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PERFORMANCE AND RADIATION TOLERANCE TESTS OF SMALL-SIZED INORGANIC SCINTILLATION DETECTORS

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A B S T R A C T

Preliminary results of the radiation tolerance of CsI(Tl) and CsI(Na) scintillation detectors produced by the Institute of Scintillation Materials (ISMA) are presented based on the experimental data obtained with a help of RADEF heavy ion beam line at the University of Jyvaskyla cyclotron facility.

Figure 1. RADEF test facility at the University of Jyväskylä.

- The performance tests were carried out in the vacuum chamber of the RADEF heavy ion beam line (on the right in Figure 1). All energies used were obtained by directly adjusting the beam energy. The accuracy of the selected beam energies was about 0.5 %. The test facility included a CCD-camera to verify the beam position in the chamber. The beam diameter was approximately 5 cm.

Detectors

MANUFACTURER – INSTITUTE FOR SCINTILLATION MATERIALS (ISMA) OF THE INSTITUTE FOR SINGLE CRYSTALS R&D CORPORATION, KHARKIV, UKRAINE

2 detectors – CsI(Tl) cubical scintillator crystals – 5 x 5 x 5 mm^3;
2 detectors – CsI(Na) cubical scintillator crystals – 5 x 5 x 5 mm^3;
+ large area silicon PIN photodiodes PDC 50s-CR of "Detection Technology", Finland, with active area 5 x 5 mm^2.

Wrapping and reflecting – white pain with a total thickness of ~ 200 micrometers.

Names: tested

ISMA1 – CsI(Tl) - for performance

ISMA2 – CsI(Na) – for peformance + radiation tolerance

ISMA3 – CsI(Tl) – for radiation tolerance

ISMA4 – CsI(Na) - for radiation tolerance

1. Performance tests

Test setup

Preamplifiers with their power supplies were installed in the immediate vicinity of the vacuum chamber (Figure 3) The cable length between detectors and the preamplifier inputs was about 1 m. The data collection electronics were setup in the user barrack with the distance (cable length) of about 15 m between the preamplifiers and the shaping amplifiers.

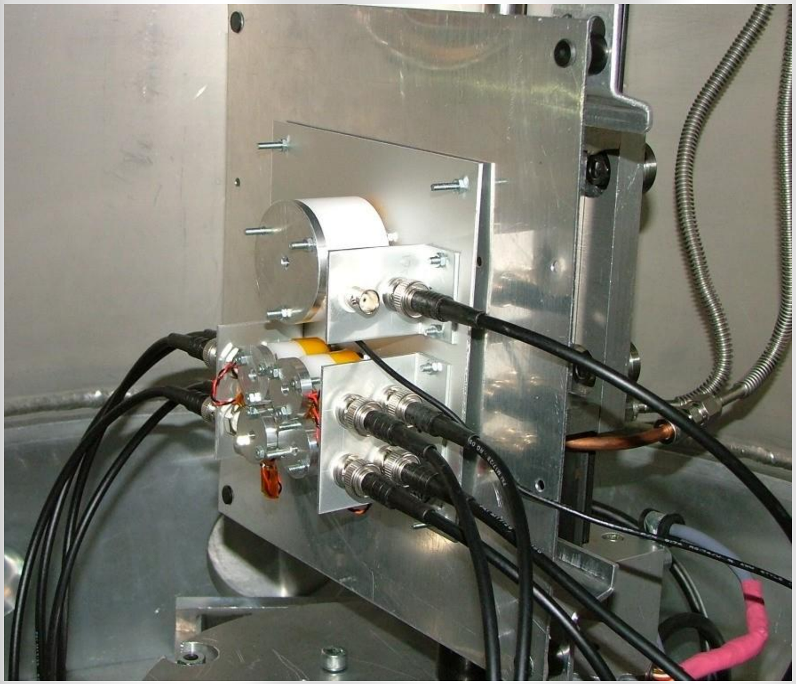


Figure 2. Performance test detectors in the vacuum chamber.

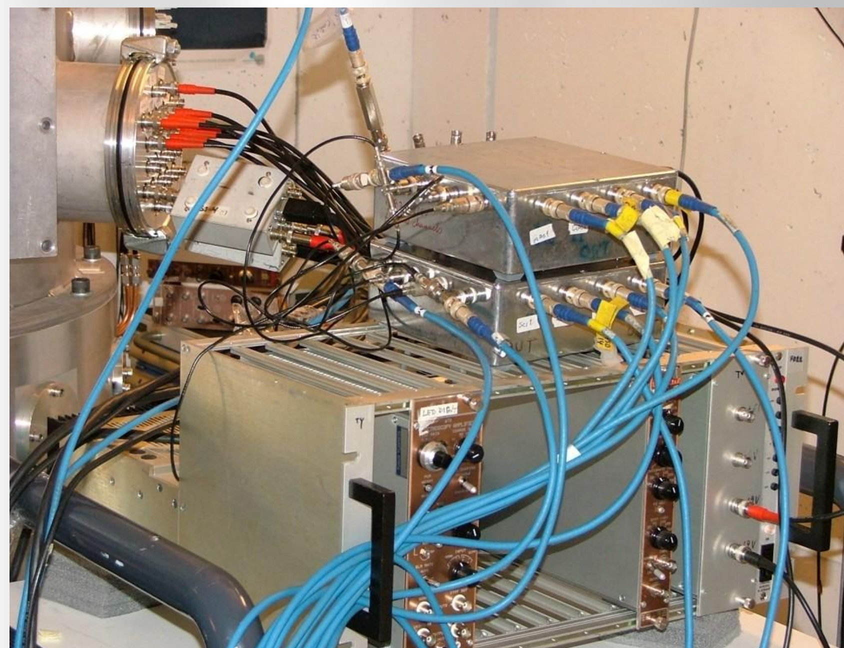


Figure 3. Front-end electronics in the experiment cave outside the vacuum chamber.

Test Procedure

- Measurements were started with 15 MeV beam energy.
- The intensity of the beam was adjusted so that the counting rate of each trigger detector was less than a few hundred counts/s.
- The detectors were positioned in the beam (its known position) by hand with the aid of a CCD camera.
- From 15 MeV the beam energy was lowered first to 10 MeV, then to 6 MeV and 4 MeV.
- The 20 MeV energy was the last to be measured before raising the energy to 55 MeV for radiation tolerance tests.

Energy calibration

Table 1. Amplifier channel conversion factors and electronic noise

Detector + amplifier channel	Conversion factor (keV/Ch)	FWHM electronic noise @ 720 keV (keV)
ISMA1	1.064	24
ISMA2	1.111	27

Fig.4. Pulse height distributions - ISMA1 - CsI(Tl)

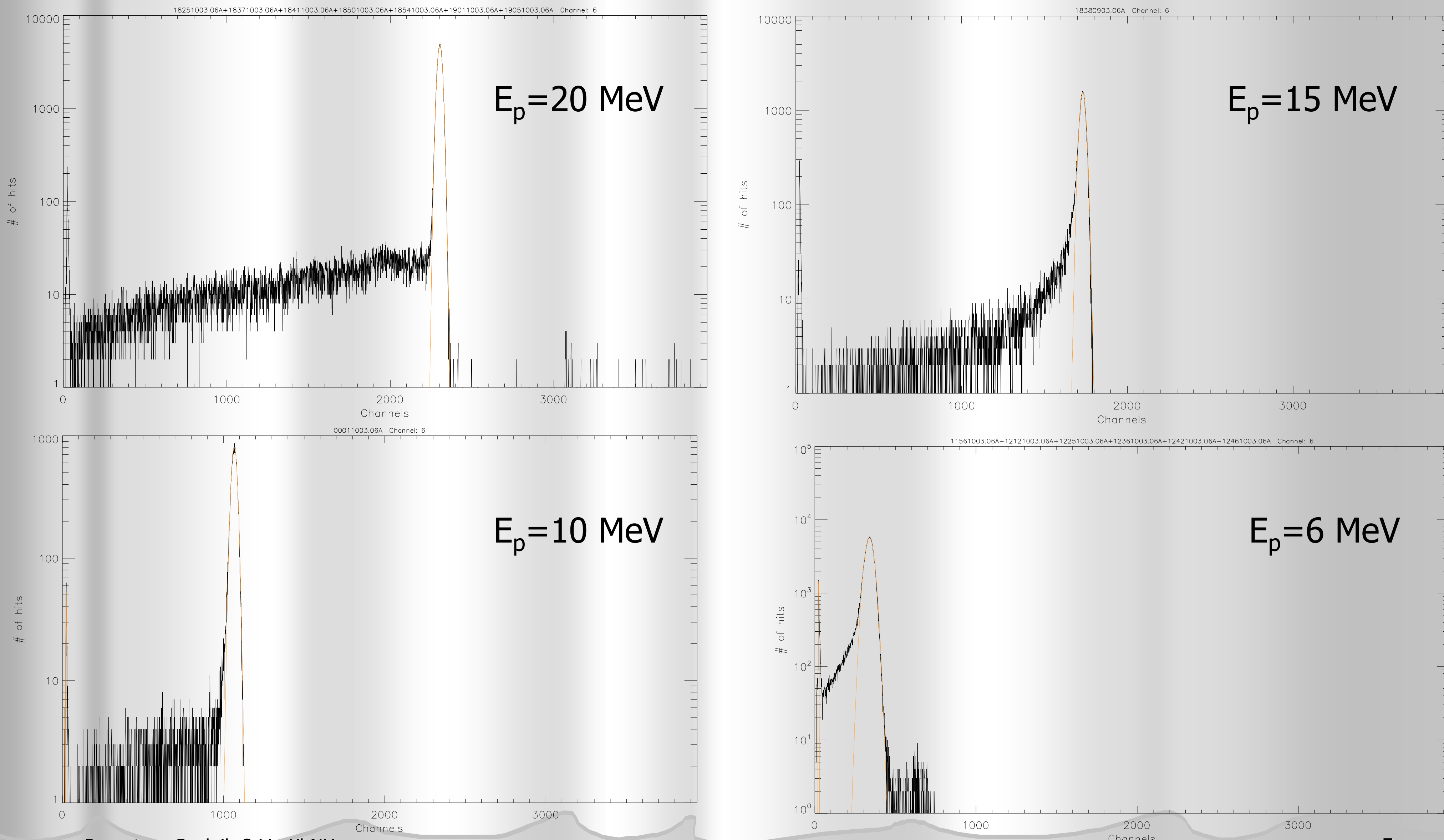


Fig.5. Pulse height distributions - ISMA2 - CsI(Na)

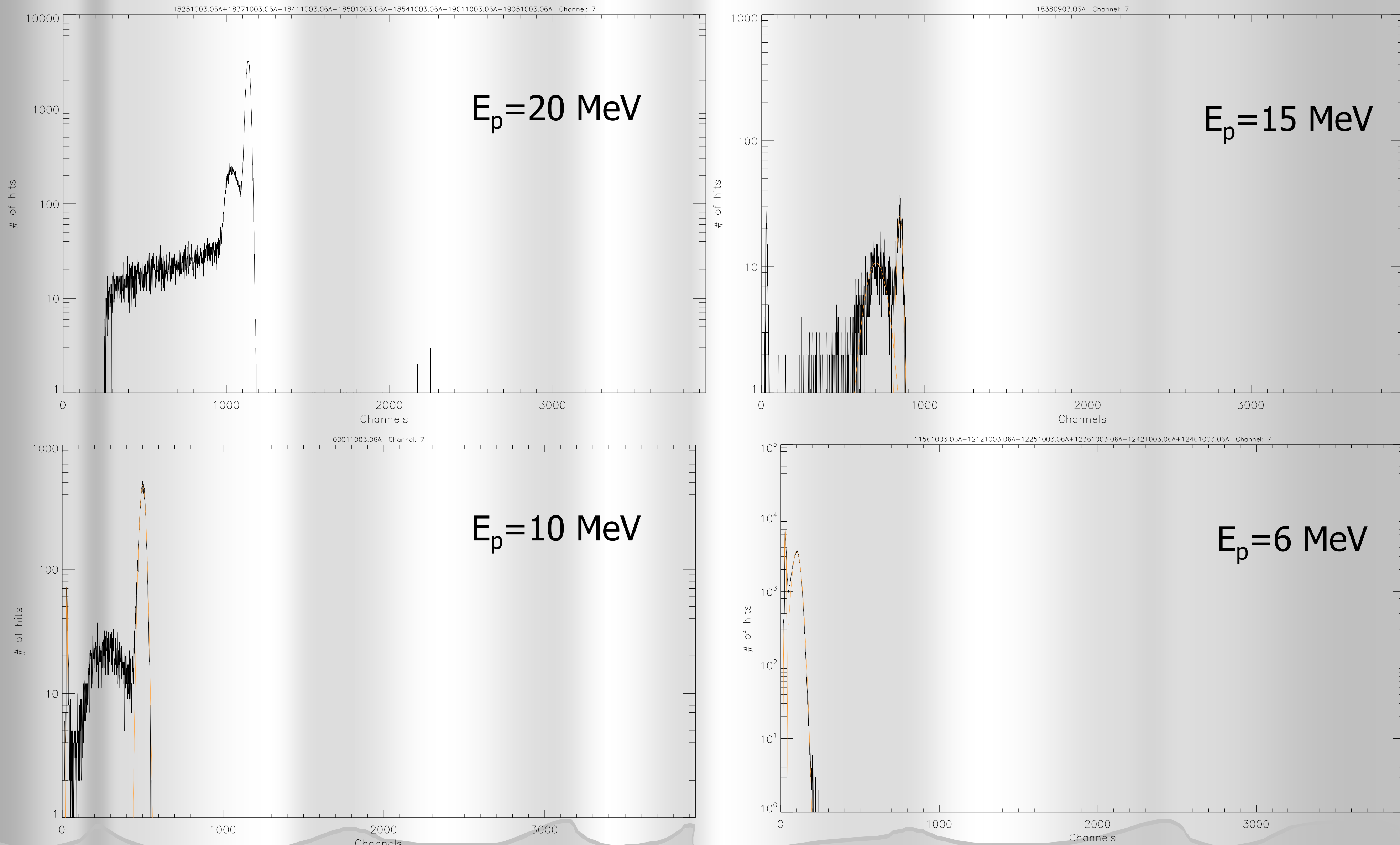
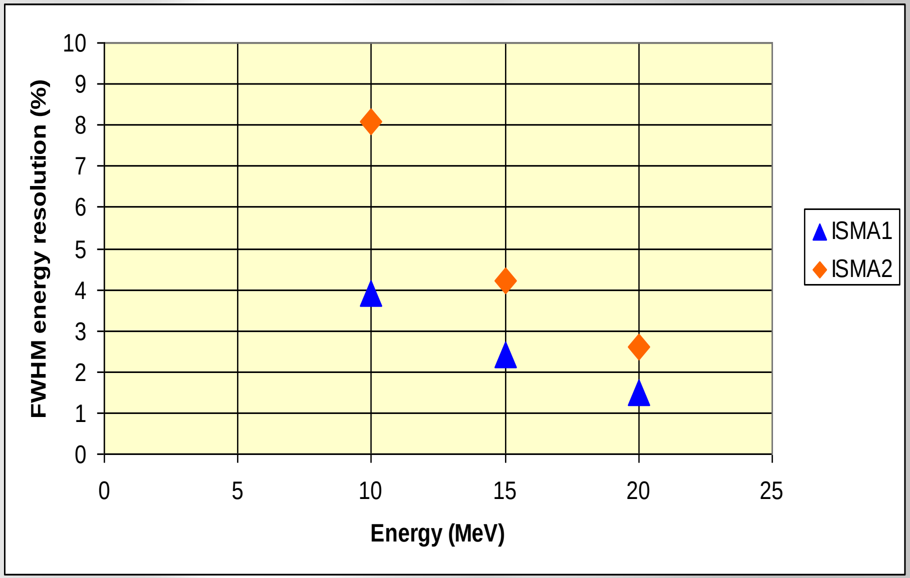
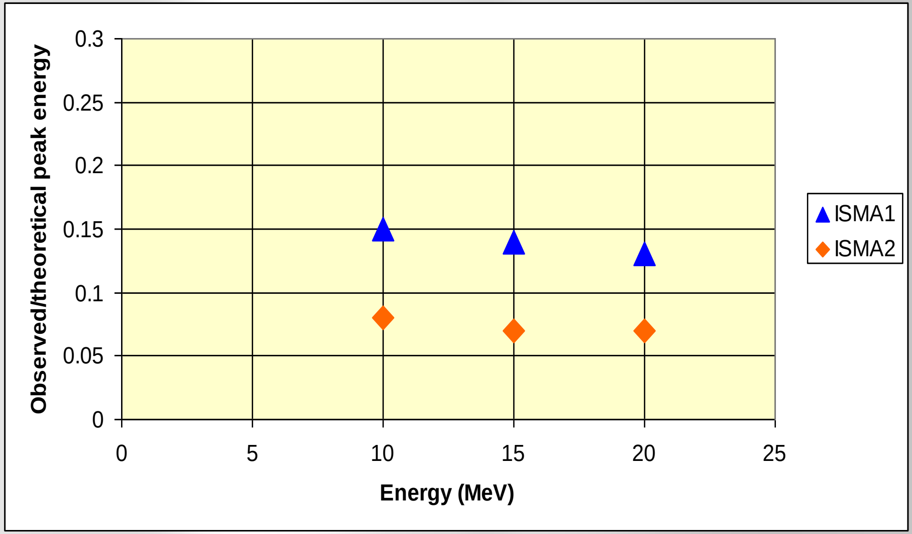


Table 2. Peak position and energy, peak width, energy resolution, and ratio of observed and calculated peak energy for ISMA1 and ISMA2 scintillators.

Beam energy (MeV)	Peak posit. (Chan-nel)	Peak energy (keV)	FWHM width (keV)	FWHM resolution (%)	Calcula-ted peak (keV)	Ratio obs./calc. peak
ISMA1						
20	**2304**	**2451**	**37**	**1.5**	**18630**	**0.13**
15	**1732**	**1842**	**44**	**2.4**	**13210**	**0.14**
10	**1067**	**1135**	**44**	**3.9**	**7400**	**0.15**
6	**339**	**361**	**67**	**18.4**	**480**	**--**
ISMA2						
20	**1134**	**1260**	**33**	**2.6**	**18630**	**0.06**
15	**848**	**942**	**39**	**4.2**	**13210**	**0.07**
10	**501**	**556**	**45**	**8.1**	**7400**	**0.08**
6	**100**	**112**	**62**	**55.4**	**480**	**--**





2. Radiation tolerance tests

- Test setup

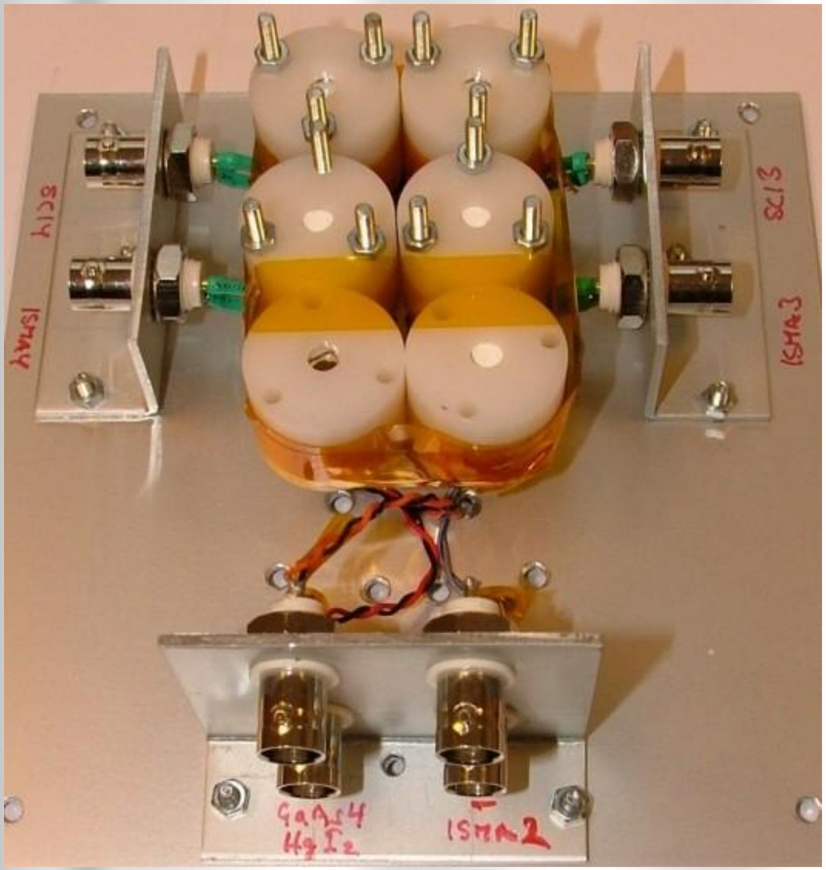
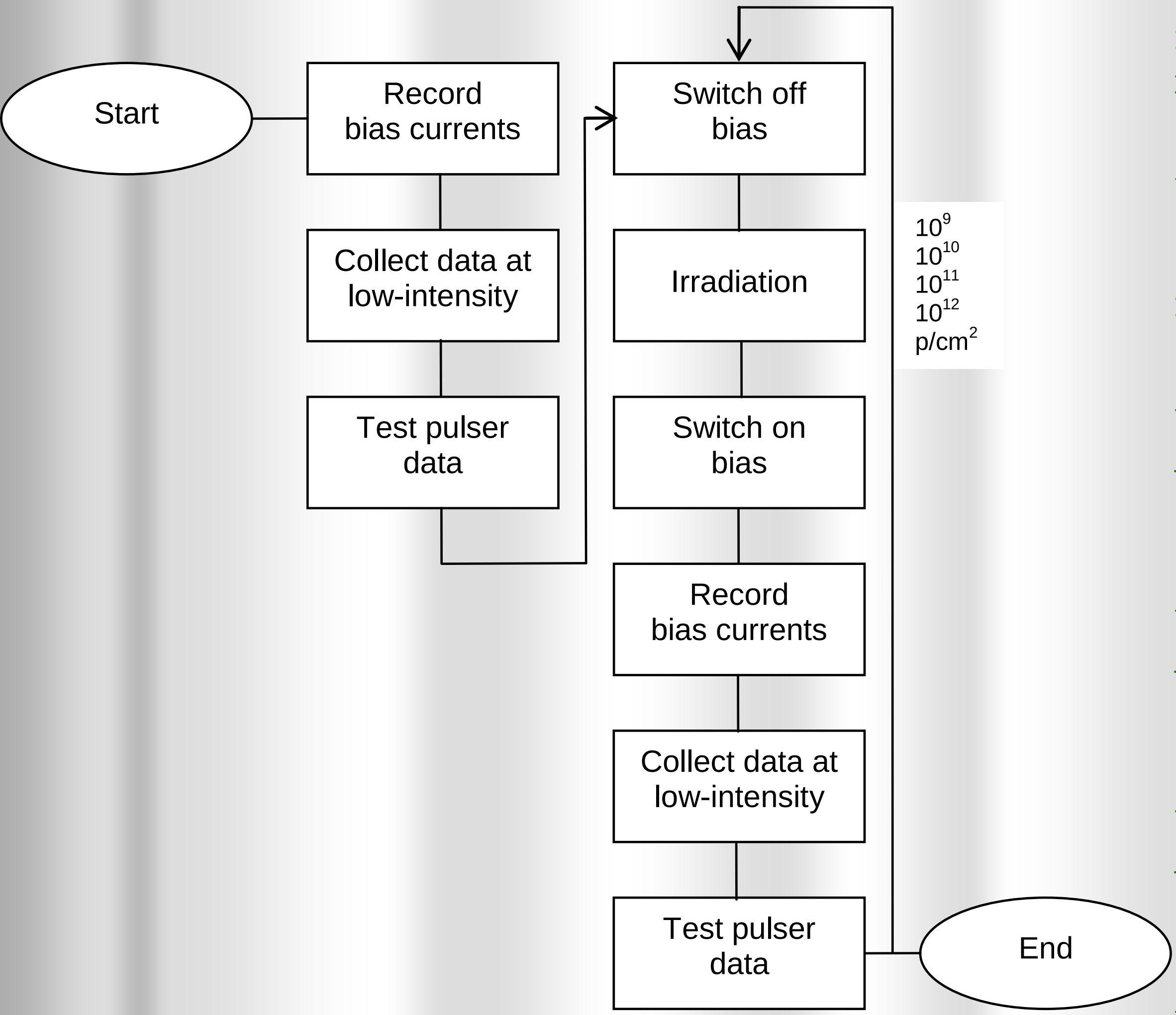


Figure 6. Detector test fixture used in the radiation tests.

- Irradiations for all detectors were carried out simultaneously.
- The beam energy in the radiation tests was 55 MeV resulting in ~50 MeV, when reaching the test devices
- Detectors were mounted on the test fixture without collimators, except for the plastic holder with a 5-mm opening.
- The wall thickness of this holder at the entrance to the detector is 2.0 mm, and it covers the corners of the 5-mm cube ISMA scintillators.
- The homogeneity of the beam was estimated to be about 20 % over the surface covered by the detectors.
- ISMA3 and ISMA4 scintillators were placed at the centre of the beam, thus receiving roughly 20 % more radiation than their neighbouring detectors.

Test Procedure



- At the beginning of the test and after each irradiation, the detector bias currents were recorded
- Data were collected by using the 50 MeV beam at low intensity and the test pulser.
- Four irradiations were carried out at fluences 10^9, 10^{10}, 10^{11}, and 10^{12} protons/cm^2.
- Irradiation 1: 1.01×10^9 protons/cm^2 . Total time – 755 s. Main phase duration – 30 s. Average/maximum flux: 3.3×10^7 cm^{-2} s^{-1} / 3.51×10^7 cm^{-2} s^{-1}
- Irradiation 2: 1.04×10^{10} protons/cm^2 . Total time – 112 s. Main phase duration – 6 s. Average/maximum flux: 1.45×10^9 cm^{-2} s^{-1} / 1.52×10^9 cm^{-2} s^{-1}
- Irradiation 3: 1.0×10^{11} protons/cm^2 . Total time – 1284 s. Main phase duration – 1100 s. Average/maximum flux: 9.0×10^7 cm^{-2} s^{-1} / 1.03x108 cm^{-2} s^{-1}
- Irradiation 4: 1.0×10^{12} protons/cm^2 . Total time – 3128 s. Main phase duration – 2910 s. Average/maximum flux: 3.3×10^8 cm^{-2} s^{-1} / 1.06×10^9 cm^{-2} s^{-1}.

Fig. 7. Pulse height distributions of 50 MeV protons before and after irradiations of 10^{12} protons/cm^2 .

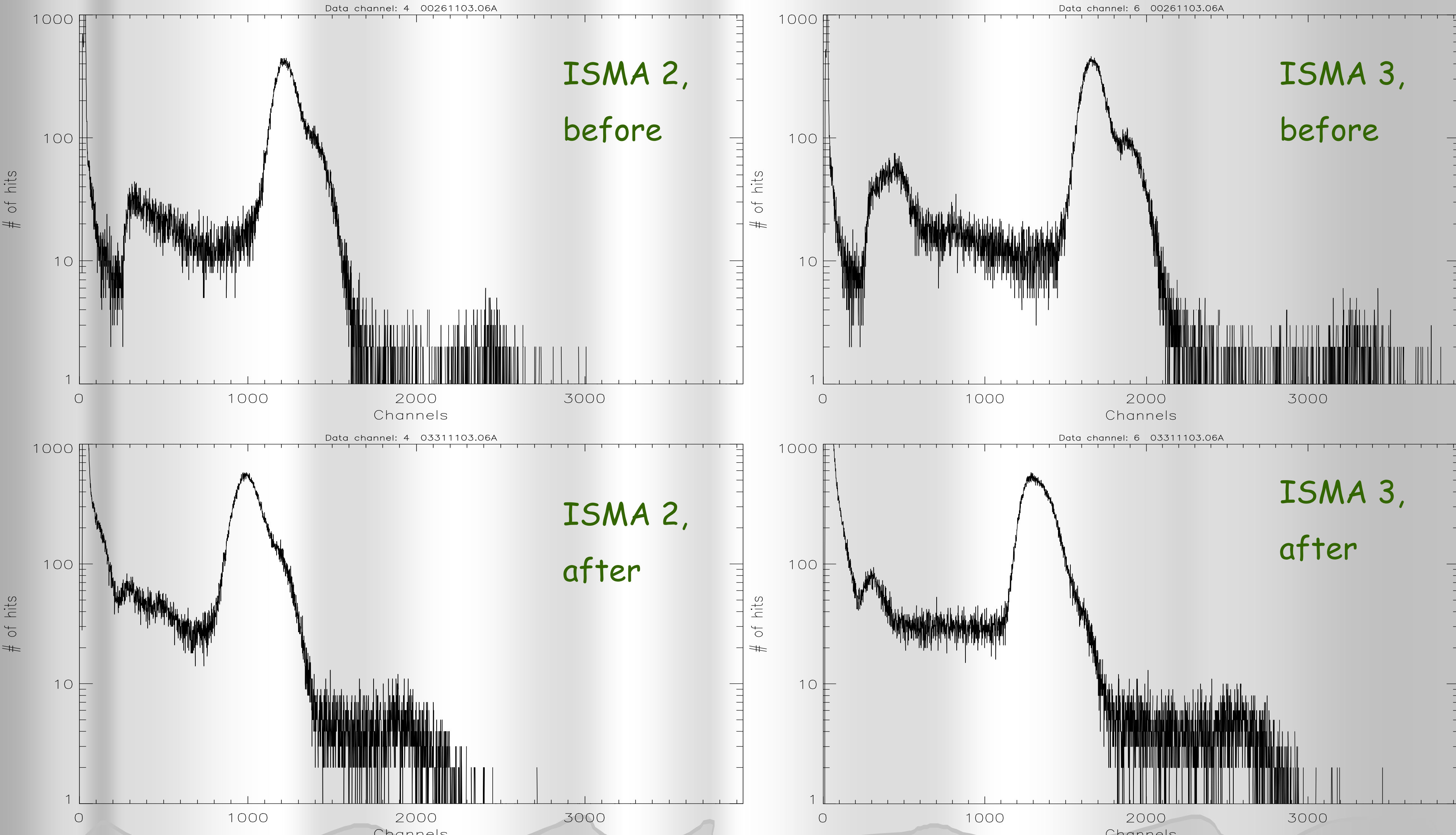


Fig. 7. Pulse height distributions of 50 MeV protons before and after irradiations of 10^{12} protons/cm^2.

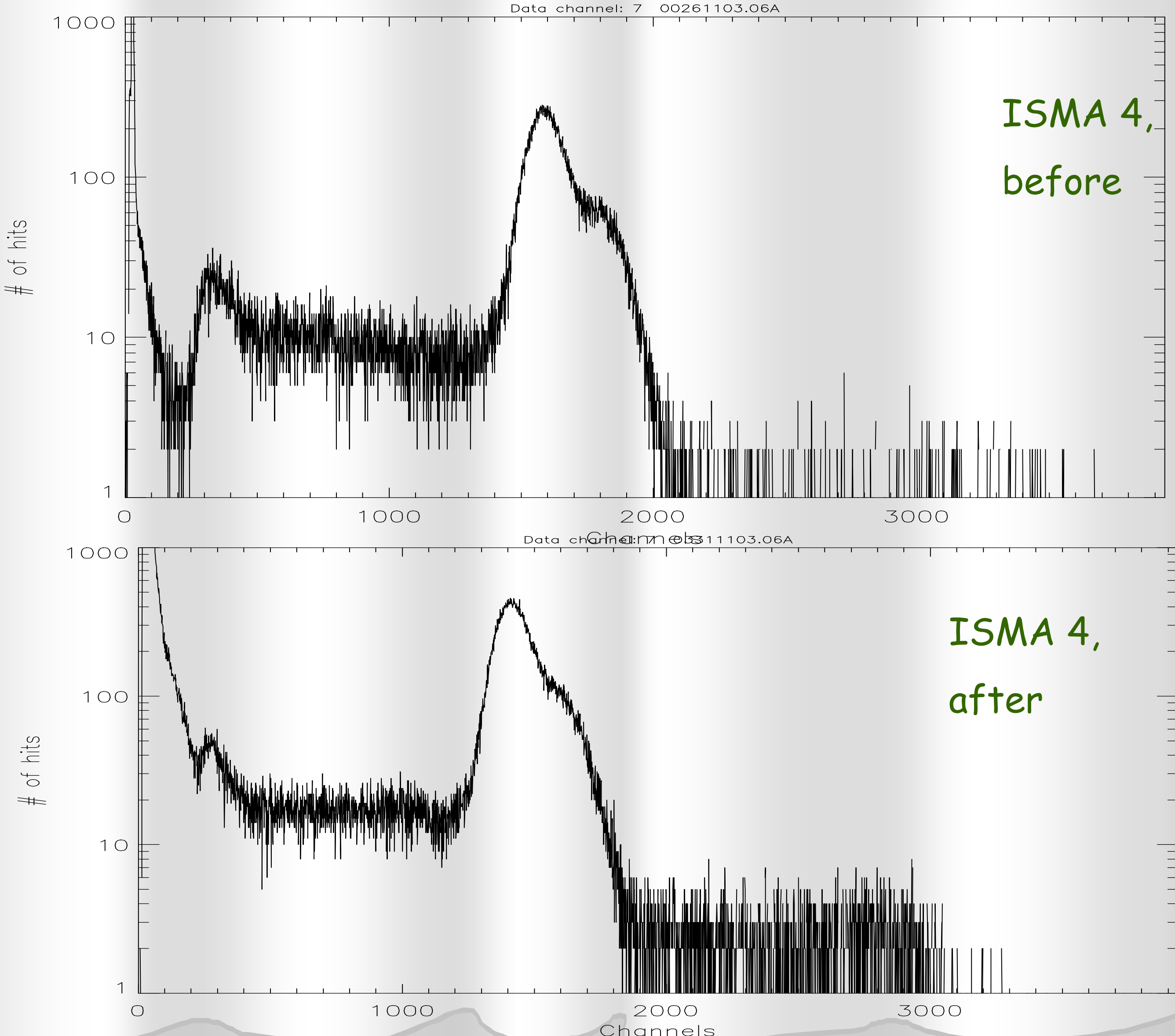


Table 3. Measured peak energies and peak FWHM of 50 MeV protons before radiation tests and after each irradiation

Irradiation		ISMA2	ISMA3	ISMA4	
	Peak energy (keV)				
Before		2573	3545	3537	
1st		2568	3541	3524	
2nd		2552	3528	3501	
3rd		2490	3498	3430	
4th		2094	2801	3131	
	Peak FWHM (keV)				
Before		306	323	387	
1st		305	326	324	
2nd		306	327	334	
3rd		297	320	318	
4th		374	446	300	

Table 4. Peak energies and peak FWHM of test pulser measurements before radiation tests and after each irradiation

Irradiation		ISMA2	ISMA3	ISMA4	
	Peak energy (keV)				
Before		741	726	763	
1st		757	732	774	
2nd		757	732	773	
3rd		757	732	771	
4th		754	727	765	
	Peak FWHM (keV)				
Before		44	46	51	
1st		44	49	51	
2nd		47	54	52	
3rd		51	54	57	
4th		78	89	98	

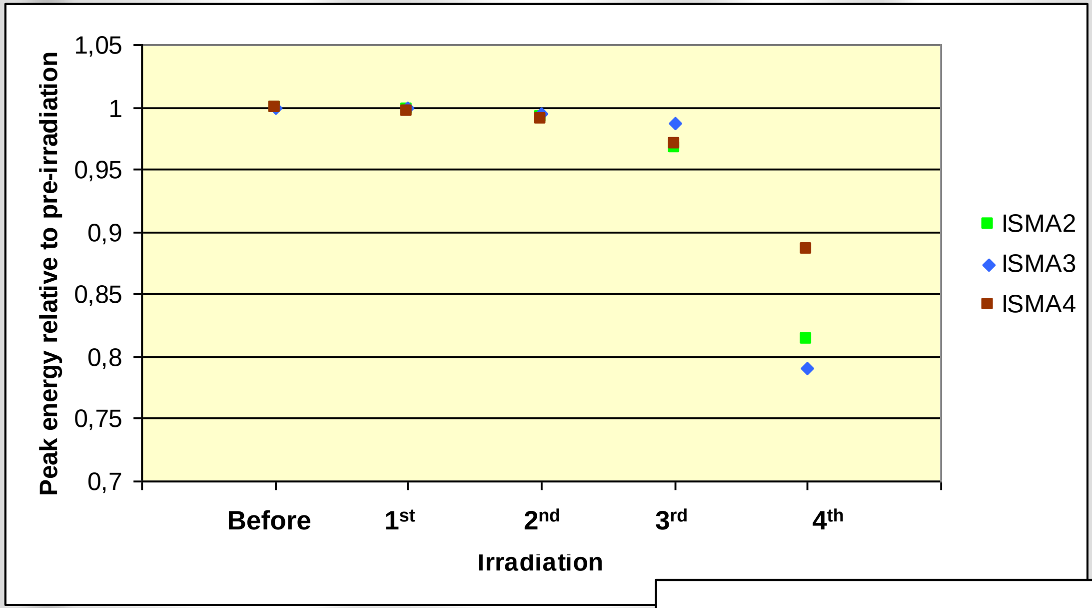


Figure 8. Relative peak energies after each irradiation.

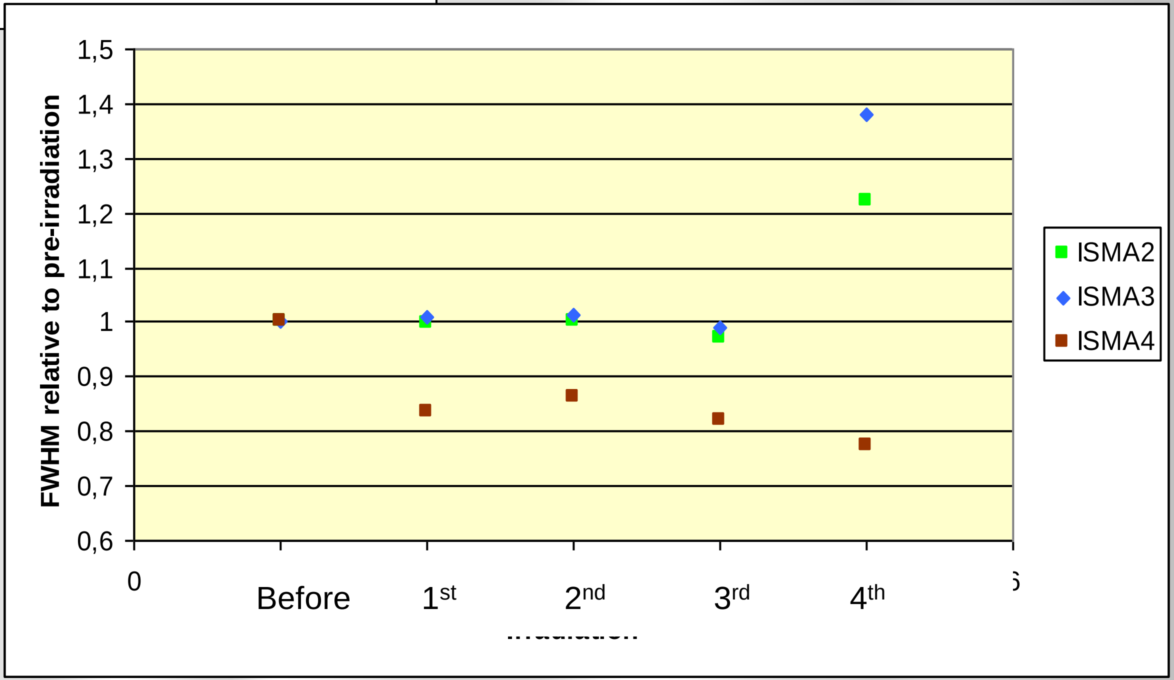


Figure 9. Relative peak FWHM after each irradiation.

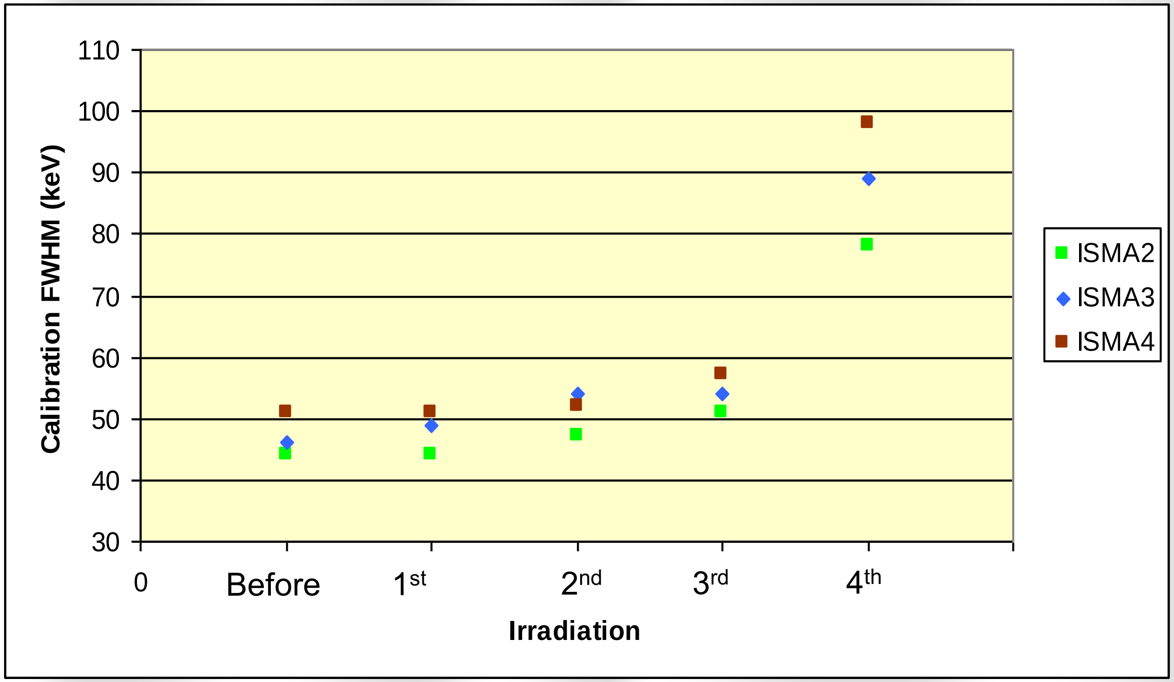


Figure 10. FWHM of the test pulser peak after each irradiation.

Calculated total and non-ionising dose

✓ The Mulassis simulation toll was used to estimate the total absorbed dose and the non-ionising energy loss (NIEL) in the scintillators corresponding to the proton beam energy and fluences applied.

✓ In the calculation the thickness of the ISMA scintillators was 5.0 mm. The thickness of photodiode was 380 mm.

✓ The total absorbed dose for the ISMA scintillators were 125 krad and 235 krad – for photodiode.

✓ The non-ionising energy loss was calculated at the top and bottom of the scintillators and at the top and bottom of the photodiode. For the photodiodes the JPL/NRL/NASA 2003 silicon coefficient was applied. The values 3.9×10^9 MeV/g (top), 4.7×10^9 MeV/g (bottom) were obtained for scintillators and 4.8×10^9 MeV/g (top) and 5.7×10^9 MeV/g (bottom) for the photodiodes after the fluence of 10^{12} protons/cm^2.

Conclusions

- The response of small scintillation crystals (5 mm x 5 mm x 5 mm) seem to change with absorbed dose (fluence of 10^{12} protons/cm^2). Decrease in the observed 50 MeV proton peak energy was up to 20 %.

- The response of scintillation detectors with a photodiode readout is good and sufficient energy resolution can be obtained even with CsI(Na) material when the total dose not more than ~ 100 krad.