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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

# A study on undoped CsI crystals

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This report summarizes main results of a study on scintillation properties and radiation resistance of large size undoped cesium iodide (CsI) crystals produced in former Soviet Union. The results of this study indicate that with existing quality, undoped CsI crystal may be used in high counting rate environment with integrated radiation dosage up to 10 krads. Improvements in radiation resistance are needed, however, if they are to be used in very high radiation environment, such as SSC and LHC.

## 1. Introduction

As one of the fast scintillators, undoped cesium iodide (CsI) crystal recently received much attention [1–3]. The fast speed and high radiation resistance expected from undoped CsI crystals have attracted many potential users, especially high energy physicists pursuing precision electromagnetic calorimeters at future hadron colliders: superconducting super collider (SSC) at US and large hadronic collider (LHC) at Europe.

The "gammas, electrons and muons" (GEM) collaboration at SSC has proposed a barium fluoride crystal ($BaF_2$) calorimeter as one of two options for its precision electromagnetic calorimeters [4]. Much progress has been made in understanding the application of $BaF_2$ crystals at the SSC and quality requirements to the crystals [5]. Although the radiation resistance of large size $BaF_2$ crystals has been improved a great deal in past few years [5–7], it is not yet satisfactory for an SSC application. An extensive R&D program is being carried out, aiming at producing large size $BaF_2$ crystals with required quality [8].

Alternative crystals were proposed by several GEM collaborators. Selivanov of Kurchatov Institute, Moscow, Russia, proposed undoped CsI crystals for GEM EM calorimeter in January 1992, and pointed out that large size high quality crystals have been produced in former Soviet Union in large quantity [9]. It is thus interesting to evaluate the feasibility of this proposition. Two large size undoped CsI crystal were collected from Selivanov and Greene of Los Alamos National Laboratory (LANL), and were studied at Caltech.

This report summarizes main results of this study on scintillation properties and radiation resistance of large size undoped cesium iodide (CsI) crystals. The results of this study indicate that pure CsI crystal may be used in high counting rate environment with radiation dosage up to 10 krads. Improvements in radiation resistance are needed, however, if they are to be used in very high radiation environment, such as SSC and LHC.

## 2. Samples

Four samples of undoped CsI were tested. All samples were produced by All-Union Scientific Research Institute of Single Crystal at Khar'kov, an institute in former USSR, and now the Republic of Ukraine. Except sample CsI-4, which was a courteous loan of Greene of LANL, all other three samples were provided by Selivanov. Table 1 lists the size and shape of these samples.

All surfaces of these samples were optically polished. Except the surface contracting with light sensitive detector, all other surfaces were wrapped with three layers of Teflon film or aluminum foil for good light reflection, as listed in table 1. The light sensitive device used in this study is Hamamatsu photomultiplier tube (PMT) R2059 which has a quartz window and a bialkali photocathode with full spectrum response. The crystals were optically coupled to the PMT by using Dow Corning 200 Fluid which has very good UV transmittance.

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Table 1
Properties of scintillation crystals

| Sample | Dimension [cm] | Wrapping |
|---|---|---|
| CsI-1 | ∅2×2 | Teflon |
| CsI-2 | ∅2×2 | Teflon |
| CsI-3 | 4×4×20 | aluminum |
| CsI-4 | 5×5×19 | aluminum |

Table 2
Properties of scintillation crystals

| Sample | $F$ [%] | $\tau_F$ [ns] | $S$ [%] | $\tau_S$ [ns] |
|---|---|---|---|---|
| CsI-1 | 33 | $6.1 \pm 1.2$ | 67 | $30 \pm 8$ |
| CsI-2 | 29 | $6.6 \pm 1.7$ | 71 | $27 \pm 5$ |
| CsI-3 | 22 | $7.1 \pm 1.0$ | 78 | $41 \pm 6$ |
| CsI-4 | 27 | $6.8 \pm 1.1$ | 73 | $43 \pm 6$ |

## 3. Basic property measurement

### 3.1. Decay time

The decay time of CsI crystals were measured with two independent methods:
- by analysing scintillation waveform recorded with digital scope HP54111; and
- by analysing decay time spectrum obtained with single photon counting technique using a reference $BaF_2$ counter.

Fig. 1 shows waveforms collected from four samples: (a) CsI-1, (b) CsI-2, (c) CsI-3 and (d) CsI-4. It is clear that the scintillation light of undoped CsI contains at least two components, the decay time of the fast one is about 7 ns, and the slower one is about 30 to 40 ns. The waveforms were further fitted to an analytic form with two decay constants:

$$Y(t) = \frac{F}{\tau_F} e^{-t/\tau_F} + \frac{S}{\tau_S} e^{-t/\tau_S}, \qquad (1)$$

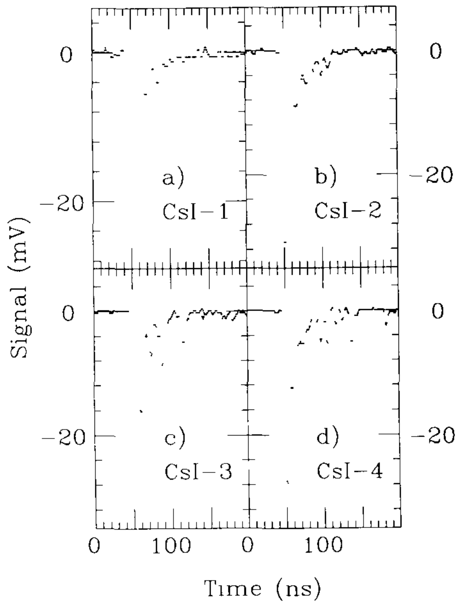


Fig. 1. Waveforms collected by a digital scope HD54111D from four undoped CsI samples: (a) CsI-1, (b) CsI-2, (c) CsI-3, (d) CsI-4.

where $F$ and $S$ are the normalized total light yield in each component, and $F + S \equiv 1$, while $\tau_F$ and $\tau_S$ are their decay time constants. The result of the fitting is listed in table 2.

It is interesting to notice that larger crystal (CsI-3) has smaller fraction f the fast component. This may be explained by stronger absorption of the fast component.

Fig. 2 shows a decay time spectrum obtained from sample CSI-1 by using single photon counting technique. The reference counter used in this measurement was a $BaF_2$ crystal which has a fast decay time of less than 1 ns. The spectrum was fitted to the same function as eq. (1). The result of this measurement indicates that $\tau_F = 5.8 \pm 1.4$ ns and $\tau_S = 44.2 \pm 3.4$ ns in agreement with waveform analysis, shown in table 2.

In summary, we conclude that the scintillation light of undoped CsI has two components with a fast decay time about 6 to 7 ns and a slow decay time about 30 to 40 ns. Our measurement is in good agreement with results of Kubota et al. [10] ($\tau_F = 10$ ns, $\tau_S = 36$ ns) and Woody et al. [11] ($\tau_F = 7$ ns, $\tau_S = 29$ ns), and is different from Schotanus et al. [12] ($\tau_F = 2$ ns, $\tau_S = 22$ ns).

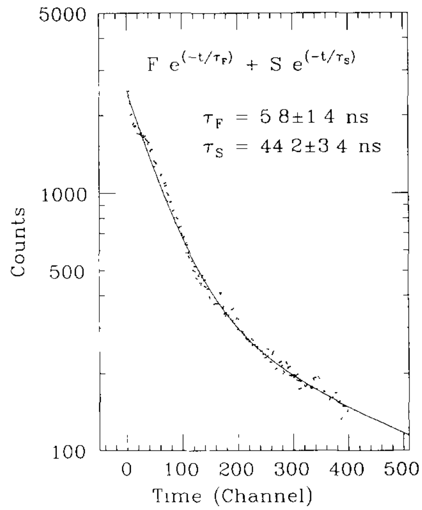


Fig. 2. Decay time spectrum (0.1 ns/channel) from an undoped CsI.

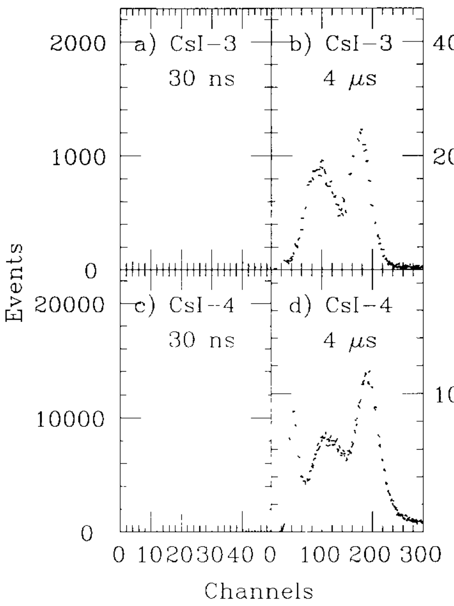


Fig. 3. $^{137}Cs$ pulse height spectra obtained from two large size undoped CsI crystals for two gate widths.

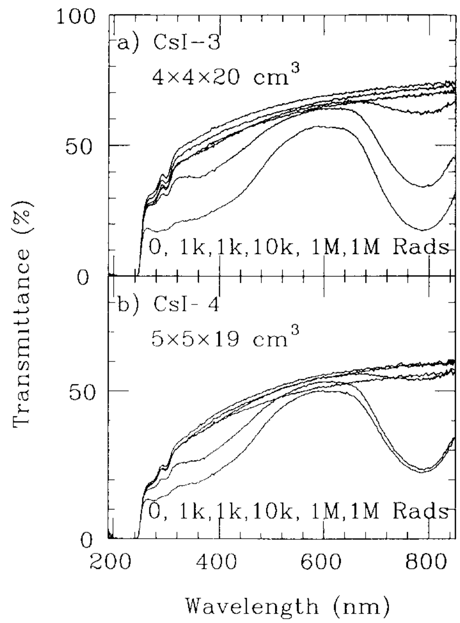


Fig. 4. Transmittance spectra of two large size undoped CsI crystals obtained before and after 100, 1 k, 10 k, 100 k and 1 Mrads of $^{60}Co$ γ-ray irradiation.

### 3.2. Light yield

The scintillation light yield, in terms of photoelectrons (p.e.) numbers per MeV of energy deposition, of these samples were measured by using a $^{137}Cs$ γ-ray source with a 2 in. diameter Hamamatsu PMT R2059. The scintillation light pulses collected by the PMT were integrated by a Lecroy 3001 QVT in the Q mode. A short gate of 30 ns and a long gate of 4 μs were provided by a Lecroy 2323A gate generator to measure the light yield. Fig. 3 shows the $^{137}Cs$ γ-ray pulse height spectra collected from two large CsI crystals. The results of this measurement is listed in table 3. The numbers in this table are consistent with the fast/slow ratio obtained from waveform analysis listed in table 2.

### 3.3. Transmittance measurement

The transmission of undoped CsI samples were measured with Hitachi U-3210 spectrophotometer which has double beam, double monochromator and a large sample compartment. The accuracy of the transmittance measurement was about 0.5%, as indicated in repeated measurements to a $BaF_2$ crystals [5]. The spectra before irradiation are plotted as the top curves in fig. 4. The curve decreases smoothly to zero at around 250 nm. The transmission is dominated by reflection and scattering losses at the surfaces and does not correlate to the bulk absorption. A small absorption peak at 300 nm was found in both CsI-3 and CsI-4, which indicates the T1 contamination.

Table 3
Light yield from undoped CsI crystals

| Sample | S.G. [ns] | L.Y. [p.e./MeV] | L.G. [ns] | L.Y. [p.e./MeV] |
|---|---|---|---|---|
| CsI-3 | 30 | 55 | 4000 | 96 |
| CsI-4 | 30 | 55 | 4000 | 94 |

### 3.4. Summary

Table 4 shows a comparison of main properties between undoped CsI, as measured in this report, and $BaF_2$ crystals.

In table 4, the light yield of fast and slow is defined as the light yield of full size (20 to 25 cm long) crystal in each component with decay time listed. For $BaF_2$ crystal, we have listed two numbers which were measured respectively with bialkali and solarblind photocathode, such as K–Cs–Te or Rb–Te. The solar blind cathode suppresses the slow component produced by $BaF_2$.

From this table, one finds several advantages of CsI:

1) because of its shorter radiation length, the total volume of CsI crystals may be reduced to 85% to construct a crystal calorimeter, comparing with barium fluoride;

2) because of its lower density, the total weight of a CsI calorimeter may be reduced to 78%, comparing with a barium fluoride calorimeter;

Table 4
Comparison between CsI and $BaF_2$ crystals

| Crystal | Pure CsI | $BaF_2$ | $CsI/BaF_2$ |
|---|---|---|---|
| Density [$g/cm^3$] | 4.51 | 4.88 | 0.924 |
| Radiation length [cm] | 1.85 | 2.06 | 0.898 |
| Nuclear interaction length [cm] | 37.0 | 29.9 | 1.24 |
| Refractive index | 1.8 | 1.5 | 1.2 |
| Hygroscopic | slight | slight | – |
| Luminescence-fast [nm] | 310 | 220 | – |
| Decay time-fast [ns] | 6 | < 1 | – |
| Light yield-fast [p.e./MeV] | 30 | 80, 50 | – |
| Temperature dependence | ? | No | – |
| Luminescence-slow [nm] | 450? | 310 | – |
| Decay time-slow [ns] | 30–40 | 600 | – |
| Light yield-slow [p.e./MeV] | 70 | 500, 25 | – |
| Temperature dependence | ? | – 2.4%/°C | – |
| Light yield-total [p.e./MeV] | 100 | 580, 75 | – |

3) because of its higher refractive index, it would be easier to achieve the light response uniformity for a long tapered CsI crystal, assuming a good reflective surface can be obtained;

4) because of its longer nuclear interaction length, the effective e/h ratio would be lower, and there would be less hadronic energy deposited in CsI.

Note, the light yield of CsI-4 was measured by Greene [3] to be 227 p.e./MeV by using a 3 in. diameter PMT, as compared with our 94 p.e./MeV. This can partially be explained by 65% effective light collection area of our 2 in. diameter PMT for crystal CsI-4.

## 4. Radiation resistance

Like barium fluoride, there are many different reports on radiation resistance of pure CsI, see e.g. ref. [11]. Winstein's group did obtain a good 20 cm long crystal from Solon which is radiation hard enough up to 15 krads, i.e. no apparent change in light yield and uniformity [13].

We measured radiation resistance of two large samples: CsI-3 and CsI-4. The $\gamma$-ray irradiation was performed in a radiation facility at JPL, which has a $^{60}Co$ source of 9000 Ci. The doses were delivered at a rate of 10 (for 100, 1 and 10 krads) and 19 (for 100 krads and 1 Mrads) rads/s. The transmission measurements were done after integrated dosage of 100, 1, 10 and 100 krads and 1 Mrads at room temperature, and followed by the light output measurements.

Fig. 4 shows transmittance spectra measured before and after 100, 1, 10 and 100 krads and 1 Mrads doses. Both samples show a prominent absorption band at 800 nm and several absorption bands in the 250–550 nm region after 10 krads dosage. This 800 nm band has been tentatively identified as caused by an F-center. However, contrary to $BaF_2$, there was no saturation effect observed in transmission measurement up to 1 Mrads.

It was very difficult to measure the light output of undoped CsI after irradiation, because of intense phosphorescence in both samples. The light output measurement was performed two days after the irradiation. Fig. 5 shows light yields as a function of integrated dosage for a short gate (30 ns) and a long gate (4 $\mu$s), normalized to the values measured before irradiation. The light output decreased by about 10% up to 1 krads, and further decreased to 20–30% of the original values after 1 Mrads dosage, for both short and long gates. There was no saturation observed in light yield either.

Note, the result discussed here was obtained from two large size crystals, while tests with small crystals, such as CsI-2 which was specially produced at Khar'kov for radiation test purpose, showed essentially the same result. The transmittance and light yield started decrease after 1 krads. The light yield decreased to 75% after 1 Mrads, comparing with about 20% for 25 cm long crystals. The light yield was further reduced to 50% after 10 Mrads. No saturation was observed in this small crystal.

A 25 cm long $BaF_2$ crystal produced by Shanghai Institute of Ceramics (SIC) was irradiated together with long CsI crystals. After 10 krads dosage, the light output of this $BaF_2$ crystal decreased to 40–50% of its

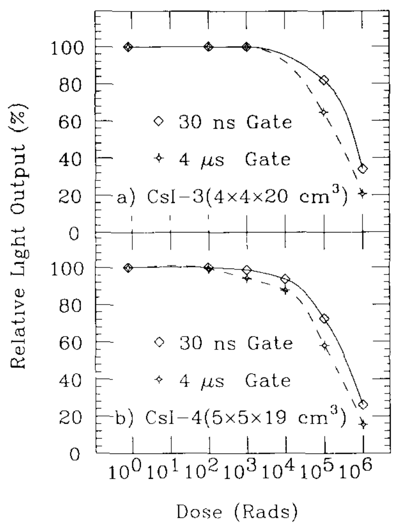


Fig. 5. Relative light yields measured with two different gate widths from two large size undoped CsI crystals are shown as a function of dosage.

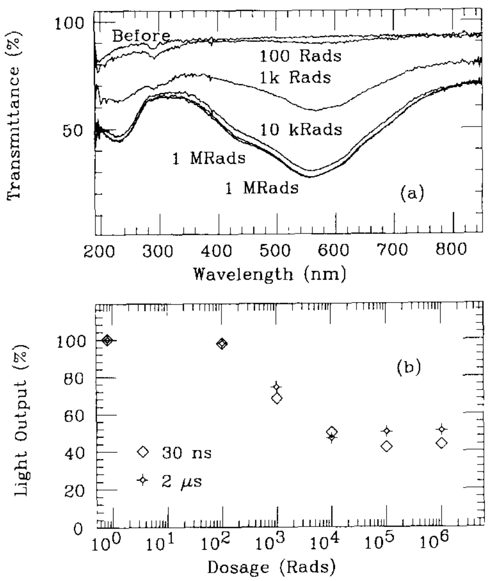


Fig. 6. Transmittance (a) and relative light output (b) measured with a 25 cm long $BaF_2$ crystal from SIC are shown as a function of dosage.

original value, and had no further loss up to 1 Mrads. Both transmittance and light yield show clear saturation after 10 krads, as shown in fig. 6.

## 5. Conclusions

In summary, undoped CsI is an interesting fast scintillator. It has a fast component with a decay time of about 7 ns and a slow component with a decay time of about 30 to 40 ns. The light yield of undoped CsI is adequate for a precision electromagnetic calorimeter. It is also believed that the slow component contamination can be handled electrically [14].

The main uncertainty is its radiation damage. The damage of undoped CsI does not saturate. Both transmittance and light yield continue decrease after 1 krads. This hints that the radiation damage of undoped CsI is related to crystal lattice, rather than impurities. The conclusion thus is: with existing quality, the undoped CsI crystals can certainly be used in high counting rate environment with radiation dosage up to 10 krads. Improvements in radiation resistance are needed, however, if they are to be used in very high radiation environment, such as SSC and LHC.


## Acknowledgement

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## References


[1] C. Woody et al., Proposal on generic R&D on undoped cesium iodide and lead fluoride, unpublished.

[2] B. Winstein et al., Proposal for a new tevatron search for direct CP violation in the $2\pi$ decays of the neutral kaon, unpublished.

[3] S. Greene, private communication.

[4] GEM Collaboration, Letter of Intent to the SSCL, November 30, 1991.

[5] R.Y. Zhu, On quality requirements to the barium fluoride crystals, Caltech Preprint, CALT-68-1767 and GEN note GEM TN-92-48 (1992).

[6] P.J. Li et al., in: Super Collider 4, ed. J. Nonte (Plenum, New York, 1992) p. 801

[7] G. Chen et al., in: Super Collider 4, ed. J. Nonte (Plenum, New York, 1992) p. 809

[8] $BaF_2$ Collaboration, R&D Proposal submitted to the SSCL (1992).

[9] V.I. Selivanov, private communication.

[10] S. Kubota et al., Nucl. Instr. and Meth. A268 (1988) 275.

[11] C Woody et al., IEEE Nucl. Sci. Symp., Santa Fe, New Maxico (1991) and IEEE Trans Nucl. Sci. NS-37 (1990) 492.

[12] P. Schotanus et al., IEEE Trans. Nucl. Sci. NS-37 (1990) 177.

[13] A. Roodman, private communication.

[14] D. Marlow, private communication.