Radiation studies for the upgrade of the ATLAS detector

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“Workshop on Discovery Physics at the LHC” (Kruger2022)

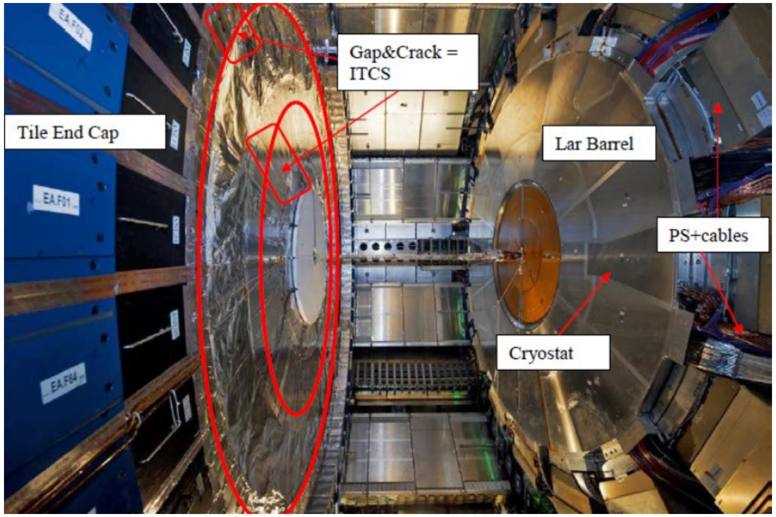
Outline

- Introduction
- Motivation
- IBR-2M neutron irradiation facility at JINR
- Radiation hardness study of blue and green emitting scintillators
- Conclusion

Introduction

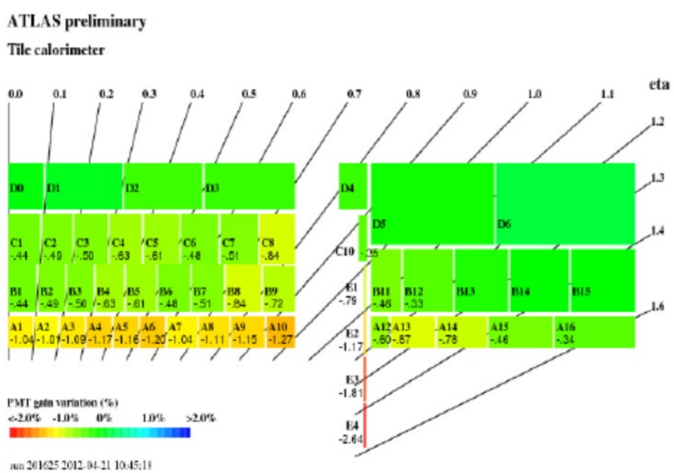
- Collaboration between Wits University and DLNP JINR groups began a few years ago within the frame of JINR-SA cooperation.
- Wits University group was initially led by Prof. Bruce Mellado and now is led by Prof. Elias Sideras-Haddad. JINR group is headed by Dr. Yuri Davydov.
- Our research is aimed at developing new radiation hard materials, used in nuclear detectors and related electronic devices and studying their radiation damage.
- Another goal is a training of students and involving them in scientific research.

Motivation

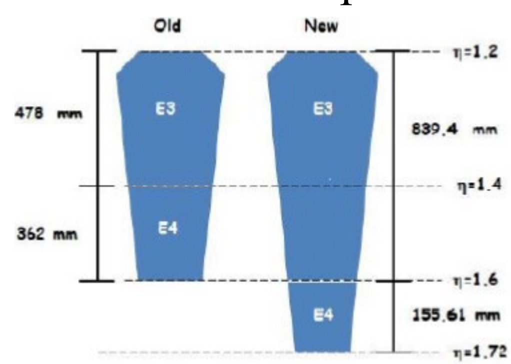


Operation of LHC at high luminocity (HL-LHC) will require to use radiation hard getectors placed in harsh radiation environments on the ATLAS. Among them are MBTS detector and crack and gap detectors E3 and E4.

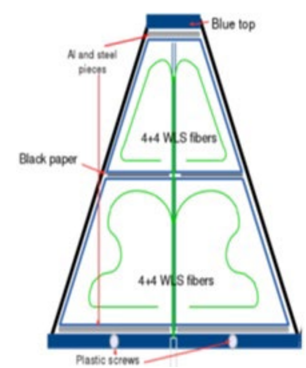
Plastic scintillators from different producers were tested. Irradiations were carried out at proton tandem generator at the Wits University and in neutron beam of IBR-2M reactor at JINR



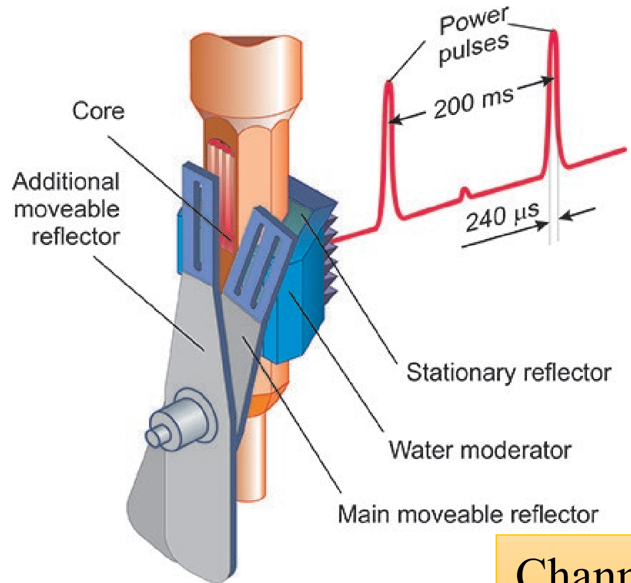
Old and new versions of E3 and E4 plates



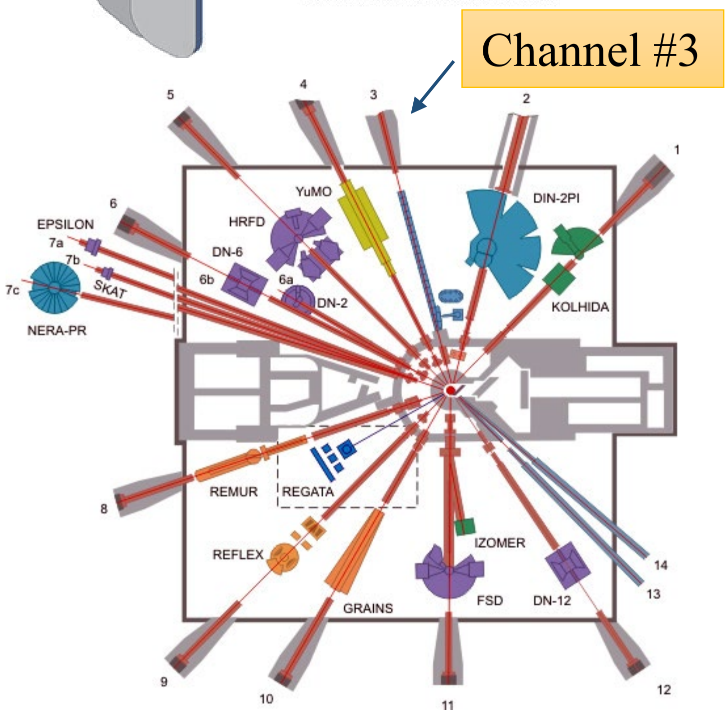
Old version of the MBTS



IBR-2M reactor at JINR



IBR-2 at Frank Laboratory of Neutron Physics, JINR is a pulsed fast reactor of periodic operation. Its main difference from other reactors consists in mechanical reactivity modulation by a movable reflector. During a two week cycle one can get a fluence $>10^{18}$n/cm^2 next to a water moderator.

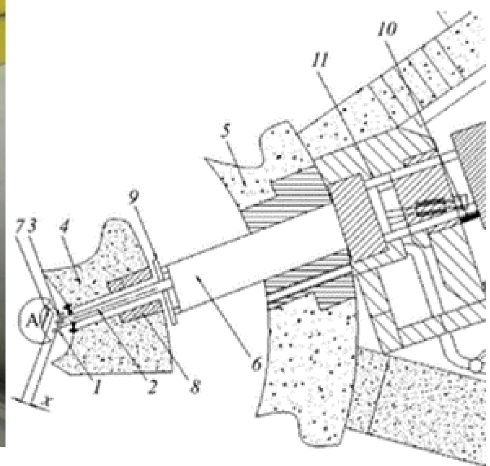


Average power, MW	2
Fuel	PuO_2
Number of fuel assemblies	69
Pulse repetition rate, Hz	5; 10
Pulse half-width, µs:	240
Rotation rate, rev/min:	
main reflector	600
auxiliary reflector	300
Thermal neutron flux density from the surface of the moderator:	
- time average	10^{12} - 10^{13} n/cm²·s
- burst maximum	~ 10^{16} n/cm²·s

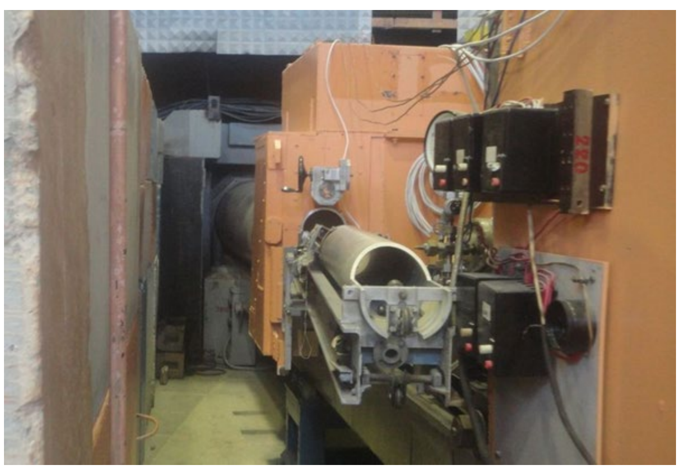
http://flnph.jinr.ru/en/facilities/ibr-2/parameters

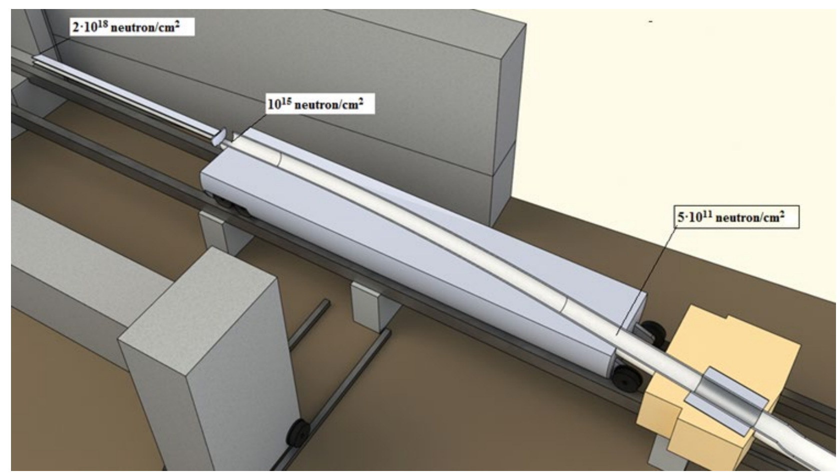
Neutron irradiation channel

Irradiating samples could be placed inside of the pipe or on the I-beam. In running position I-beam end is within a few cantimeter from the water moderator

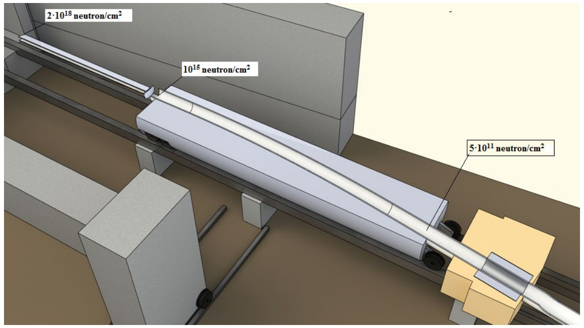


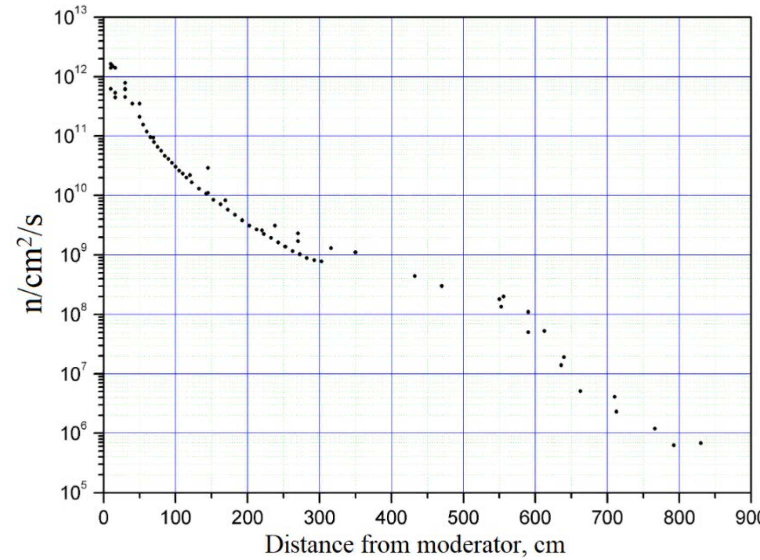
During a running cycle fluence is 10^{18} n/cm^2 on the I-beam end and 10^{16} n/cm^2 and 10^{11} n/cm^2 on the pipe beginning and end respectively

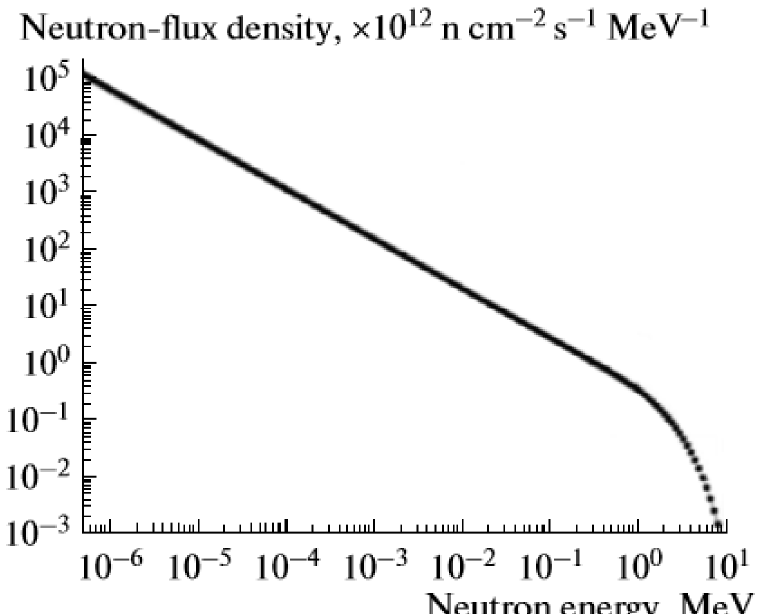




Neutron flux and spectrum







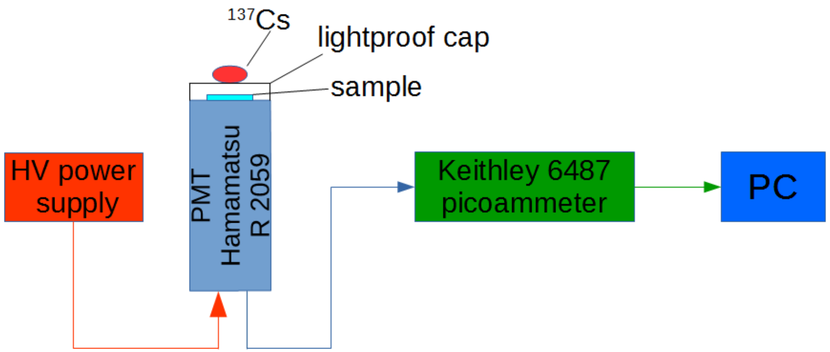
The neutron flux decreases with distance from the water moderator

Irradiation of samples at IBR-2M

UPS-923A samples, 2x2x0.6 cm^3
Polystyrene based with 2% paraterphenyl (PTP) and 0.03% POPOP

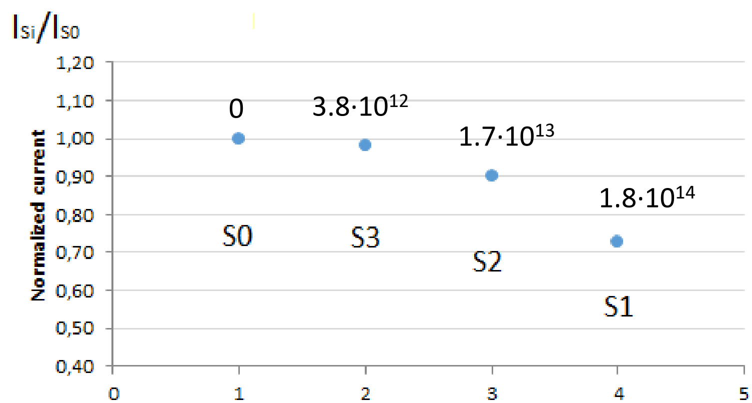
Sample	Flux, $n/cm^2 \cdot c$	Fluence, n/cm^2
S01	$1.2 \cdot 10^8$	$1.8 \cdot 10^{14}$
S02	$1.2 \cdot 10^7$	$1.7 \cdot 10^{13}$
S03	$2.5 \cdot 10^6$	$3.8 \cdot 10^{12}$

Plastic scintillators light yield measurements



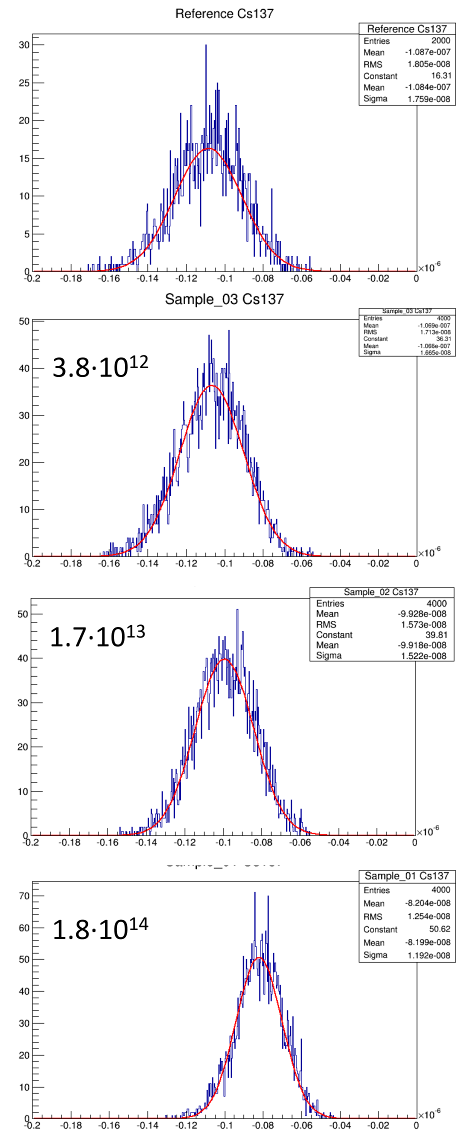
The block diagrams of the test setup

Preparation to the test measurements



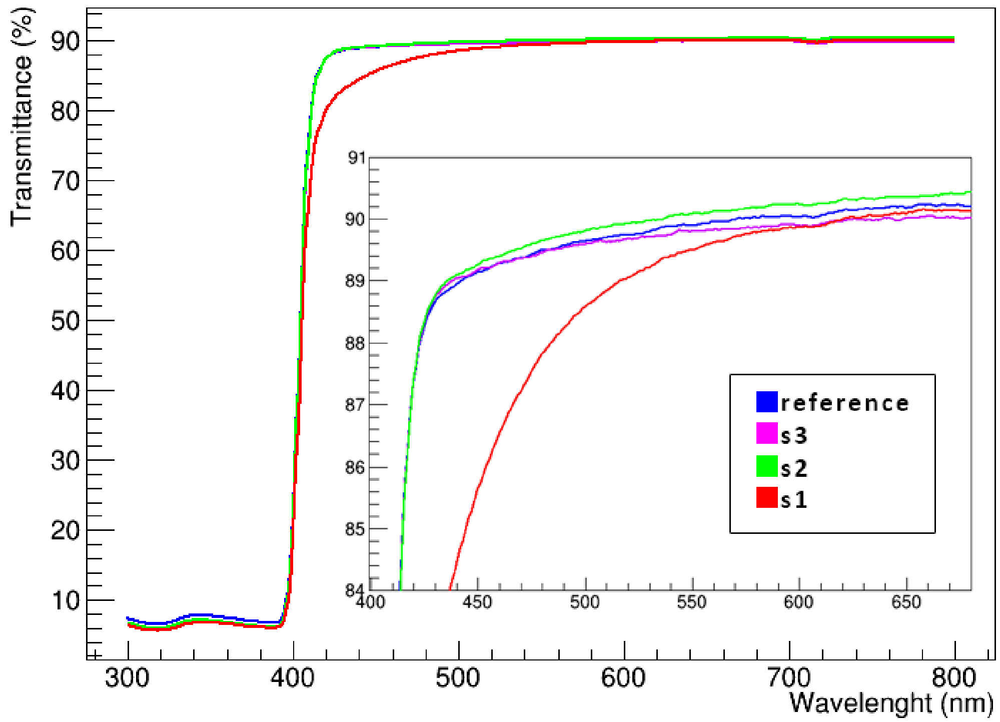
The light yield decreased by ~28% after the neutron irradiation of $1.8\cdot10^{14}$ n/cm^2

Sample currents



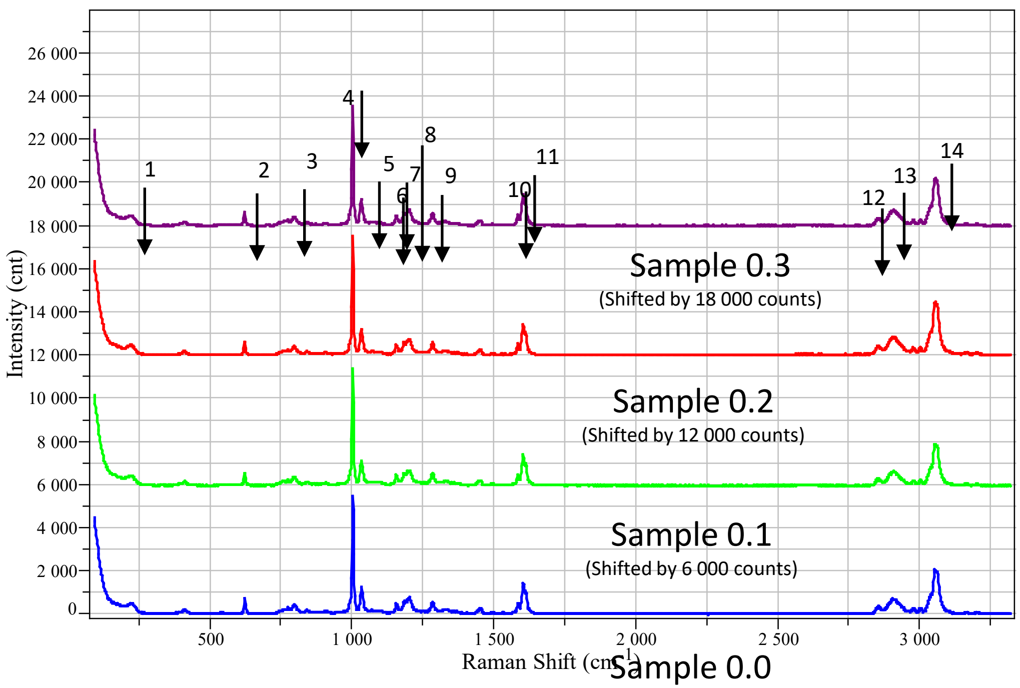
Light transmission of the irradiated samples

Measurements in the wave length range 300-800 nm were made at WITS University (Varian Carry 500 spectrophotometer) and at JINR (SolidSpec-3700 DUV spectrophotometer)

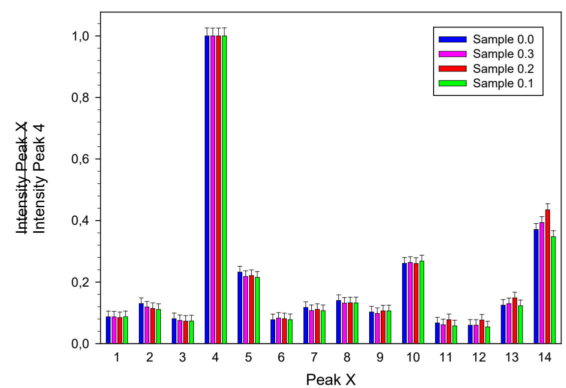


Fluens ~ 10^{14} n/cm^2 resulted in a few percents light transmission loss in the range of 400-550 nm

Raman Spectra of plastic scintillator samples



Assigned Vibrational mode	Peak number
δ(C-C) aliphatic	1
ν(C-C) alicyclic or aliphatic chain vibrations	2-3, 5-9
ν(C-C) aromatic ring chain vibrations	4
ν(C=C)	10-11
ν(C-H)	12-13
ν(=(C-H))	14



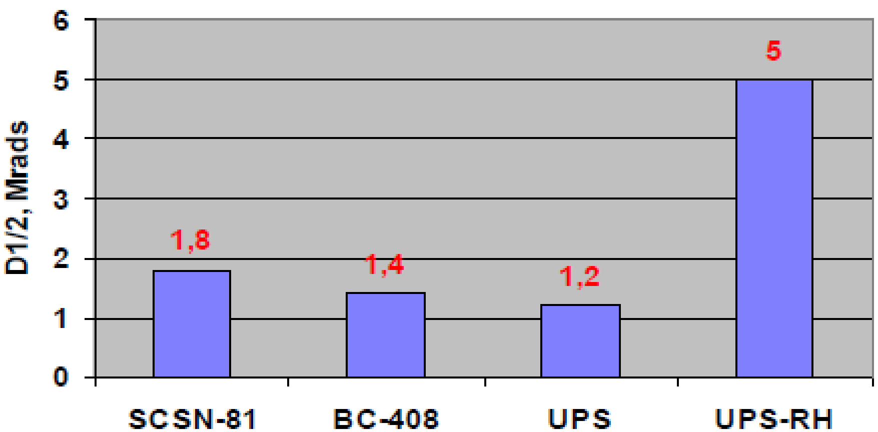
From Raman spectra we did not find structural changes or damage occured during the neutron irradiation up to $1.8 \cdot 10^{14}$ n/cm^2!

Possibility to increase a radiation hardness

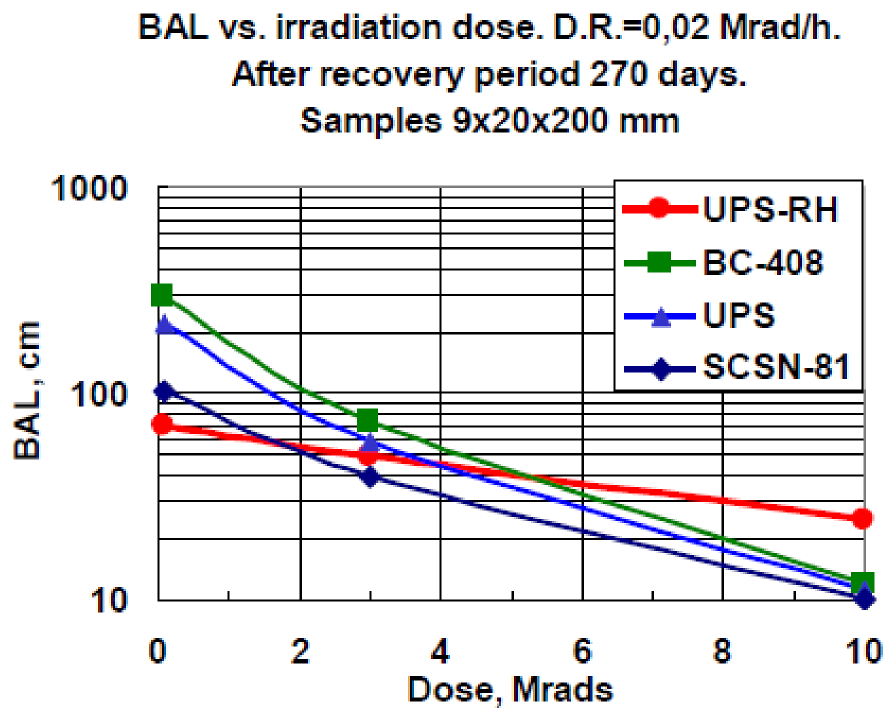
From P.Zhmurin (ISMA, Kharkov):

Radiation hardness could be improved by shifting luminescence to the longer wave length. However, that causes decrease of light yield and scintillator's mechanical properties

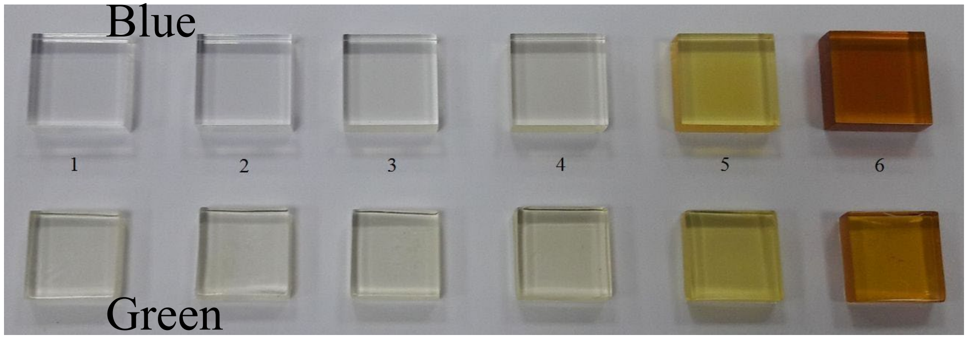
A new radiation hard plastic scintillator based on polystyrene with a single fluor dopant 3HF (3-hydroxyflavone). That moves the emission peak to ~ 530 nm.



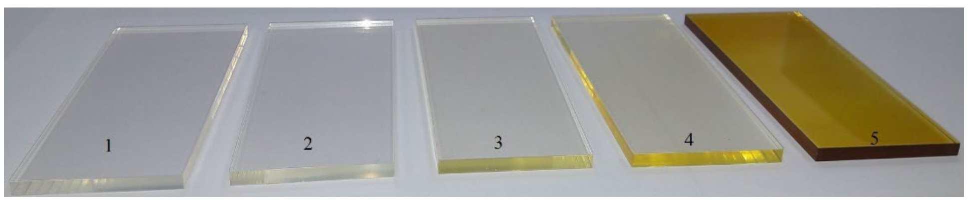
Dose when the light yield drops two times for different scintillators



Irradiation of blue and green scintillators



Blue: polystyrene based with 2%(PTP) and 0.03% POPOP
Green: polystyrene with a single fluor dopant 3HF (3-hydroxyflavone)



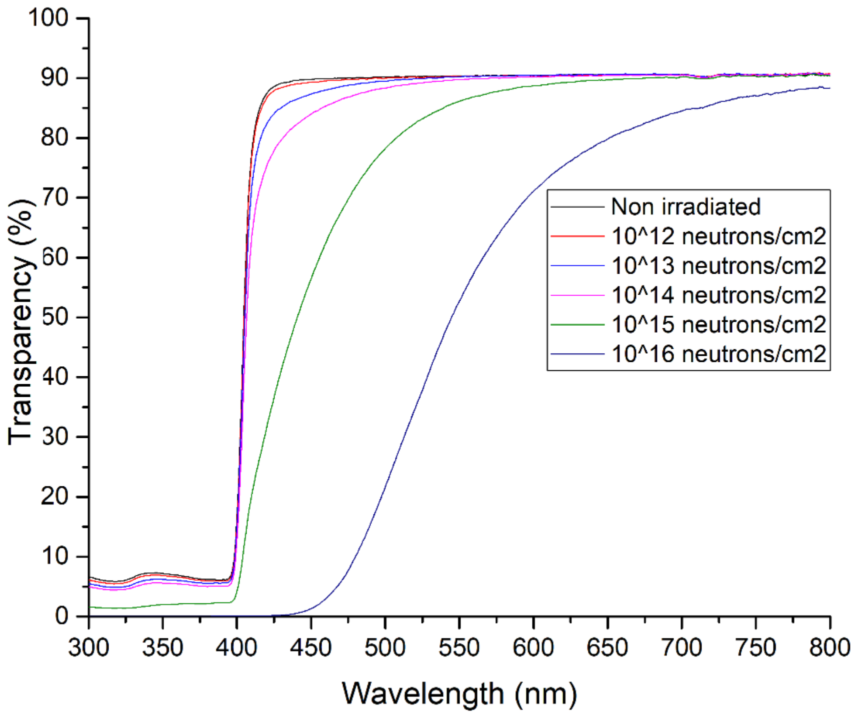
Sample #	Fluence, n/cm^2
1	Non-irradiated
2	$\sim 10^{12}$
3	$\sim 10^{13}$
4	$\sim 10^{14}$
5	$\sim 10^{15}$
6	$\sim 10^{16}$

Samples of UPS-923A and green scintillators were irradiated in wide range of neutron fluence. All samples are produced by ISMA, Kharkov.

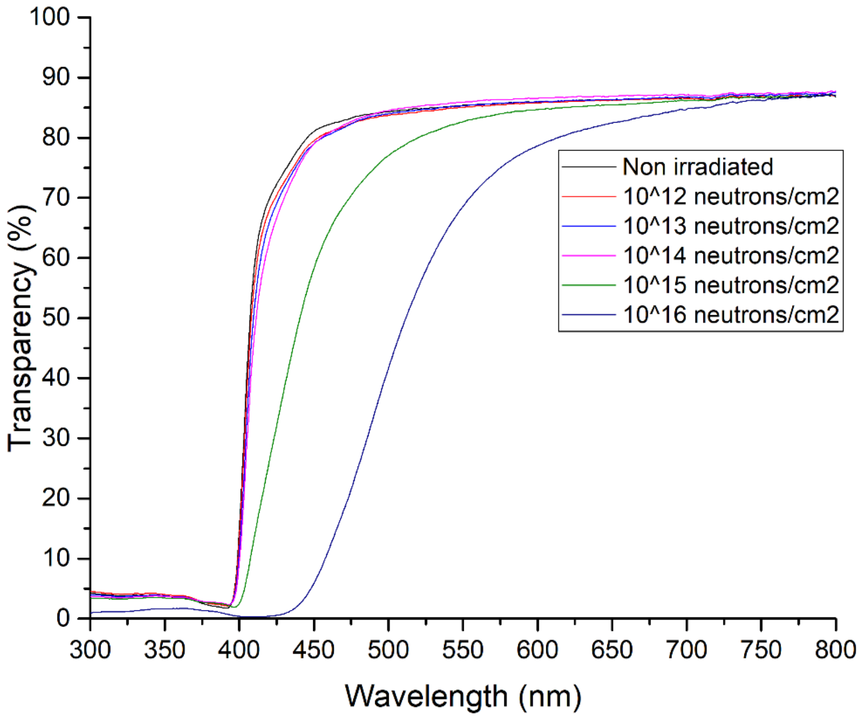
Small samples have dimension of 2x2x0.6 m (both blue and green)
Big samples have dimension of 6x15x0.6 cm

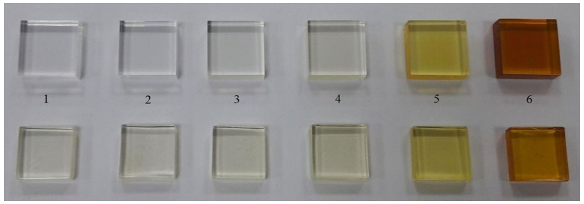
Transparency of 2x2 cm irradiated samples

UPS-923A



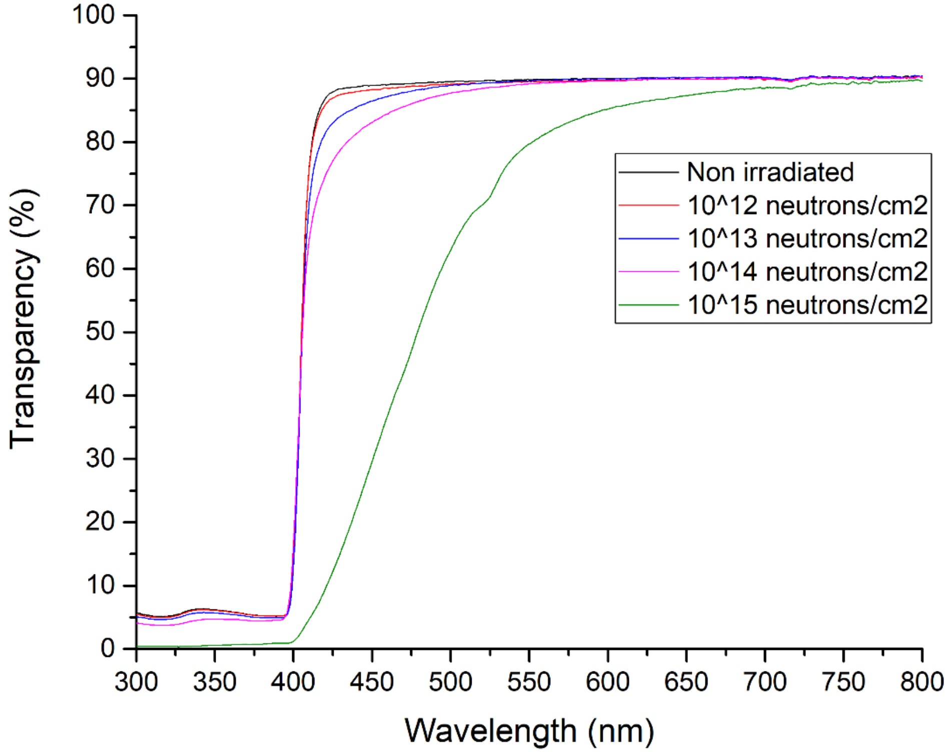
Green scintillator





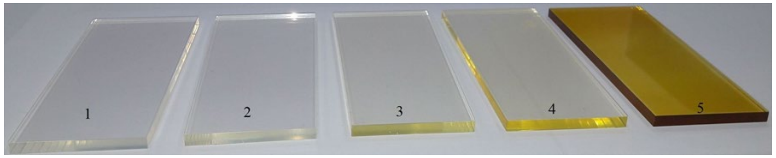
The loss of transparency of the UPS-923A scintillator is much higher in the region of its own fluorescence compared to the green scintillator

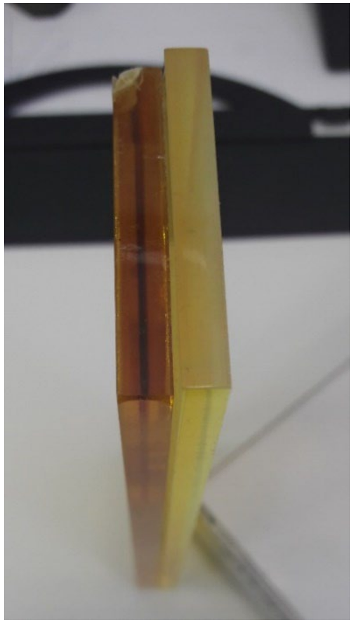
Transparency of 15x6 cm irradiated samples



UPS-923A

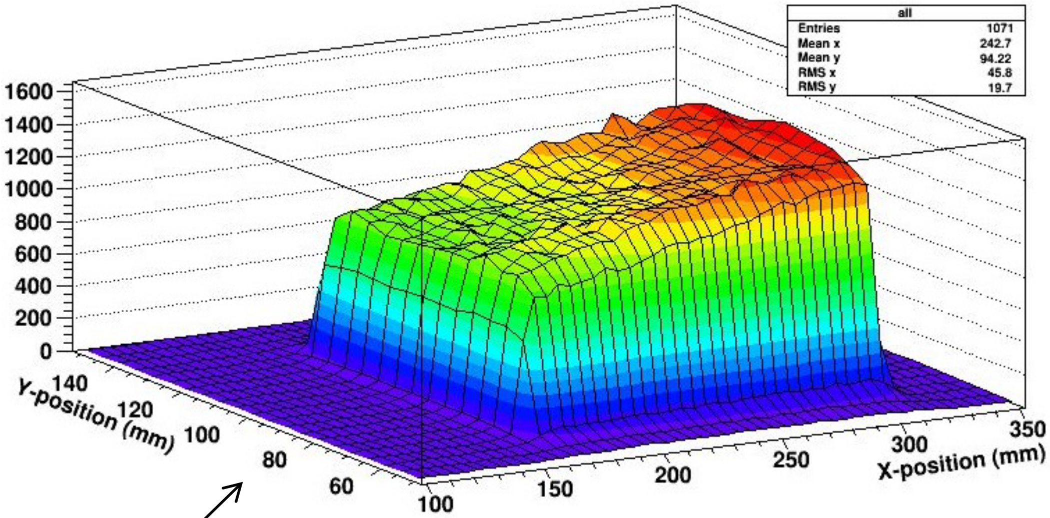
A fluence $\sim 10^{15}$ n/cm^2 leads to a significant loss of transparency of the scintillator in the region of its own luminescence.

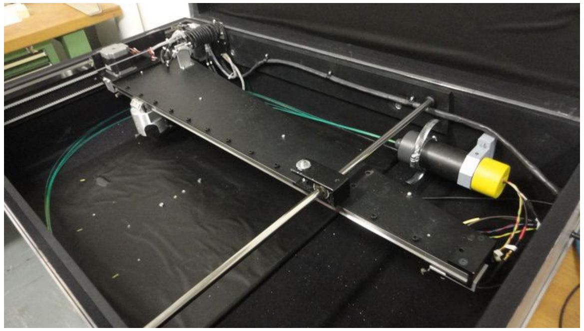




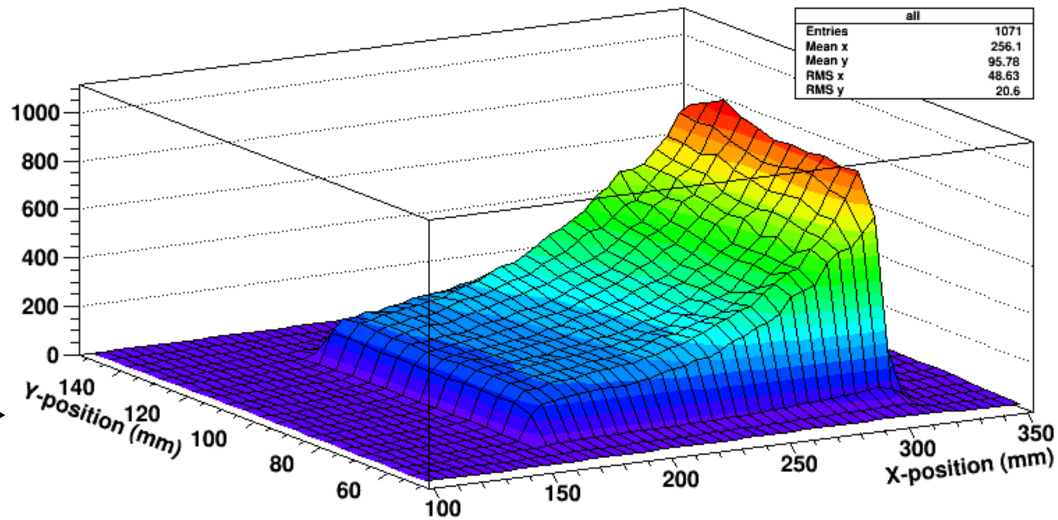
Scan of 15x6 cm samples

Scan with a radioactive source of non-irradiated and most exposed samples was carried out at CERN



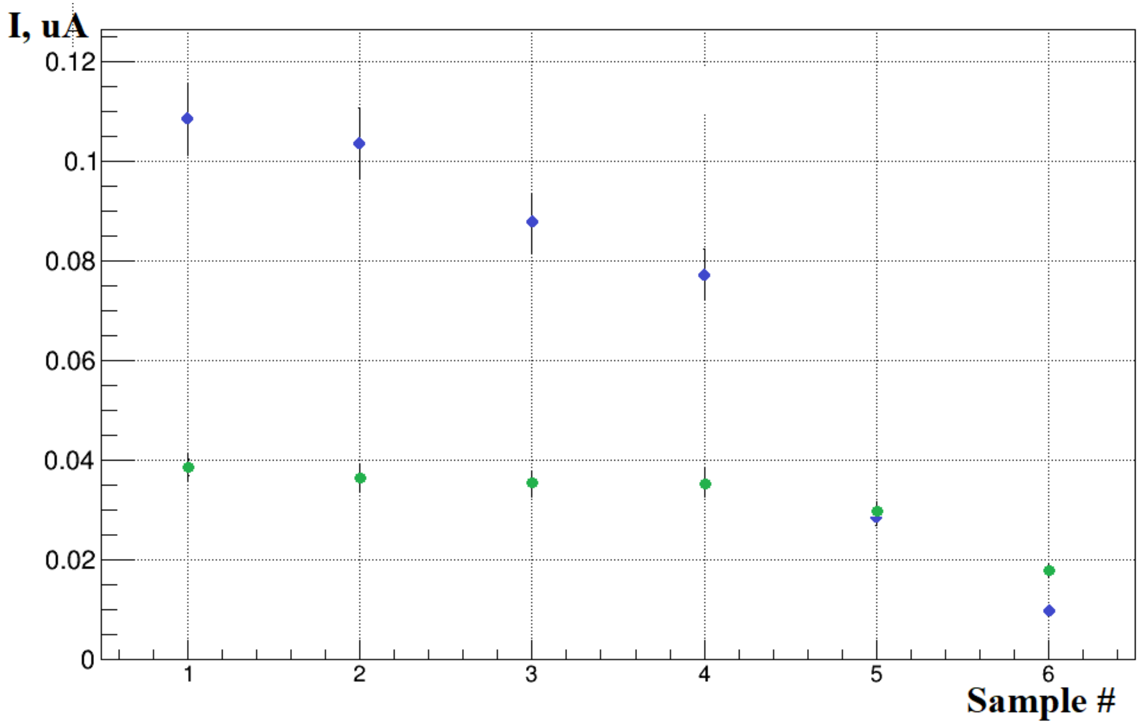


Non-irradiated

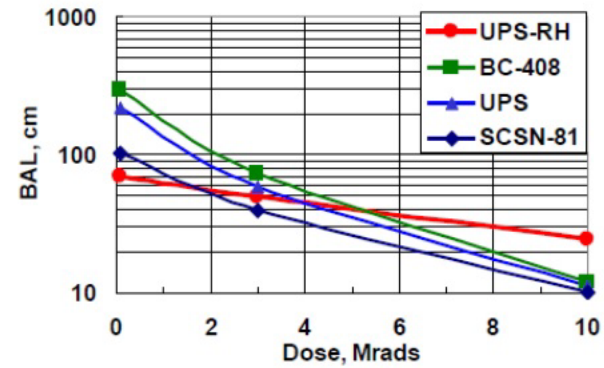


Irradiated to ~10^{15} n/cm^2

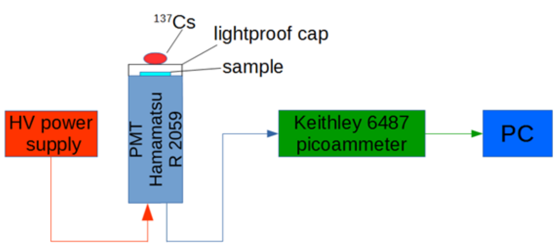
Light outputs of irradiated samples

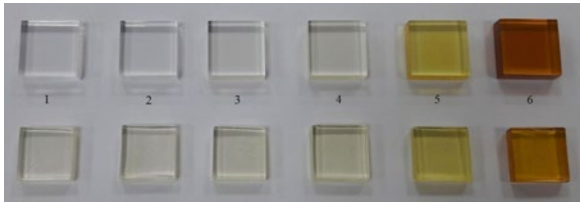


Fluence, n/cm^2 0 $\sim 10^{12}$ $\sim 10^{13}$ $\sim 10^{14}$ $\sim 10^{15}$ $\sim 10^{16}$



After irradiation the light output loss of the blue scintillator is much higher





Conclusion

- Radiation hardness of blue and green emitting scintillators irradiated with neutrons (up to 10^{16} neutrons/cm^2) from the IBR-2 reactor has been systematically studied
- Green scintillators recently developed by Kharkov colleagues have shown excellent radiation hardness and can be used in harsh radiation conditions.
- Results were reported at ATLAS meetings and on conferences

Students involved in the study

	Status during a project	Current status
Harshna Jivan	PhD student	PhD
Joyful Mdhluli	MS student	PhD thesis submitted
Skhathisomusa Mthembu	MS student	PhD student
Phuti Tjale	Honors in physics	PhD student
Nthabiseng Khanye	Honors in physics	PhD student
Humphry Tlou	MSc student	PhD student
Nthabiseng Lekalakala	MSc student	In industry
Thabo Masuku	MSc student	In industry
Gaogalalwe Mokgatitswane	PhD student	PhD student

Students were involved in the project at different stages and used the results of the project in the presentations and theses.

The results obtained during the work on the project were reported by students at several conferences and published in many articles

Back-up slides

Loss of BaF_2 light output after irradiation