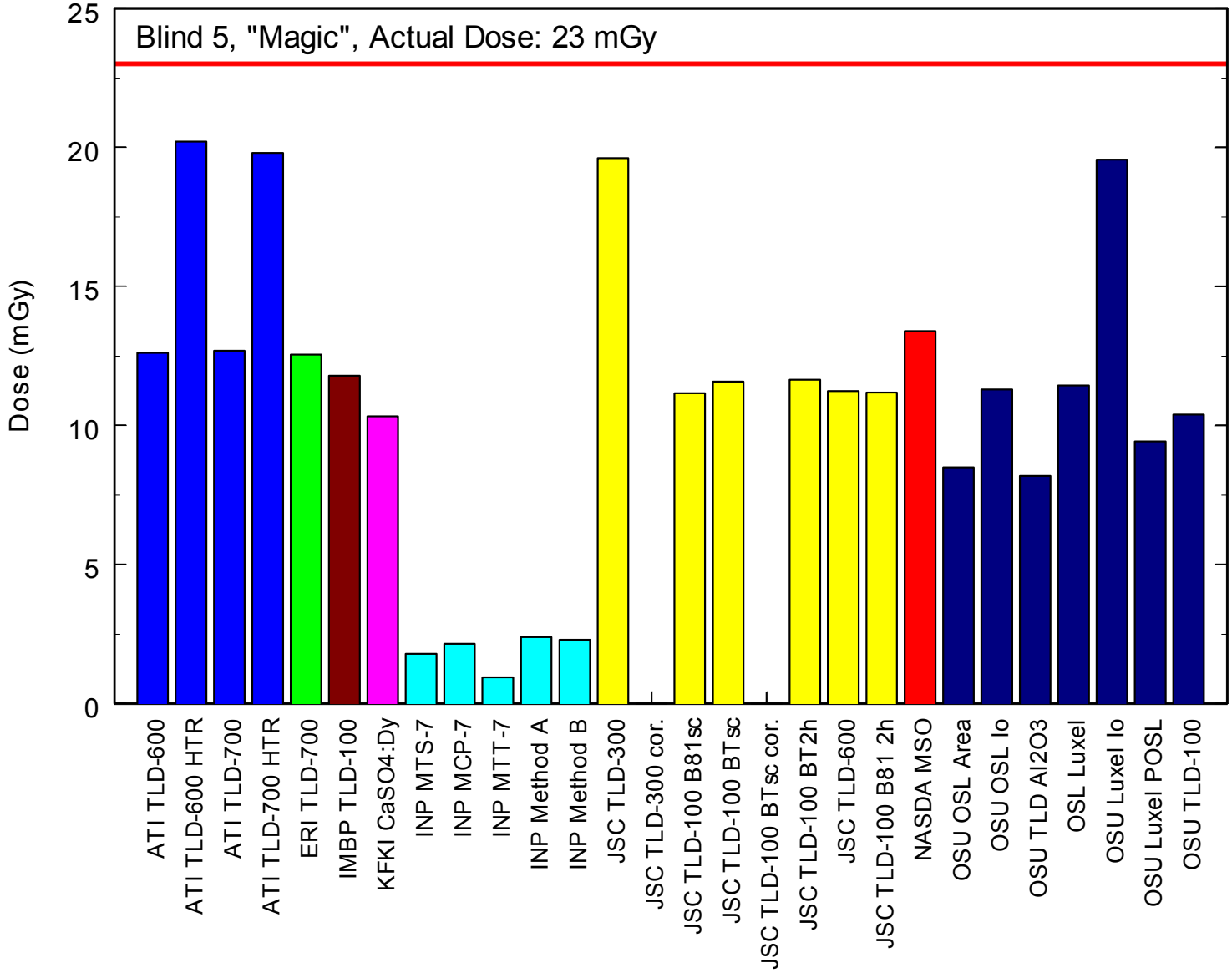


ICCHIBAN-2: Blind No. 3 PNTD Result

Results similar to that from Blind No. 1:

- Although 6 groups exposed CR-39 for Blind 1, only 4 groups provided dose equivalent from CR-39.
- Only 2 groups provided Dose and Dose Equivalent from combined TLD+CR-39.
- Lack of LET spectrum made it impossible to determine how dose (and dose equivalent) was measured.
- CR-39 analysis appears to have been “reversed engineered.” Small tracks assumed to be C, medium tracks assumed to be Si and large tracks assumed to be Fe.

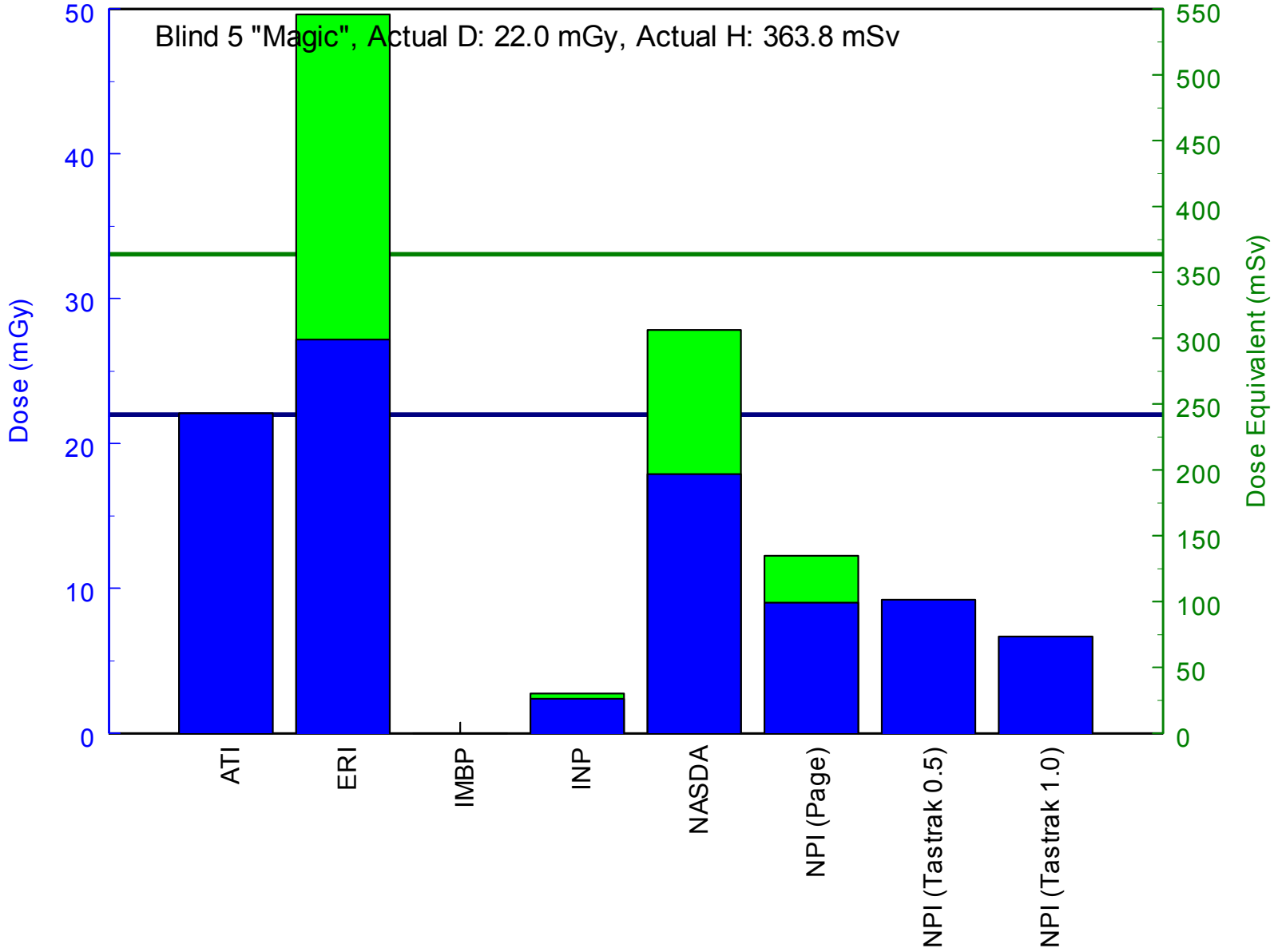
ICCHIBAN-2: Blind No. 5 TLD/OSLD



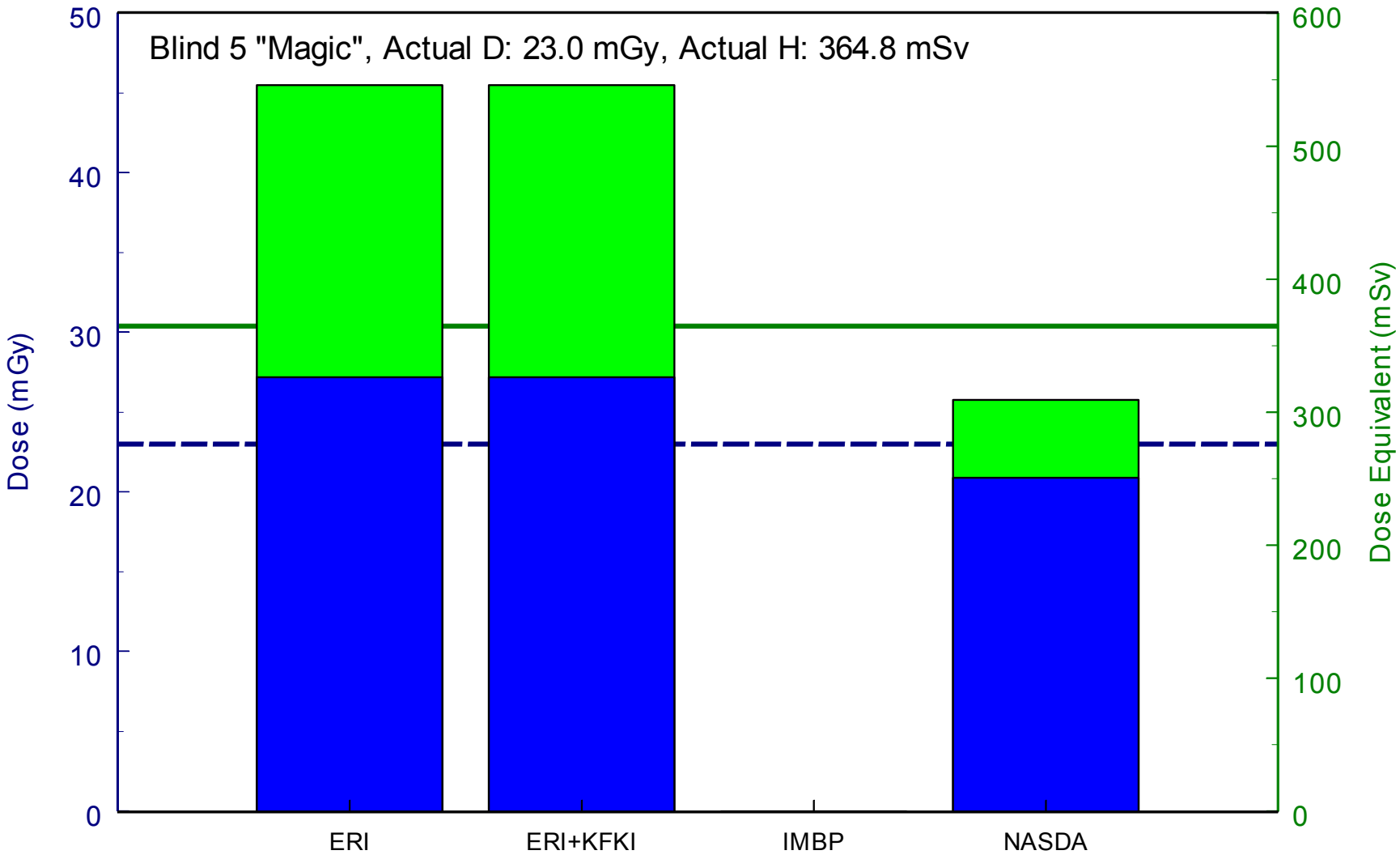
ICCHIBAN-2: Blind No. 5 TLD Results

- Largest contribution from Fe and smallest contribution from He, opposite of Blind No. 1
- Worst performance by TLDs of all blind exposures.
- Best results for ATI HTR corrected TLDs, JSC TLD-300 and OSU Luxel I_0 OSL. However, doses still low by >12%.

ICCHIBAN-2: Blind No. 5 CR-39 PNTDs



ICCHIBAN-2: Blind No. 5 TLD+PNTD



ICCHIBAN-2: Blind No. 5 PNTD Results

- Difficult to analyze CR-39 since detector was saturated by high dose, especially after long etch (B= ~40 μm).
- Short etch needed to measure Fe and Si tracks.
- Long etch needed to measure C tracks.
- Saturation of detector led to large errors in reported results.
- Not like any real “space” exposure…unrealistic.

ICCHIBAN-2: Conclusions-1

Two types of Conclusions can be drawn from the ICCHIBAN-2 Experiment.

- Conclusions concerning performance of the different passive dosimeters and associated analysis methods.
- Conclusions concerning how to conduct a passive dosimeter intercomparison experiment.

ICCHIBAN-2: TLD Conclusions

- Best TLD performance was JSC uncorrected TLD-300 (CaF_2:Tm), followed by ATI TLD-600/700 (LiF) after HTR correction.
- Honorable mention: OSU Luxel I_0 OSL performed well in high-LET dominated exposures (Blind 3 & 5), but poorly in realistic low-LET dominated exposure (Blind 1).
- Some of the differences in the results may have been from differences in measured quantity (dose in air vs. dose in tissue).
- Need to establish Space Radiation TLD/OSL Standard.

ICCHIBAN-2: PNTD Conclusions

- Originally expected PNTDs from only 2 groups (ERI & NASDA). Pleased to have PNTDs from 4 other groups.
- Only ERI provided LET spectrum. Not known how other groups determined PNTD dose.
- Best PNTD results and PNTD+TLD results were from NASDA (however no LET spectrum).
- Some groups used methods that could not be used for PNTDs exposed in space in order to measured PNTD dose.

ICCHIBAN-2: Overall Conclusions

- All Blind exposures, except Blind No. 1, not very realistic. We have already attempted to correct this problem in the Blind exposures during ICCHIBAN-4.
- TLDs alone yielded only dose, although some materials/methods yielded quite accurate measurement of dose.
- CR-39 + TLD needed to obtain dose equivalent.
- Intercomparison Report, including results for all 8 blind runs, is nearly completed and will be included in first NIRS ICCHIBAN report to be published by the end of these year.

ICCHIBAN-2: Overall Conclusions

- Reports from many groups were not detailed enough to understand how analysis was performed.
- Many groups did not provided dose/dose equivalent values with which to make comparison. Other requested results were often also not provided.
- Perhaps ICCHIBAN Working Group needed to provide more explicit instructions on the reporting of results.
- Because participation in ICCHIBAN-2 was completely voluntary, no way to require participants to provide all requested results.

ICCHIBAN-4 & Proton ICCHIBAN

- Participants currently analyzing results from ICCHIBAN-4 experiment, May 2003. (one group has already provided preliminary results).
- Proton ICCHIBAN will be carried out this weekend at Loma Linda. Already have received most participants' passive dosimeters.
- Will report on results for ICCHIBAN-4 and Proton-ICCHIBAN Intercomparison at WRMISS-9 next year.

Proton ICCHIBAN SPE Simulation

- SPE simulation uses fixed proton energy spectrum between 30 and 210 MeV, based on spectrum measured from Sept. 1989 solar particle event.
- 1 m^2 field size achieved using sweep magnets and array of 9 beam spots.
- Proton spectrum achieved using variable range shifter.
- Simulation designed by George Coutrakon, Peter Koss, Steven Rightnar (LLUMC) and Eric Benton (ERI).
- First trial was last weekend…very successful. Exposed Luilin & Hawk TEPC (Uchihori & Kitamura, NIRS), Shuttle-style TEPC (Gersey, CARR), and Pille TLD system (Deme & Apathy, KFKI).