SCINTILLATION SCREEN INVESTIGATIONS FOR HIGH ENERGY HEAVY ION BEAMS AT GSI *

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Abstract

Various scintillation screens were irradiated with Uranium at 269 MeV/u and Carbon at 296 MeV/u over a large intensity range as extracted from the GSI synchrotron SIS18. Their imaging properties were studied with the goal to achieve a precise transverse profile determination. Sensitive scintillators, ceramics and Quartz-glasses were investigated. A linear light yield over four orders of magnitude was found for some materials. For the various screens, remarkable differences up to ±30 % concerning the image width were determined.

CHOICE OF MATERIALS

For transverse profile determination, scintillation screens are frequently used [1], because they deliver a high resolution 2-dimentional beam image and can be realized with reasonable cost. For the anti-proton and heavy ion facility FAIR, these devices are foreseen at about 40 locations for profile determination of intense primary beams as well as very low intensity radioactive ion beams. Different materials are investigated with the focus on the dynamic range i.e. the linearity of the light output as a function of beam current. The image quality for profile reproduction is represented by the image width and higher statistical moments.

Table 1: Investigated Materials and their Thickness

Type	Material	Thick.(mm)	Supplier
Single Crystal	YAG:Ce	1	Saint Gobain
	CsI:Tl	.8	Crystals
Powder on Al	P43 (Gd_2O_2S:Tb)	layer of 50 µm	Proxitronic
Ceramics	Al_2O_3	.8	BCE Special
	Al_2O_3:Cr (Chromox)	.8	Ceramics
	ZrO_2:Mg (Z507)	1	
	ZrO_2:Y (Z70020A)	1	
Quartz-glass	Ce doped (M382)	1	Heraeus
	Pure (Herasil 102)	1	Quartzglass

Standard, purpose built scintillators, namely YAG:Ce and CsI:Tl were irradiated as well as the phosphor powder P43 to elaborate the low intensity limit. Non-transparent ceramics were investigated due to their mechanical stability including the standard screen material Al2O3:Cr (Chromox). They are compared to Ce-doped and un-doped Quartz-glasses. The different materials are compiled in Table 1. The choice was based on previous experience gained at beam energies below 12 MeV/u [2,3] and with Carbon beams above 50 MeV/u [4].

*Work supported by the German Ministry of Science (BMBF) under contract No. 06DA9026.

EXPERIMENTAL SETUP AND ANALYSIS

The results described here were achieved with a Carbon beam of 296 MeV/u as a representative of light ions and with Uranium at 269 MeV/u as a heavy ion species. These beams were slowly extracted from the GSI heavy ion synchrotron SIS18 within typically 0.3 s and transported to the target location. The number of particles per pulse (ppp) was determined with an accuracy of 10 % by an Ionization Chamber for lower intensities and by a Secondary Electron Emission Monitor for higher intensities [5]. This beam intensity was stored for each pulse to monitor any current fluctuation.

A stepping motor driven target ladder of 1.2 m length was mounted in air about 1 m upstream of a beam dump. Nine scintillation screens of 80 mm diameter maximum were mounted on the target ladder oriented 45^o with respect to the beam axis, see Fig. 1.

The light emitted by the scintillating screens was recorded by a monochrome CCD camera (AVT Marlin F033B [6] with 8 bit mode, VGA resolution, FireWire interface) mounted parallel to the scintillation screens at a distance of 42 cm. The reproduction scale was 4.1 pixel/mm. A lens system with remote controlled iris (Pentax, 16 mm focal length) was used to cope with the large dynamic range of the investigations. The lens system and the CCD sensor (Sony ICX414) is sensitive to the optical wavelength spectrum [6]. The camera was triggered with the beam delivery and an exposure time of 0.4 s was chosen. Prior to beam delivery a background picture was recorded. The data acquisition software BeamView [7] was used to store individual images in an uncompressed format.

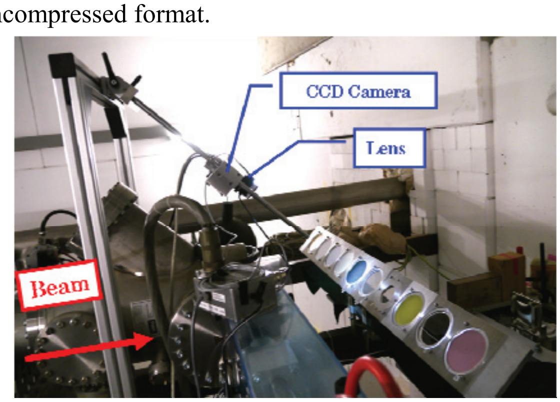

Figure 1: Experimental installation of the nine screens on a 1.2 m long target ladder.

To cope with the large dynamic range, the iris was adapted: For the individual scintillators, data recording was started as soon as an appropriate signal strength was reached for an open iris and stopped for a minimum iris diameter before saturation of the CCD sensor occurred.

In the offline analysis, a common region-of-interest was chosen for all images to calculate the projection to the horizontal and vertical plane of the beam. The projection of the background picture was subtracted individually for each image. This data was fitted with a Gaussian function and statistical moments (integral, centre μ, standard deviation σ and kurtosis κ) were calculated. Various methods of remaining background subtraction were tested, but the general tendency reported below is insensitive to the details of the applied algorithm. Projections to the beam's horizontal plane are discussed here, but a comparable tendency is achieved from the vertical one as well.

The energy loss per ion for each scintillator is compiled in Table 2. The maximum energy loss corresponds to 20 % of the ion's kinetic energy for Uranium and 1.4 % for Carbon, respectively

Table 2: The energy loss ΔE per ion in the scintillators is calculated by SRIM [8] for Uranium and Carbon of total kinetic energy 64.0 GeV and 3.55 GeV, respectively. The light yield Yrel relative to YAG:Ce was derived from Fig. 2 and 5.

Scint.	Uranium		Carbon	
	ΔE(GeV)	Y_{rel}(%)	ΔE(GeV)	Y_{rel}(%)
CsI:Tl	6.4	180	.025	
YAG:Ce	10.5	100	.044	100
P43	0.67	34	.0026	38
Al_2O_3:Cr	7.9	15	.032	15
Al_2O_3	7.9	1.4	.032	1.7
Quartz:Ce	6.7	8.3	.023	
ZrO_2:Mg	12.4	0.35	.050	
ZrO_2:Y	13.1	0.048	.053	
Herasil	6.7	0.035	.023	

RESULTS FOR URANIUM IRRADIATION

As shown in Fig. 2, the light yield of the investigated scintillators differs by more than 3 orders of magnitude. As expected, the purposed built scintillators CsI:Tl and YAG:Ce are most sensitive. A noticeable linearity between the light yield and the number of particles over almost 4 orders of magnitude is recorded. The light output for P43 is about factor of 3 less than for YAG:Ce, which is remarkable, because the powder thickness is only 50 μm compared to the transparent crystals of ≈ 1 mm thickness. The relative light yield of the scintillators compared to YAG:Ce is compiled in Table 2 as calculated from the depicted linear fits.

Due to the Chromium luminescence centre, Al_2O_3:Cr can be grouped to the sensitive screens. The doping of Ce in Quartz leads to a high light yield.

Compared to doped Al_2O_3:Cr the pure Al_2O_3 is less sensitive by a factor of ten. The ceramics ZrO_2:Mg and ZrO_2:Y are even less sensitive. They show a clear non-linear behavior concerning the light yield versus number of particles, which is probably related to saturation of the luminescence centers. The Quartz-glass Herasil is characterized by a very low light yield.

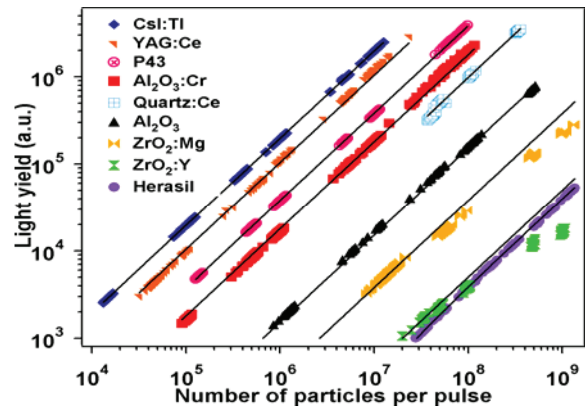

Figure 2: Light yield as a function of number of particles for various sctintillators. The beam parameters are: Uranium at 269 MeV/u and 0.3 s pulse length. Each dot represents one beam pulse, the lines are linear functions.

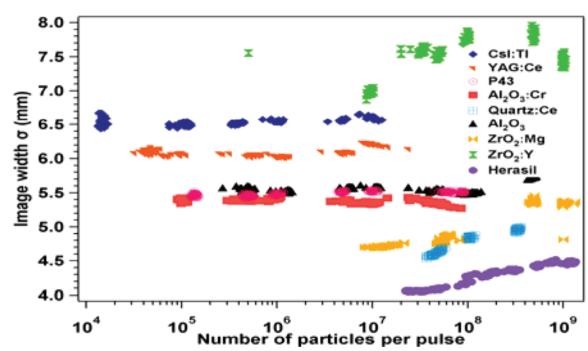

Figure 3: Image widths gained from Gaussian fits to the horizontal projections for Uranium irradiation are shown; beam parameters as of Fig. 2.

The image width, as determined from Gaussian fits, is depicted for all scintillators in Fig. 3. CsI:Tl and YAG:Ce show a significantly larger image width. This finding can not be attributed to particle number dependent saturation of luminescence centers due to the constant image width. The reason for this behavior is not completely understood, but comparable findings for YAG:Ce were reported earlier [1,2,9].

The image width of three materials P43, Al_2O_3:Cr and Al_2O_3 coincides within ±4 % through all number of particles. The profile shapes for these scintillators, as represented by the kurtosis, are comparable as well (values are not shown in this paper). We interpret this coincidence as a hint of valid beam profile reproduction.

ZrO_2:Y shows the largest beam width. It is believed that radiation modifies the material quite fast and leads to significant image deformation.

ZrO_2:Mg, Quartz:Ce and in particular Herasil show a smaller width by 5 - 30 % as compared to the group P43, Al_2O_3:Cr and Al_2O_3. We believe, that this is an underestimation of the beam width, because comparable results were obtained for Herasil at lower energies [2,3]. Presently, we can't give a stringent physical explanation.

Not only the beam width, but even the shape of the image projection is different for the materials as exemplarily shown in Fig. 4: For both purpose built scintillators CsI:Tl and YAG:Ce the projection shows significant shoulders as compared to Al_2O_3:Cr (Fig. 4, left), while the region around the maximum is reproduced in the same manner. The reason is not fully understood and will be investigated in further experiments. Because the experiment location is closed to a beam dump, there might additionally be some contributions from back-scattered radiation. The middle plot in Fig. 4 shows, that the image projection from the materials of the group P43, Al_2O_3:Cr and Al_2O_3 coincide. For Herasil, the edges of the projection are significantly different as the one of Al_2O_3:Cr. This seems to be a typical behaviour of Herasil leading to an under-estimation of the beam width.

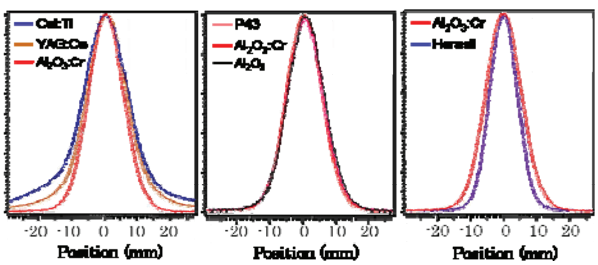

Figure 4: Comparison of the projections for the given scintillators for Uranium irradiation normalized to the maximum. The depicted plots were recorded with different particle numbers.

RESULTS FOR CARBON IRRADIATION

In Fig. 5, the light yield of some scintillators is plotted for the irradiation with 296 MeV/u Carbon beam. YAG:Ce is the most sensitive material. It is followed by P43 being a factor of about 3 less sensitive, see Table 2. The ratio between doped Al_2O_3:Cr and pure Al_2O_3 is about 10, which coincides well with the findings for Uranium. The light yield from all scintillators is linear with respect to the number of particles over three orders of magnitude. The absolute scale for the light yield of Carbon coincides with the one of Uranium within ±20 %.

The image width is depicted in Fig. 6. As for the Uranium case, the three scintillators P43, Al_2O_3:Cr and Al_2O_3 result in the same reading while the YAG:Ce scintillator produced ≈10 % larger image width comparable to the finding for Uranium irradiation.

CONCLUSION

Several scintillators were investigated under irradiation of a light and a heavy ion species. The light yield for most materials is noticeably linear with respect to the number of particles. The profiles of P43, Al_2O_3:Cr and Al_2O_3 coincide well. They seem to be adequate scintillators for our application. The transparent, purpose built scintillators CsI:Tl and YAG:Ce show a larger image width. Further experiments are required for a proper understanding. Herasil underestimate the beam profile. ZrO_2 based materials are inapplicable due to their non-linear behavior and possible radiation damage.

This type of investigations will be continued for different ion species. The issue of radiation hardness was not investigated here and will be done in further experiments. Due to radiation, significant material modifications can occur and this fact will significantly influence the choice of scintillators for FAIR.

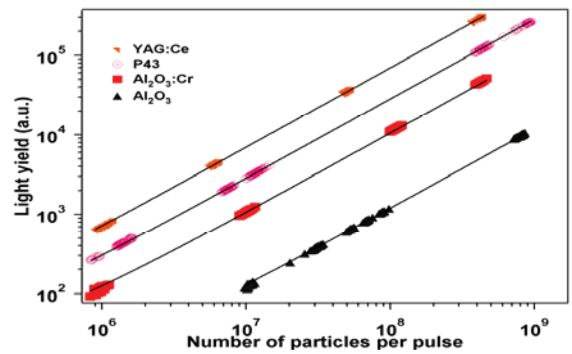

Figure 5: Light yield as a function of number of particles for selected scintillators. The beam parameters are: Carbon at 296 MeV/u and 0.4 s pulse length. Each dot represents one beam pulse, the lines are linear functions.

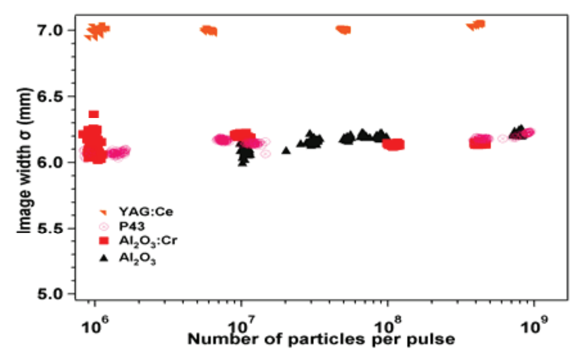

Figure 6: Image widths gained from Gaussian fits to the horizontal projections for Carbon irradiation are shown; beam parameter as of Fig. 5.

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