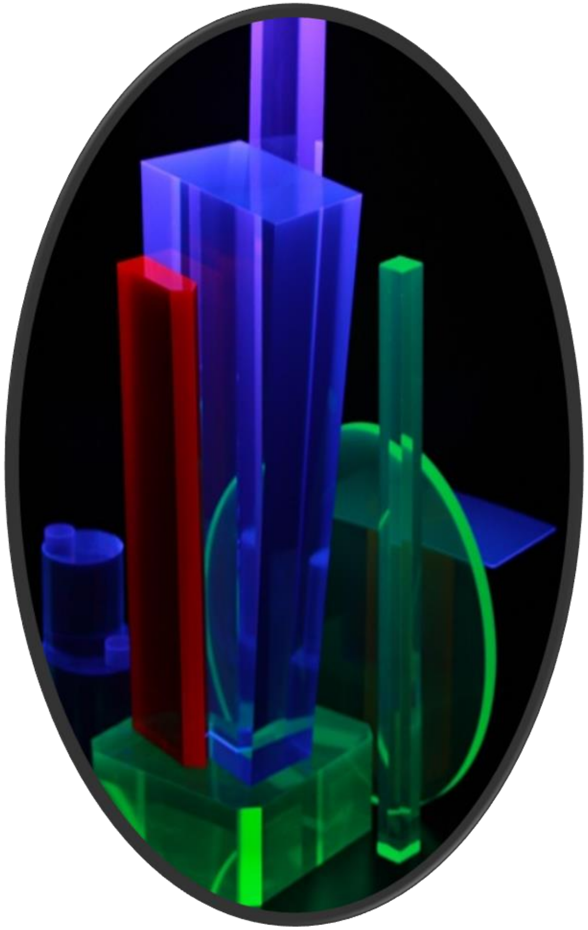
A Comparative study of the radiation hardness of plastic scintillators for the upgrade of the Tile Calorimeter of the ATLAS detector

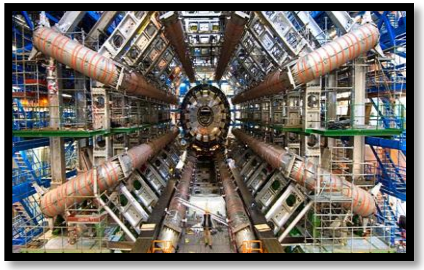
Shell-may Liao
Supervisor: Prof. Bruce Mellado

Thanks to: B. Mellado, E. Haddad, H. Jivan, C. Pelwan, G. Peters, iThemba LABS Gauteng team

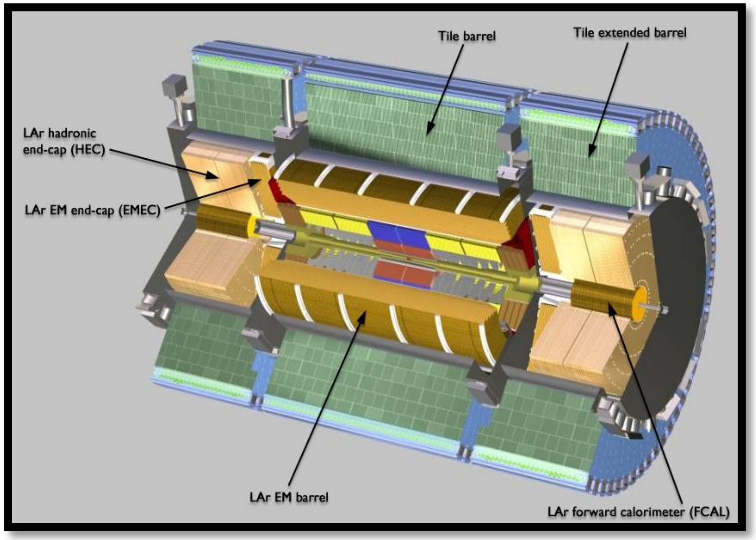
OUTLINE

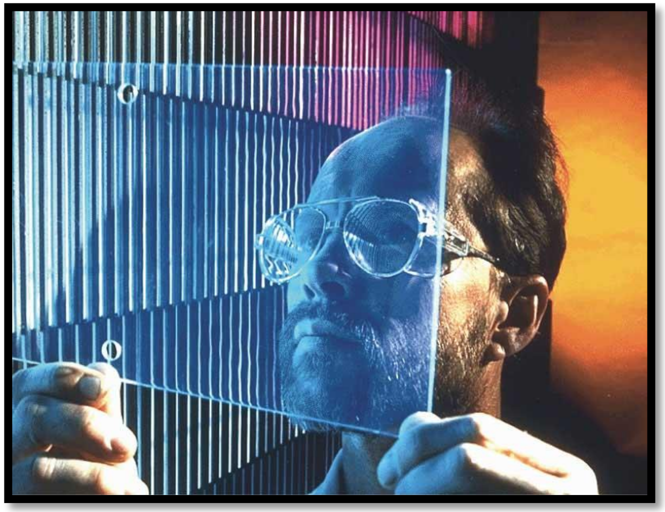
- Introduction
- Scintillation mechanism
- SRIM and TRIM simulations
- Sample preparation
- Radiation process
- Transmission spectroscopy
- Results and analysis
- Conclusion





INTRODUCTION





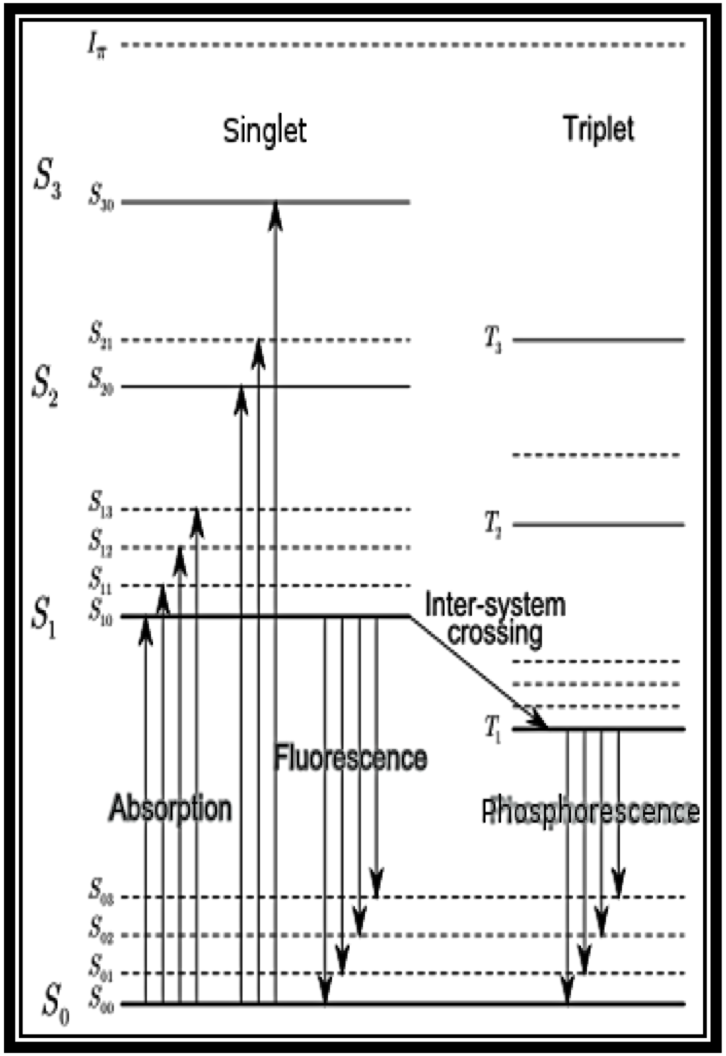
❖ Main problem encountered by scintillators

❖ Scintillators exhibit luminescence when excited by ionizing radiation

❖ PVT based scintillators: EJ 200, EJ 208, EJ 260

❖ Experimental procedure sample dimensions: 500µm x 500µm x 350 µm

SCINTILLATION MECHANISM



- ❖ Common feature in plastic scintillator = benzene ring
- ❖ Delocalized electrons are prone to excitation
- ❖ Electronic levels of a PVT molecule
- ❖ PVT base is doped with flours
- ❖ Fluors absorb the base scintillation and emit at longer wavelengths

SRIM SIMULATIONS

R Calculation: SRIM Outputs\Hydrogen in Polyvinyltoluene (ICRU-570) 1.txt

SRIM version ---> SRIM-2013.00
Calc. date ---> August 10, 2014

Disk File Name = SRIM Outputs\Hydrogen in Polyvinyltoluene (ICRU-570) 1.txt

Ion = Hydrogen [1] , Mass = 1.008 amu

Target Density = 1.0230E+00 g/cm3 = 9.8606E+22 atoms/cm3

======= Target Composition ========

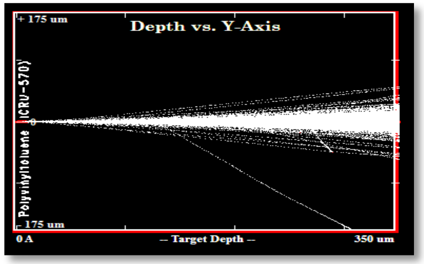
Atom Name	Atom Numb	Atomic Percent	Mass Percent
H	1	052.38	008.45
C	6	047.62	091.55

Bragg Correction = 0.00%
Stopping Units = MeV / (mg/cm2)
See bottom of Table for other Stopping units

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
3.50 MeV	1.068E-01	6.575E-05	184.54 um	7.39 um	5.01 um
3.75 MeV	1.012E-01	6.183E-05	208.00 um	8.16 um	5.61 um
4.00 MeV	9.624E-02	5.836E-05	232.72 um	8.95 um	6.24 um
4.50 MeV	8.772E-02	5.253E-05	285.83 um	11.81 um	7.59 um
5.00 MeV	8.070E-02	4.780E-05	343.83 um	14.51 um	9.05 um
5.50 MeV	7.482E-02	4.388E-05	406.64 um	17.15 um	10.63 um
6.00 MeV	6.980E-02	4.059E-05	474.17 um	19.79 um	12.32 um
6.50 MeV	6.547E-02	3.777E-05	546.36 um	22.43 um	14.12 um
7.00 MeV	6.169E-02	3.533E-05	623.16 um	25.09 um	16.03 um
8.00 MeV	5.539E-02	3.133E-05	790.16 um	34.78 um	20.16 um

- ❖ About SRIM
- ❖ Stopping Range of 6MeV protons in PVT
- ❖ Stopping range = 474.17 μm

TRIM SIMULATIONS

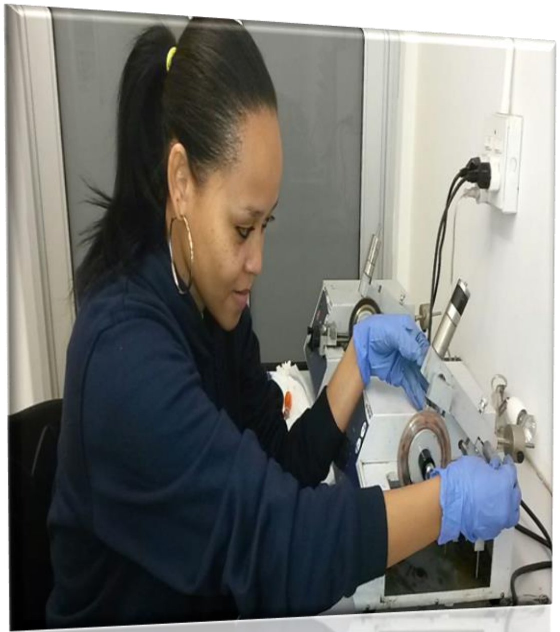


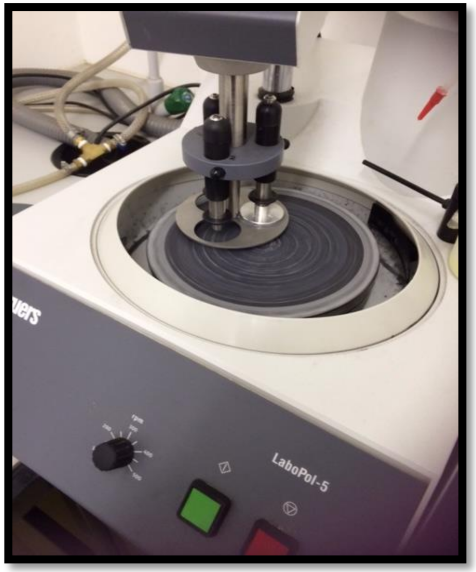

```
============================== SRIM-2013.00 ==============================
=============================================================================
===== TRIMOUT.txt: File of Transmitted / Backscattered / Sputtered Atoms =====
=  This file tabulates the kinetics of ions or atoms leaving the target.     =
=  Column #1: S= Sputtered Atom, B= Backscattered Ion, T= Transmitted Ion.   =
=  Col.#2: Ion Number, Col.#3: Z of atom leaving, Col.#4: Atom energy (eV).  =
=  Col.#5-7: Last location:  X= Depth into target, Y,Z= Transverse axes.     =
=  Col.#8-10: Cosines of final trajectory.                                   =
= *** This data file is in the same format as TRIM.DAT (see manual for uses).=
====== TRIM Calc.=  H(6 MeV) ==> Polyvinyltoluene (ICRU-5(  350 um) =========
 Ion  Atom   Energy        Depth      Lateral-Position        Atom Direction
 Numb Numb    (eV)          X(A)        Y(A)        Z(A)      Cos(X)  Cos(Y) Cos(Z)
T    1  1 .2763609E+07  3500002E+00 -.4501E+05  .2516E+05  .9996790  .0017407  .0252765
T    2  1 .2826563E+07  3500002E+00 -.2371E+05  .2213E+04  .9999814  .0047584  .0038243
T    3  1 .2703196E+07  3500000E+00  .9720E+05  .2272E+05  .9984301  .0559617  .0023670
T    4  1 .2812612E+07  3500002E+00 -.4041E+05  .2434E+05  .9995583 -.0076514  .0287186
T    5  1 .2803737E+07  3500001E+00  .9015E+05 -.7824E+05  .9967454  .0559506 -.0580358
T    6  1 .2754045E+07  3500001E+00 -.4966E+04 -.3309E+05  .9999428  .0106450 -.0010808
T    7  1 .2974872E+07  3500002E+00 -.2359E+05  .3589E+05  .9994639 -.0102957  .0310796
T    8  1 .2641811E+07  3500000E+00 -.2315E+05  .3552E+05  .9993563 -.0072222  .0351389
T    9  1 .2716459E+07  3500002E+00 -.3758E+05 -.2849E+05  .9996065  .0224155 -.0168666
T   10  1 .2891988E+07  3500002E+00  .3357E+05  .5190E+05  .9998742  .0068041  .0143275
T   11  1 .2834354E+07  3500001E+00 -.4568E+05 -.6221E+05  .9993025 -.0055902 -.0369226
T   12  1 .2852653E+07  3500002E+00  .4223E+05 -.6801E+05  .9983521  .0282221 -.0499665
T   13  1 .2929013E+07  3500000E+00  .3048E+05 -.4593E+05  .9978216  .0602653 -.0268369
T   14  1 .2823762E+07  3500002E+00 -.2533E+05 -.1785E+04  .9994604 -.0232535  .0232007
T   15  1 .2930615E+07  3500000E+00  .3324E+05  .5612E+04  .9993445  .0273326 -.0237385
T   16  1 .2908786E+07  3500000E+00  .1214E+05 -.4163E+05  .9996607  .0056814 -.0254207
T   17  1 .2884351E+07  3500001E+00 -.6837E+04  .1574E+05  .9993416  .0231999  .0278934
T   18  1 .2844844E+07  3500002E+00 -.4948E+04  .2897E+05  .9999933 -.0025253  .0026642
T   19  1 .2718841E+07  3500002E+00 -.9026E+04 -.2370E+05  .9993491  .0234105 -.0274475
T   20  1 .2895690E+07  3500002E+00  .3003E+05  .2082E+04  .9997952  .0194663  .0055414
T   21  1 .2799384E+07  3500002E+00  .1870E+05  .7439E+04  .9993571  .0326993 -.0147039
T   22  1 .2890650E+07  3500002E+00  .2534E+05 -.3261E+05  .9997599  .0038053 -.0215802
```

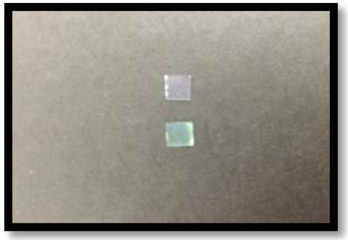
- ❖ Transport of 6MeV protons in PVT
- ❖ Average energy of transmitted protons = 2.8MeV
- ❖ Thus energy lost by 6MeV protons = **3.2MeV**

$$R = \frac{it \times E_{lost}}{q \times m}$$

Sample preparation





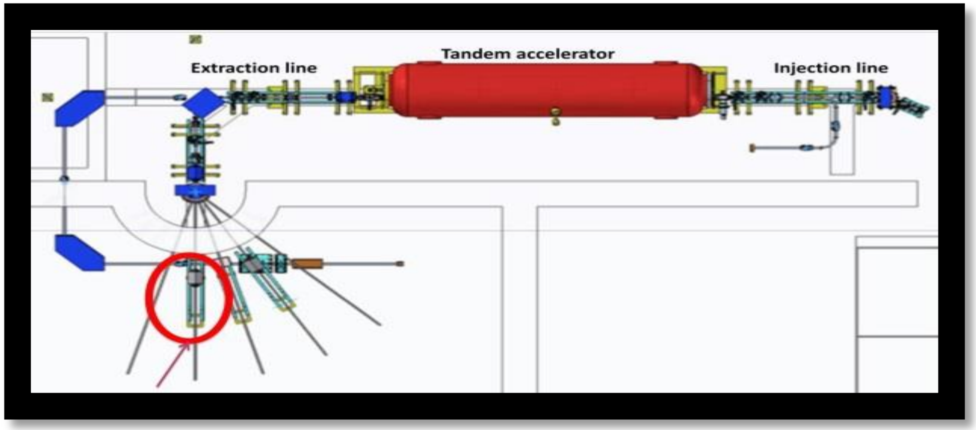


- ❖ Employed metallographic techniques:
  - Documentation
    - 20 cm x 2 cm x 1cm
  - Sectioning and cutting
  - Mounting
  - Rough Polishing
  - Final polishing

❖ Polished samples range:

300 µm – 380 µm

Radiation process



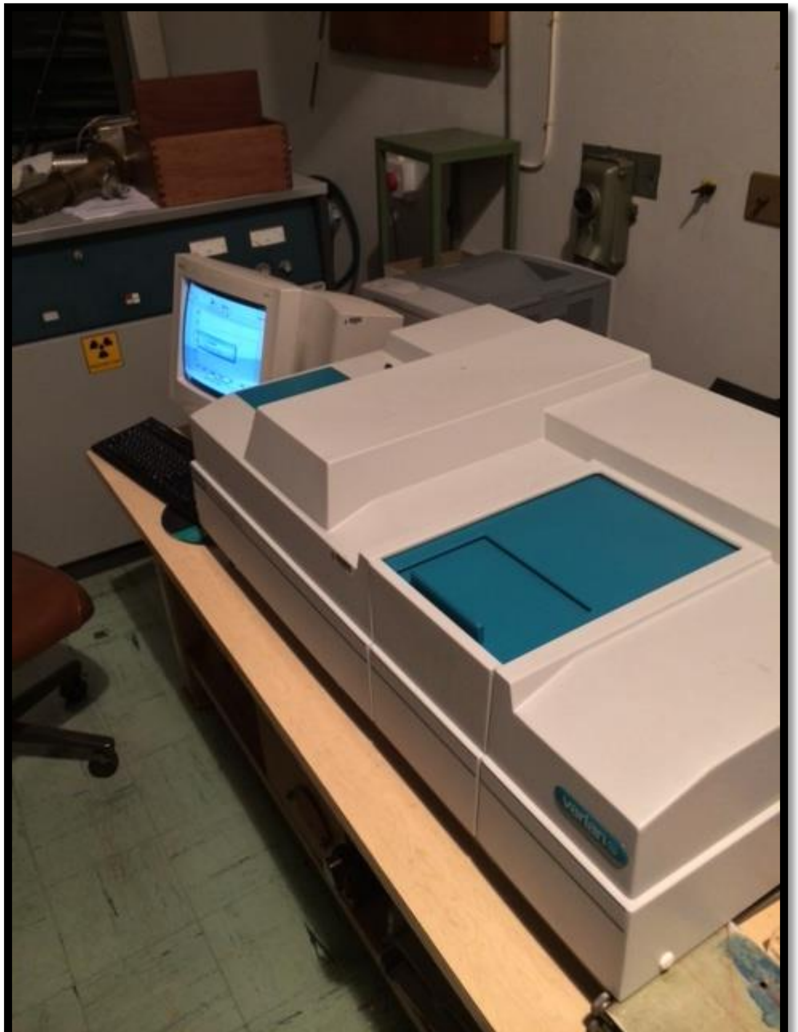
- ❖ Tandem accelerator of iThemba LABS Gauteng

- ❖ Exposure doses:
  - 80 MGy
  - 25 MGy
  - 8 MGy
  - 0.8 MGy

RADIATION PROCESS

Irradiation date	Sample type	Sample number	Sample thickness (µm)	Energy lost (MeV)	Approximate beam current	Approximate beam time (min)	Dose (Mega Gray)
27-Aug-14	EJ 200	13	365	3.4	13-16 nA	35	85.58
	EJ 208	11	320	2.83	16-18 nA	30	80.78
28-Aug-14	EJ 260	13	360	3.33	10-12 nA	45	82
18-Sep-14	EJ 208	12	300	2.71	1.2-1.4 nA	45	8.8
19-Sep-14	EJ 260	15	360	3.33	2.2 nA	23	8.5
	EJ 200	11	340	3.07	1.3 nA	39	8.3
29-Sep-14	EJ 260	18	330	2.95	0.45-0.55 nA	11	0.88
30-Sep-14	EJ 200	14	385	3.68	0.4 nA	12	0.831
	EJ 208	13	300	2.71	0.45-5 nA	12	0.858
06-Oct-14	EJ 208	15	350	3.2	2.5 nA	60	24.8
	EJ 200	16	330	2.95	3.5 nA	45	25.4
07-Oct-14	EJ 260	19	350	3.2	3 nA	52	25.8

TRANSMISSION SPECTROSCOPY

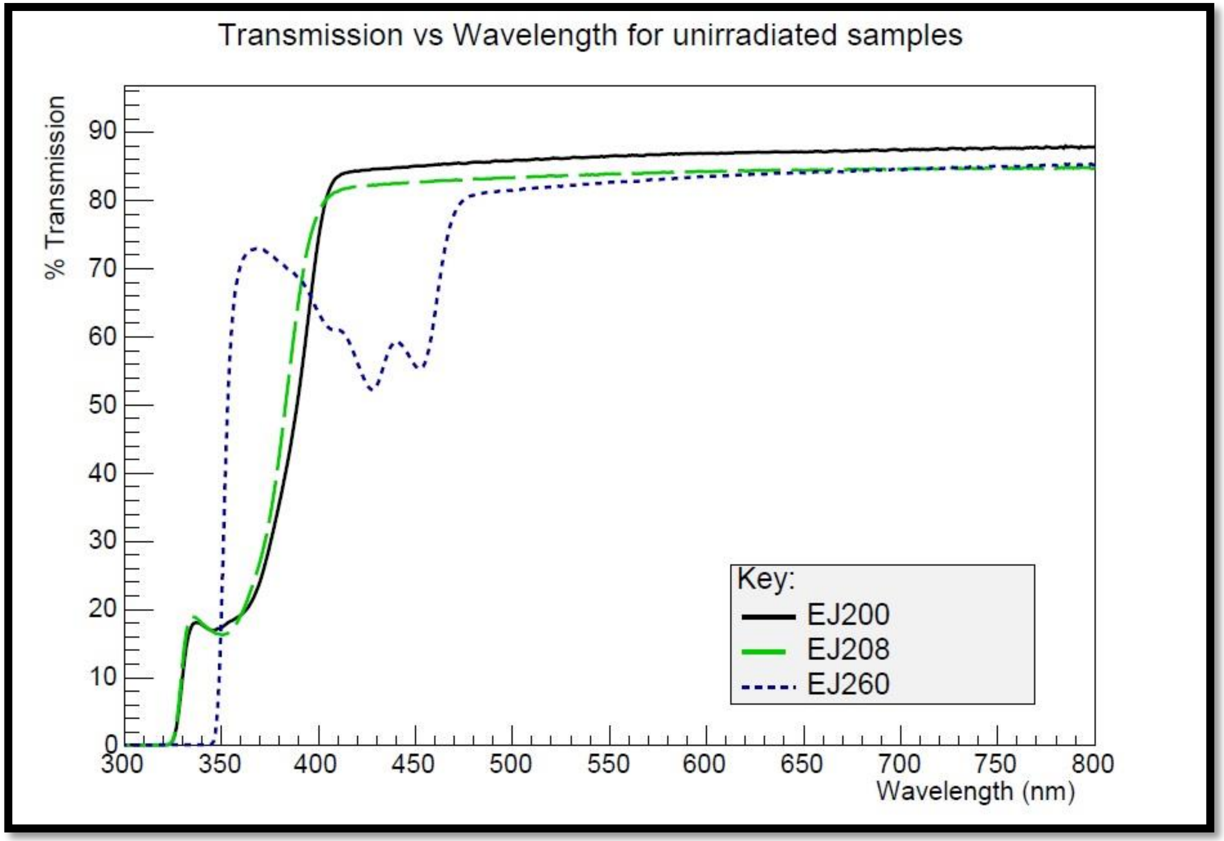


- ❖ Why transmission spectroscopy?
- ❖ Dual beam spectrometer
- ❖ Spectra recorded as percentage of light transmission through air

TRANSMISSION SPECTROSCOPY

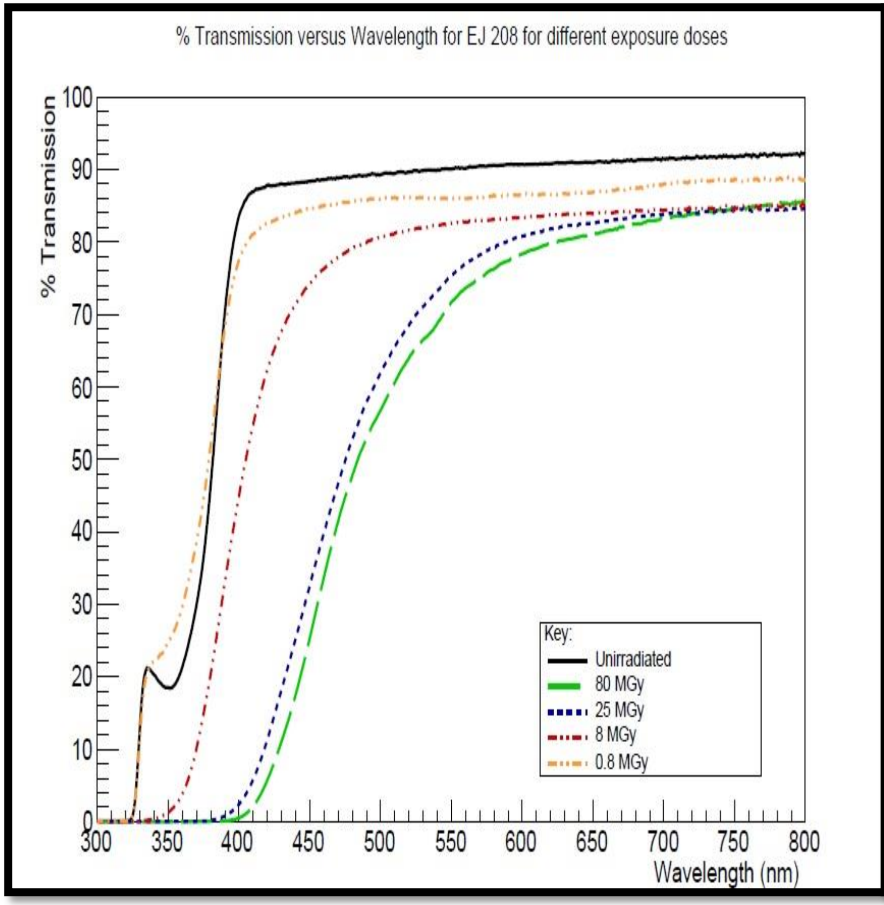
	Sample	Irradiation date	Day of irradiation	2/3 days after irradiation		1 week after	4 weeks after
				TRANSMISSION TESTING			
80 MG	EJ 200 #13	27-Aug		29-Aug		03-Sep	25-Sep
	EJ 208 #11	27-Aug		29-Aug		03-Sep	25-Sep
	EJ 260 #13	28-Aug		30-Aug		04-Sep	26-Sep
8 MG	EJ 208 (#12)	18-Sep	18-Sep	19-Sep		25-Sep	16-Oct
	EJ 260 (#15)	19-Sep	19-Sep	20-Sep		26-Sep	17-Oct
	EJ 200 (#11)	19-Sep	19-Sep	20-Sep		26-Sep	17-Oct
0.8 MG	EJ 260 (#18)	29-Sep	29-Sep	30-Sep	01-Oct	09-Oct	27-Oct
	EJ 200 (#14)	30-Sep	30-Sep	01-Oct	02-Oct	10-Oct	28-Oct
	EJ 208 (#13)	30-Sep	30-Sep	01-Oct	02-Oct	10-Oct	28-Oct
25 MG	EJ 208 (#15)	06-Oct	06-Oct	07-Oct	08-Oct	13-Oct	03-Nov
	EJ 200 (#16)	06-Oct	06-Oct	07-Oct	08-Oct	13-Oct	03-Nov
	EJ 260 (#19)	07-Oct	07-Oct	08-Oct	09-Oct	14-Oct	04-Nov

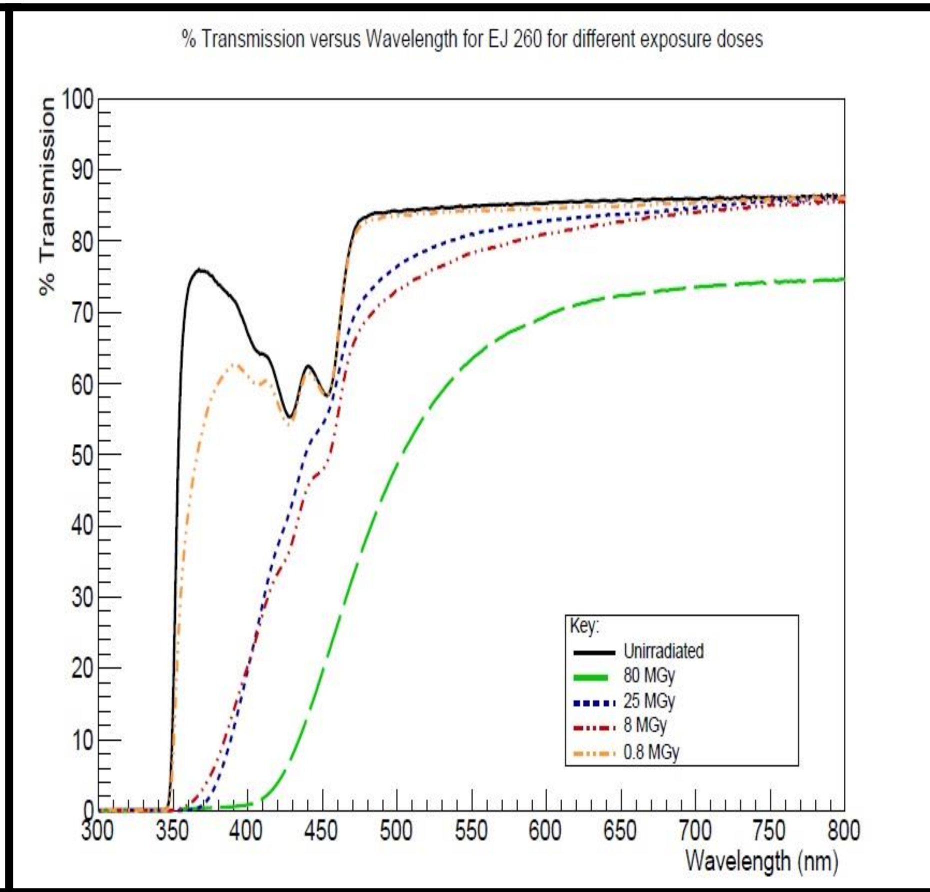
Unirradiated transmission data



- EJ 200 – 85.7%
- EJ 208 – 83.2%
- EJ 260 – 80.8%

EJ 208 & EJ 260 Transmission plots

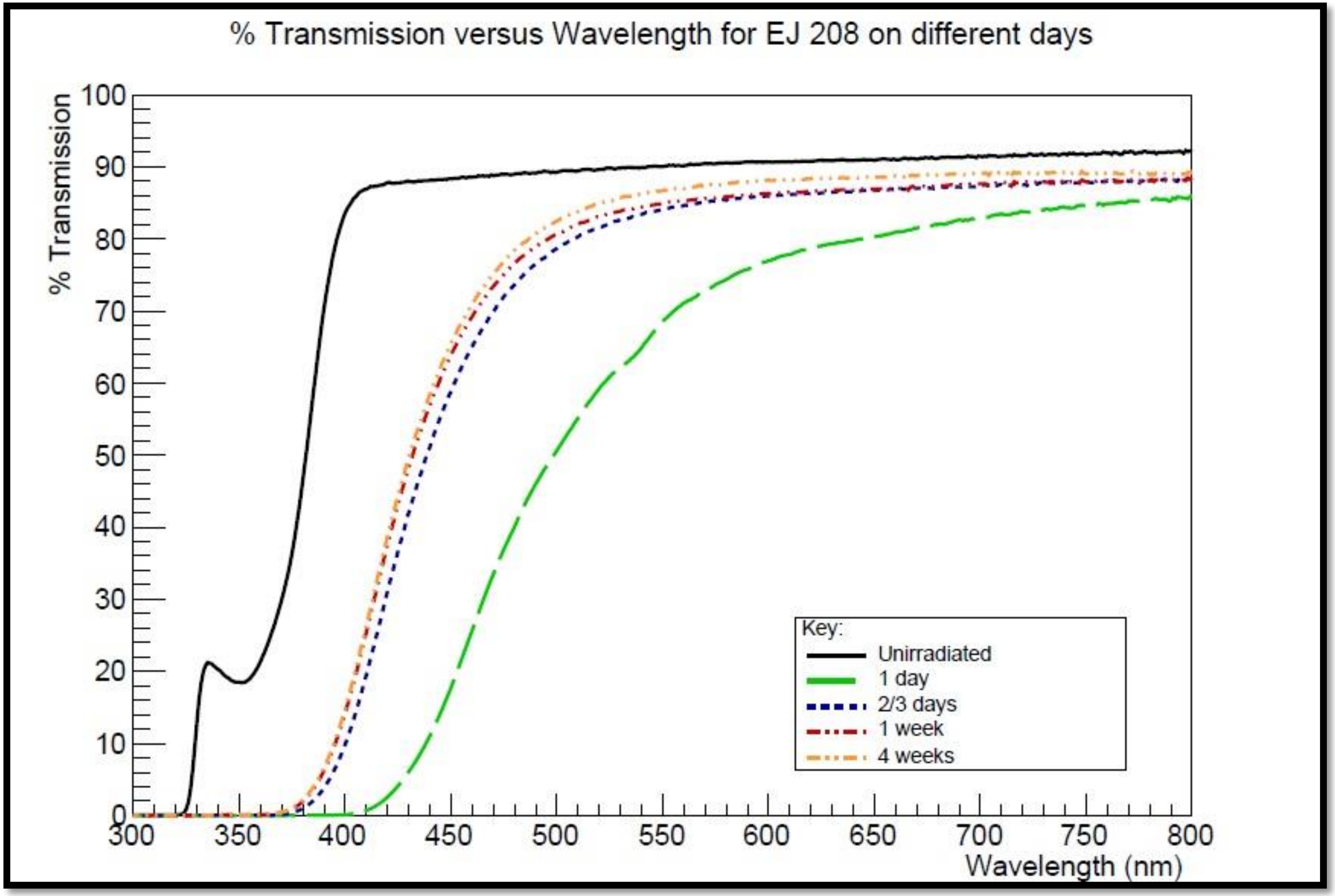




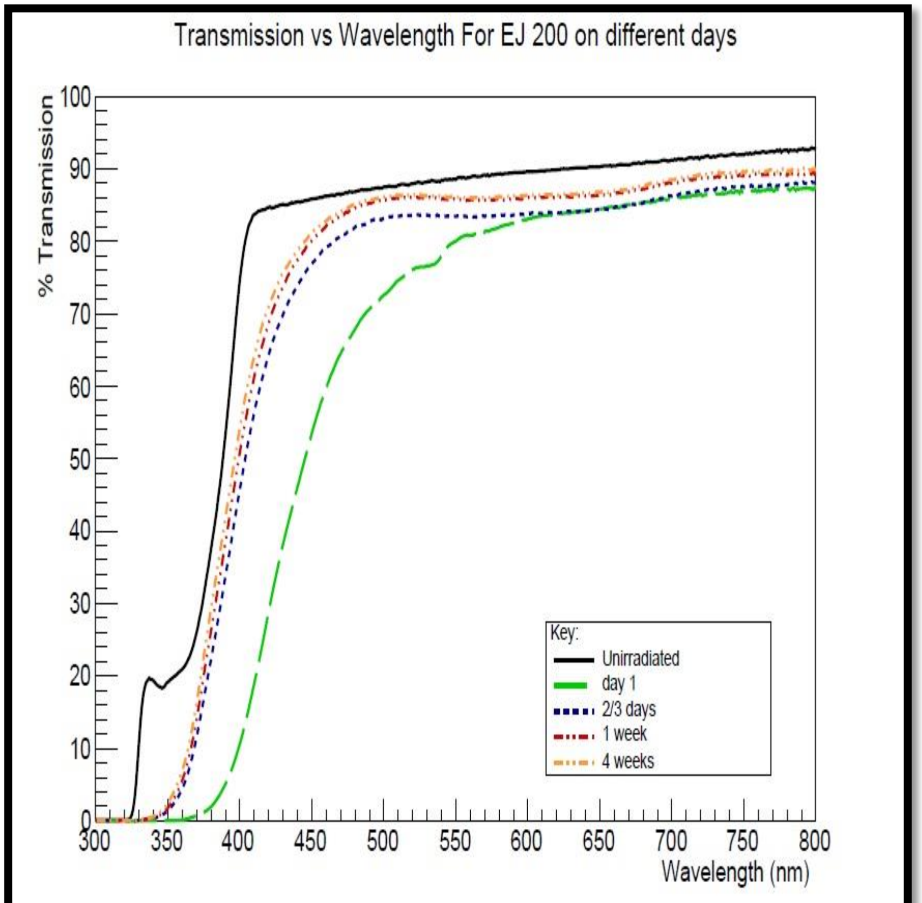
Transmission data

Sample	Dose (Mega Gray)	% Transmission difference	Sample	Dose (Mega Gray)	% Transmission difference
EJ 200	80	42.90%	PROTVINO	80	60.84%
	25	28.60%		25	34.80%
	8	14%		8	7.42%
	0.8	3.90%		0.8	3.28%
EJ 208	80	29.10%	DUBNA	80	51.23%
	25	14.90%		25	35.08%
	8	4.70%		8	26.62%
	0.8	2.50%		0.8	5.54%
EJ 260	80	44.80%	BICRON	80	45.50%
	25	15.50%		25	39.48%
	8	14.30%		8	11.45%
	0.8	6.60%		0.8	8.66%

EJ 208 TRANSMISSION PLOT (ANNEALING ID)



EJ 200 TRANSMISSION PLOT (ANNEALING ID)



	Sample	% Transmission day 1 & 1 week
25 MG	EJ 200	30.38%
	EJ 208	37.06%
	EJ 260	6.45%
		Day 1 & 4 weeks
8 MG	EJ 200	15.05%
	EJ 208	5.92%
	EJ 260	2.22%

CONCLUSION

- Radiation exposure = decrease in light transmission in all grades
- Increase in dose = decrease in transmission
- Samples undergo annealing
- Possible formation of free radicals (EPR)
- Raman and light yield studies were done by Ms. Harshna Jivan
- EJ 208 exhibits the best light transmission properties
  - Lowest decrease in % transmission for most doses
  - Large amount of healing in short period of time.

- According to Markley et al, "A radiation hard plastic scintillator can be defined as a scintillator that does not exhibit a large decrease in light yield output when exposed to ionizing radiation and which can recover a substantial amount of its light output in a short time after being irradiated".