# Measurements of $BaF_2$ Crystals from BGRI and SICCAS


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# Introduction

- Following a visit to Beijing Glass Research Institute (BGRI), Beijing, on January 9, 2015, two 3 x 3 x 20 cm $BaF_2$ crystal samples were obtained.
- Longitudinal transmittance (LT) was measured by using a Perkin-Elmer Lambda 950 spectrophotometer.
- Pulse height spectrum (PHS), Light output (LO) and light response uniformity (LRU) were measured by using a Hamamatsu R2059 PMT with a bi-alkali cathode and a quartz window and coincidence triggers from a $^{22}Na$ source for these two samples wrapped with two layers of Tyvek paper and grease coupling.
- Gamma-ray irradiation was carried out up to 100 krad for these two samples with degradation in LT, LO and LRU measured, and compared to SIC samples.

# Beijing Glass Research Institute

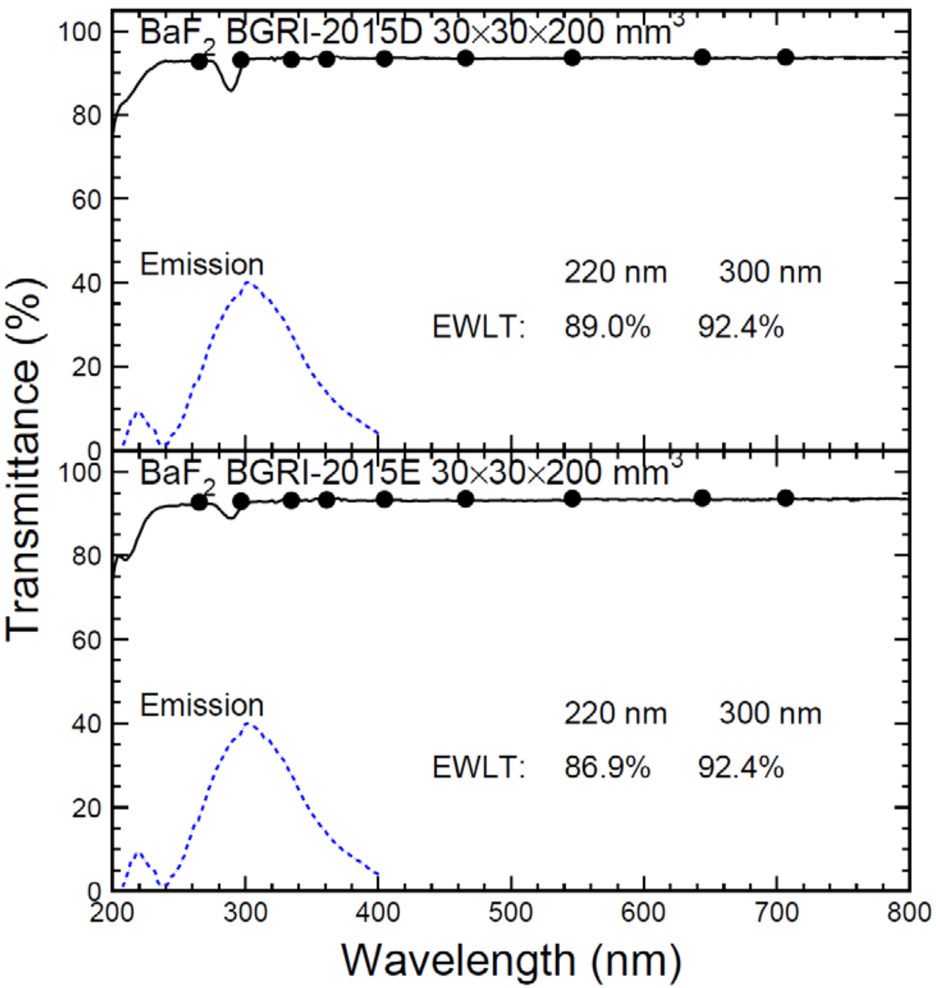

# $BaF_2$ Crystal Samples

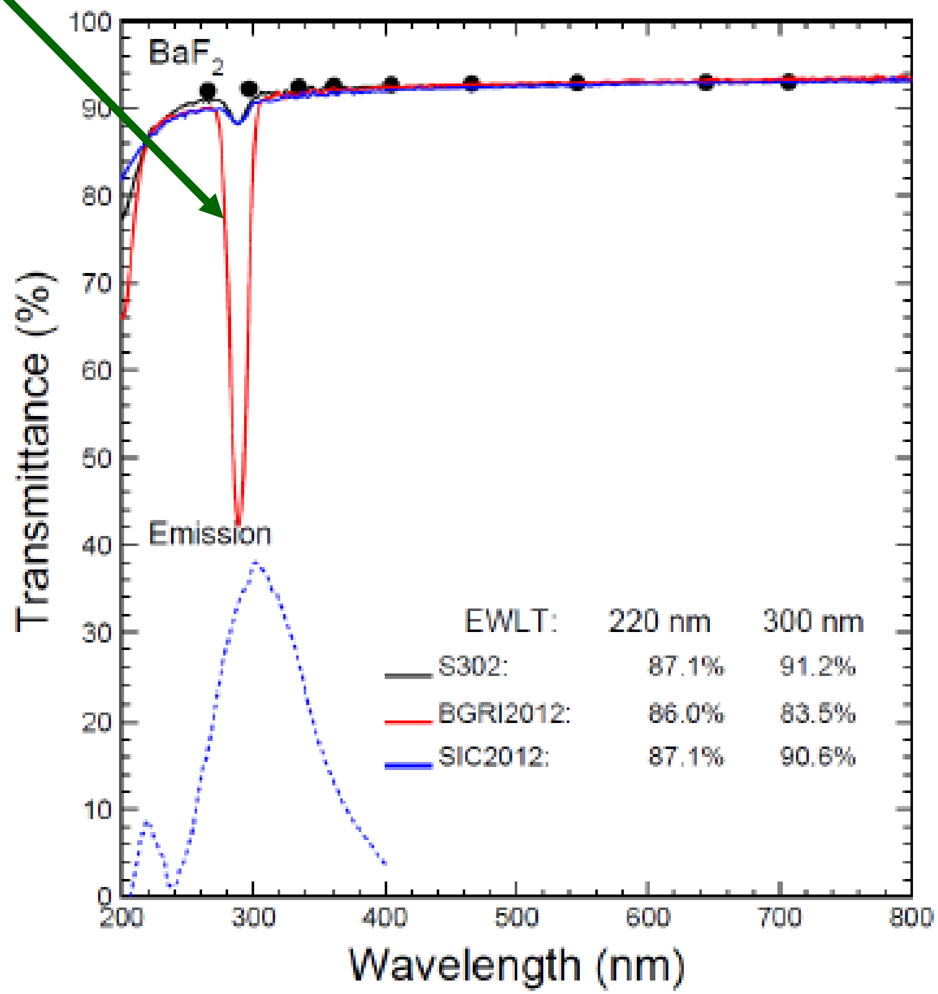

| ID | Dimension ($mm^3$) | Polishing |
|---|---|---|
| BGRI-2015D | 30x30x200 | Six faces |
| BGRI-2015E | 30x30x200 | Six faces |

Compared to 20 3 x 3 x 25 cm test beam crystals from SIC

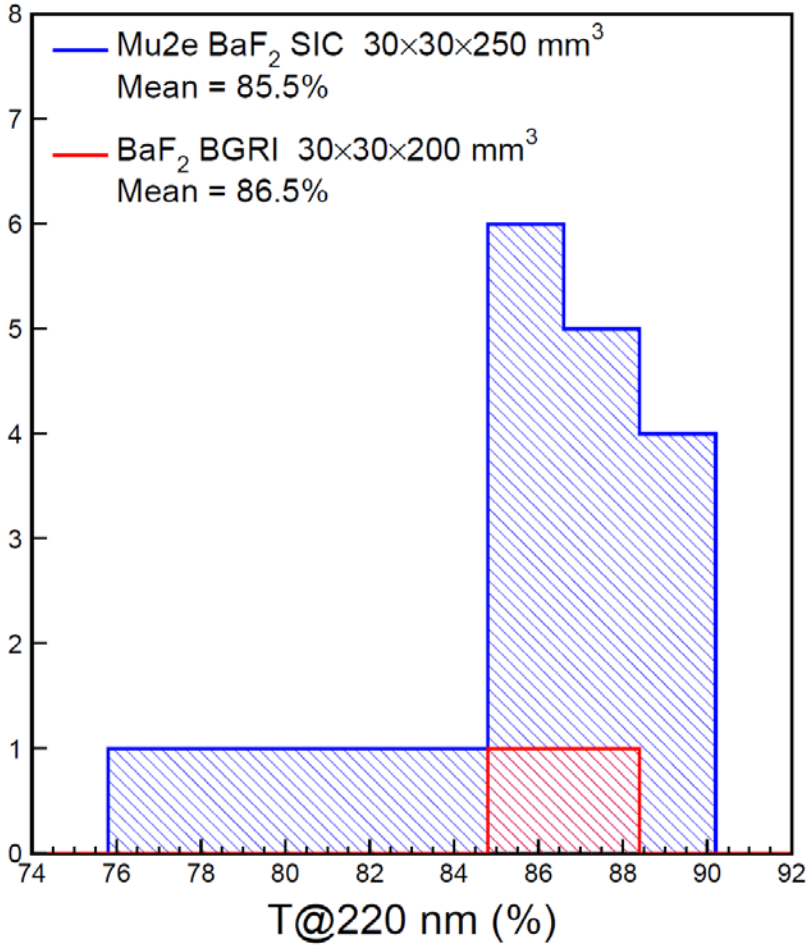
# Initial Optical Quality (LT)

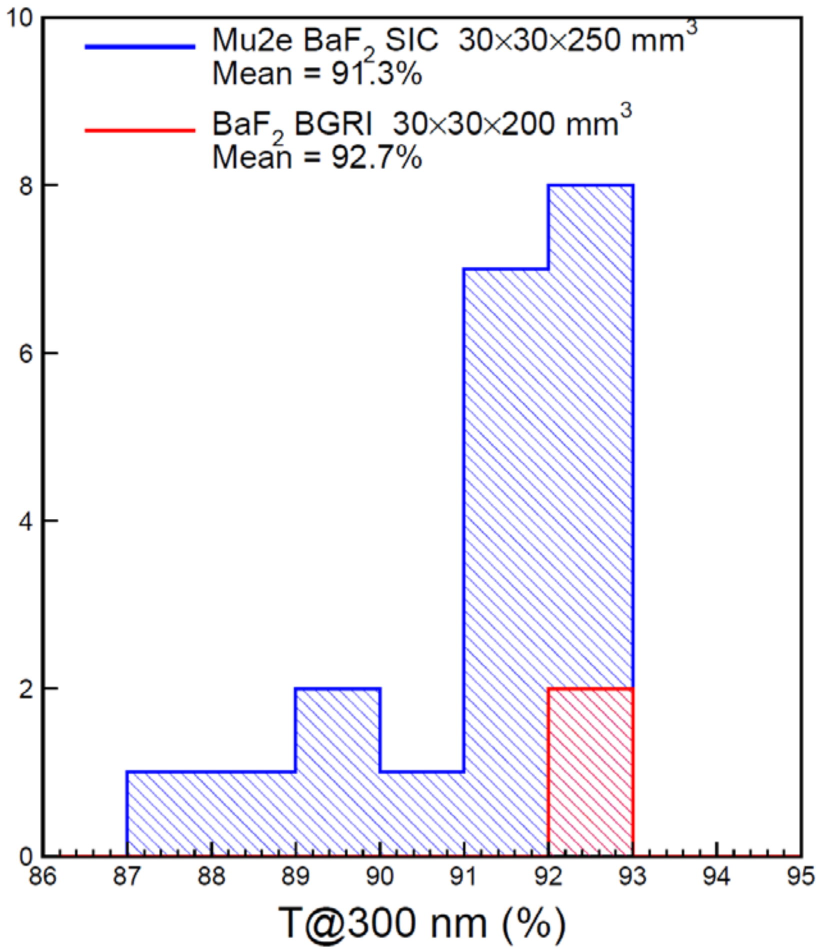
Good OQ as compared to BGRI2012 and 20 SIC samples (86%, 91%)



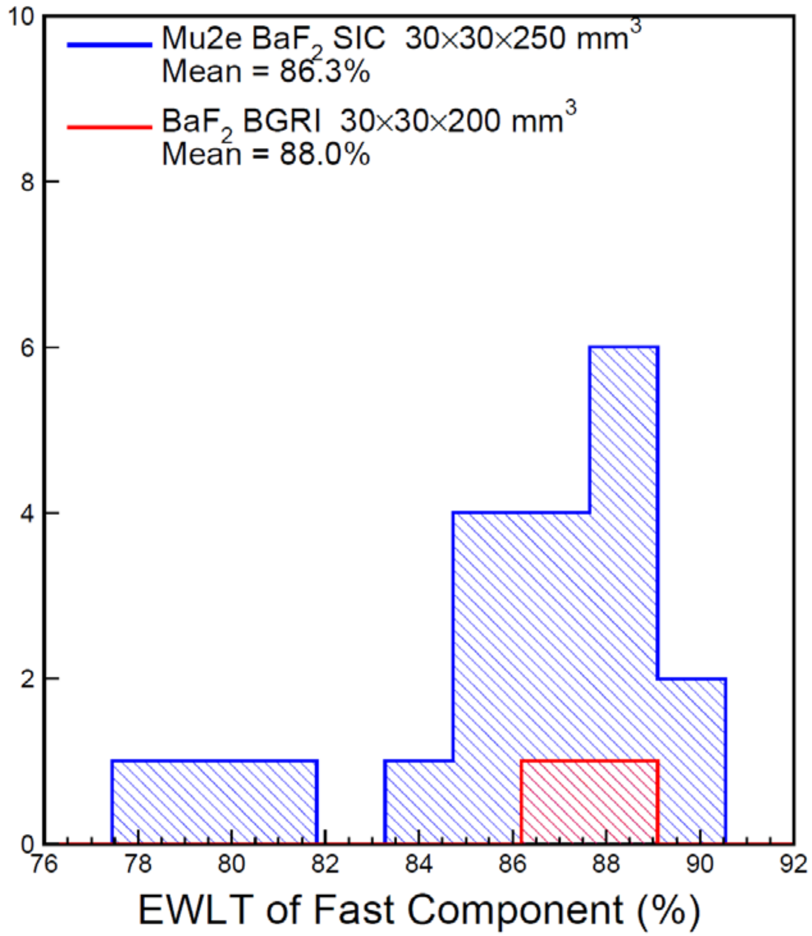



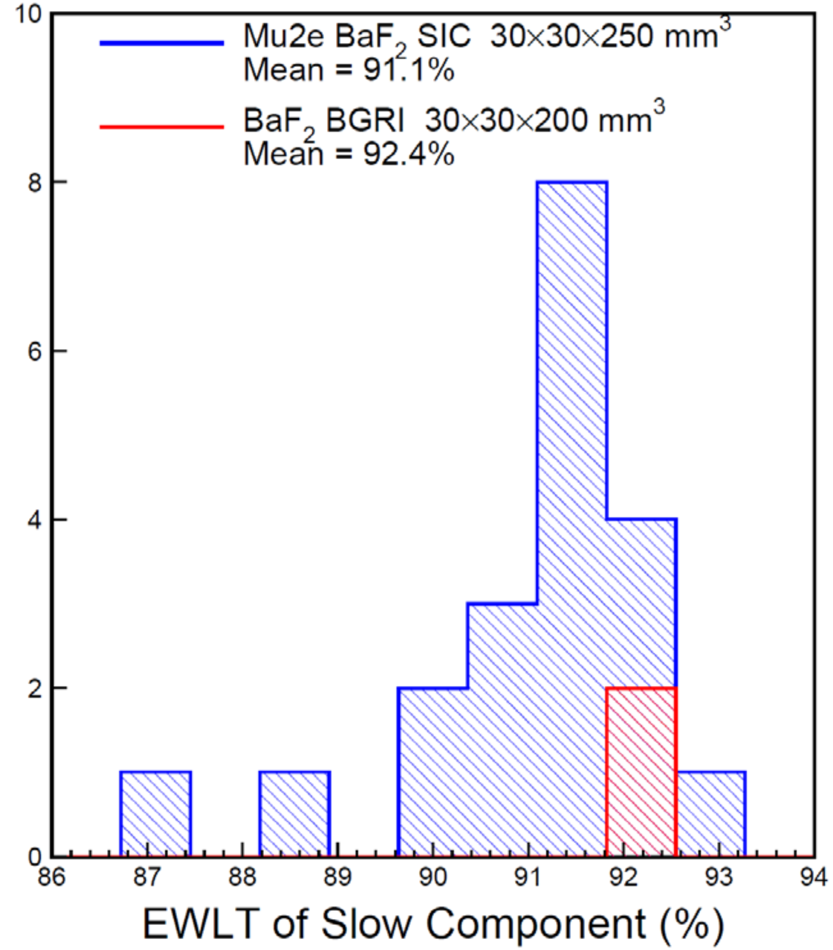
# Comparison of Transmittance



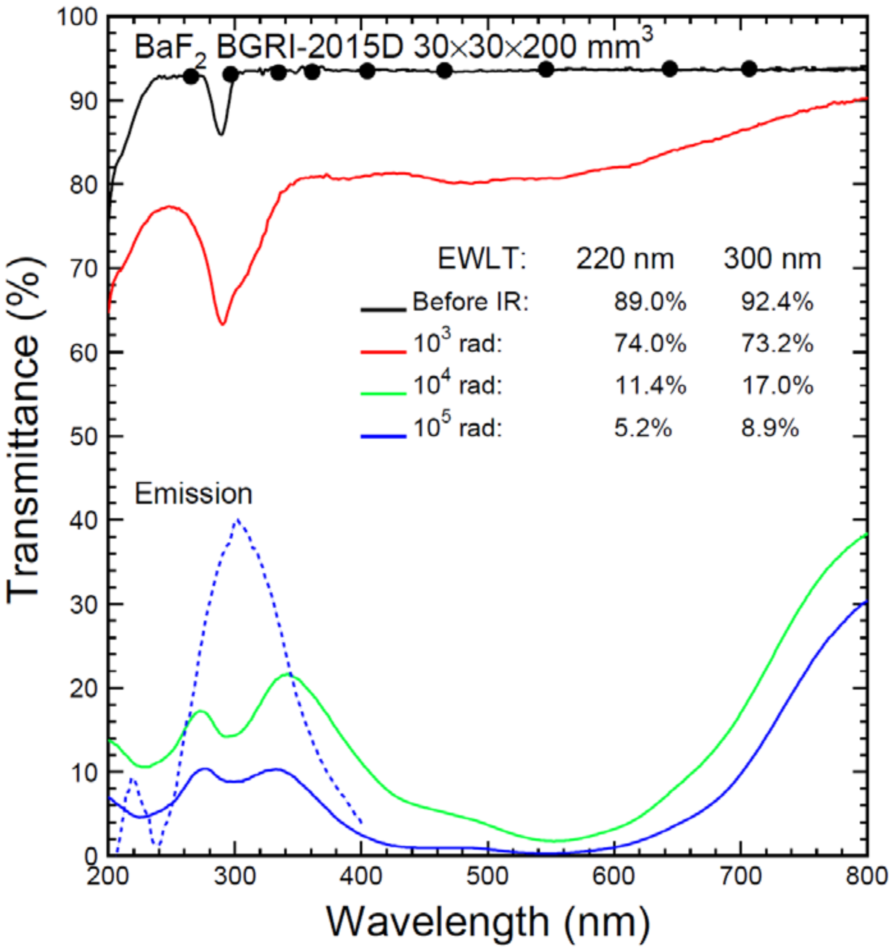
# Comparison of EWLT

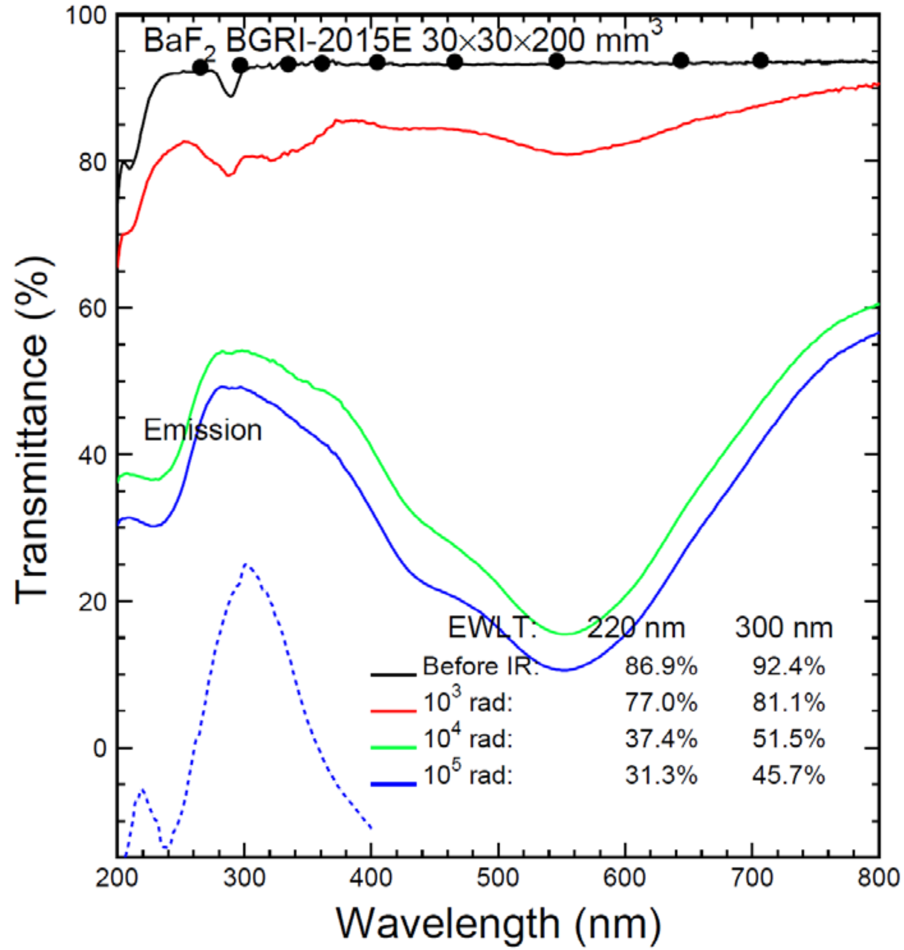


# LT Before and After Gamma-ray Irradiation

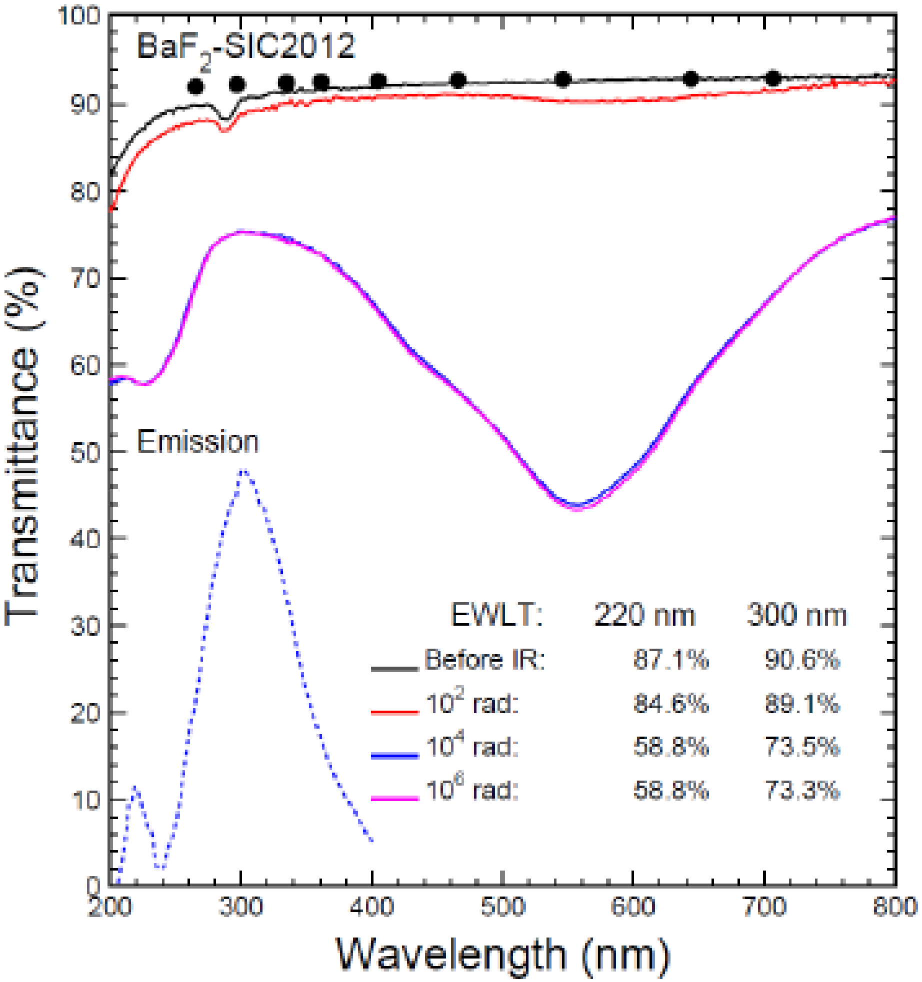
Significant damage observed after 10 krad

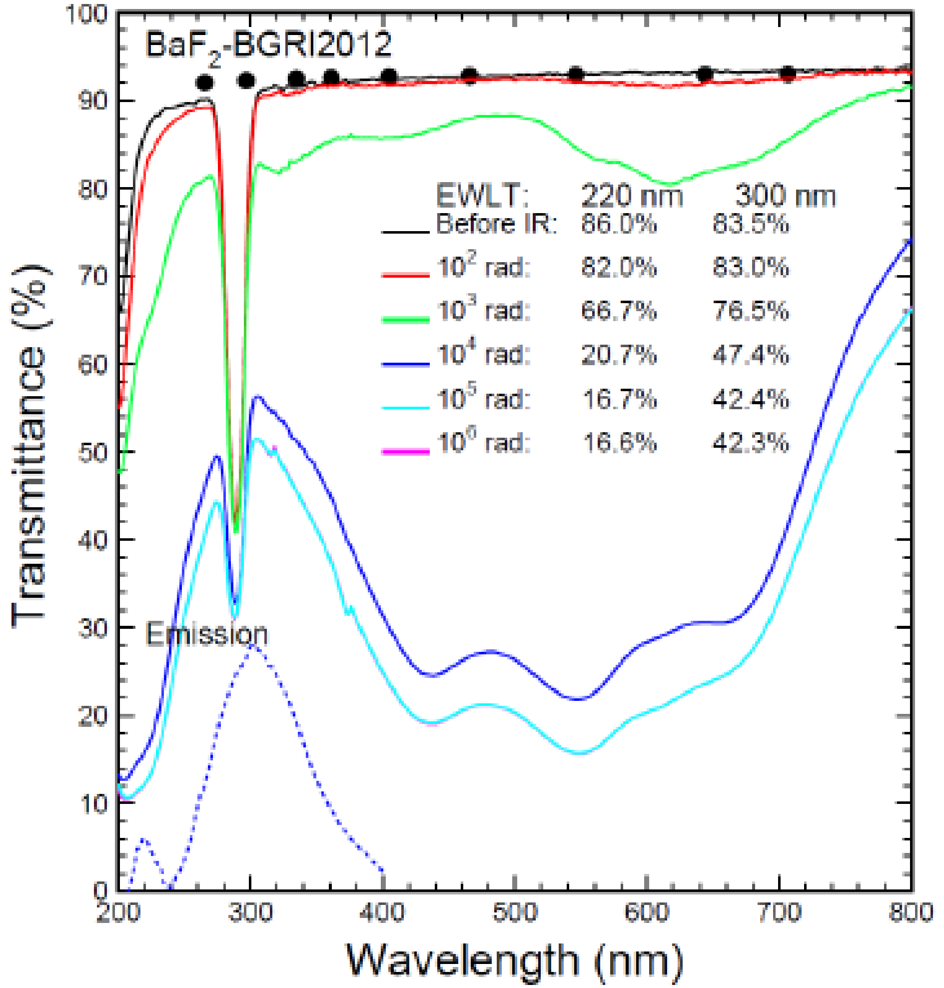


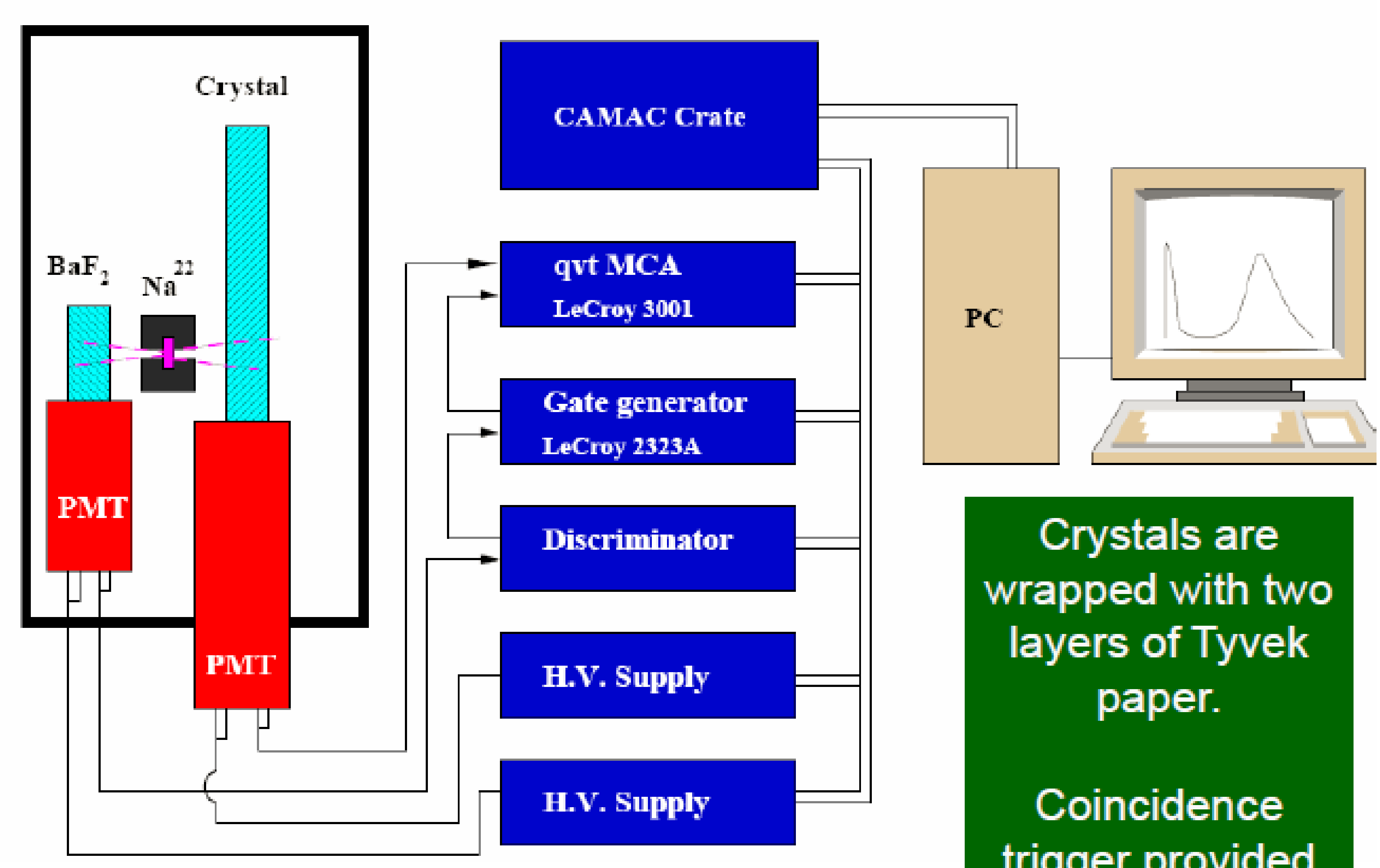
# Comparison: SIC2012 & BGRI2012

Much worse than SIC2012, but compatible with BGRI2012



# Setup for LO & LRU Measurements



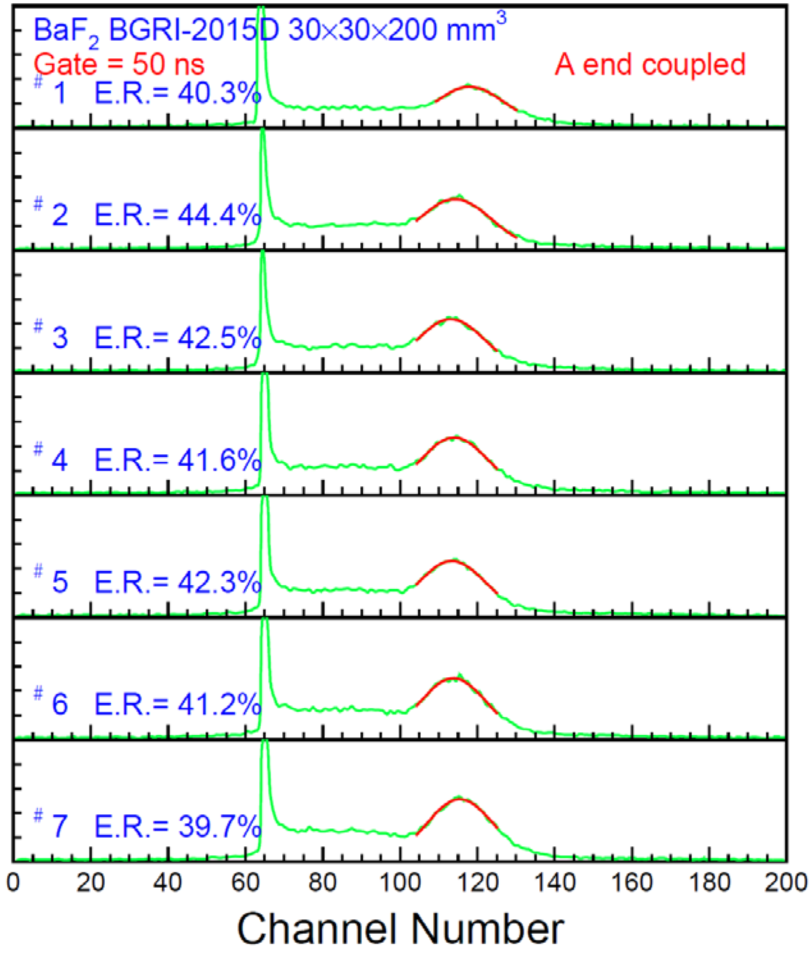

Crystals are wrapped with two layers of Tyvek paper.

Coincidence trigger provided by a $^{22}$Na source.

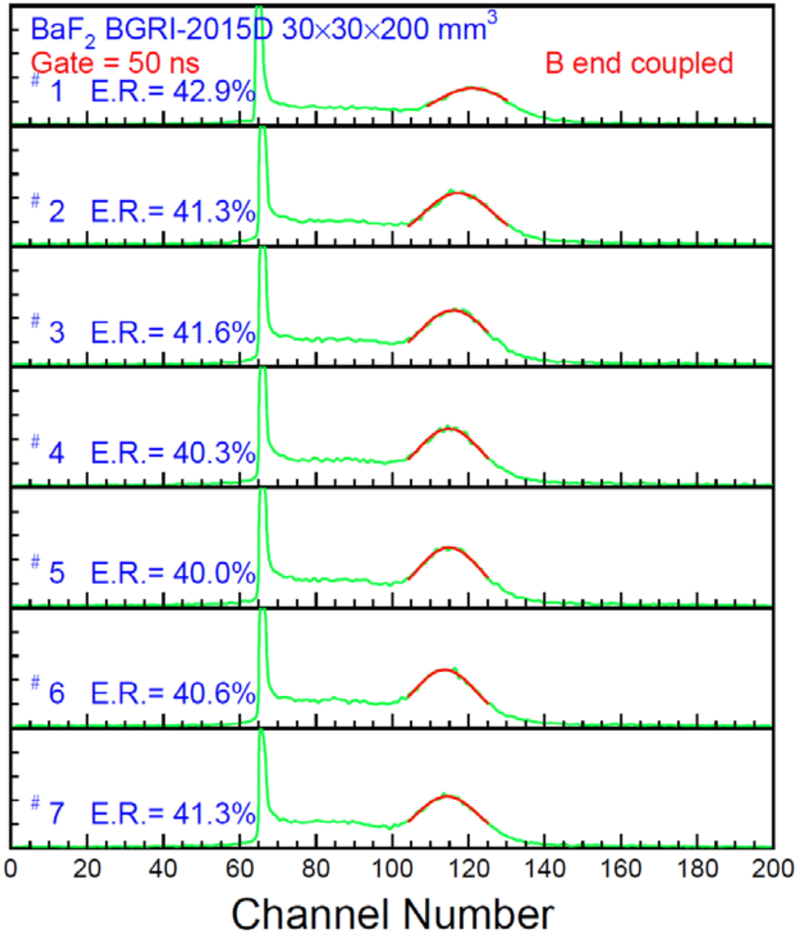
# Pulse Height Spectra: BGRI-2015D

Gate: 50 ns

Ave ER= 41.7%




Ave ER= 41.1%

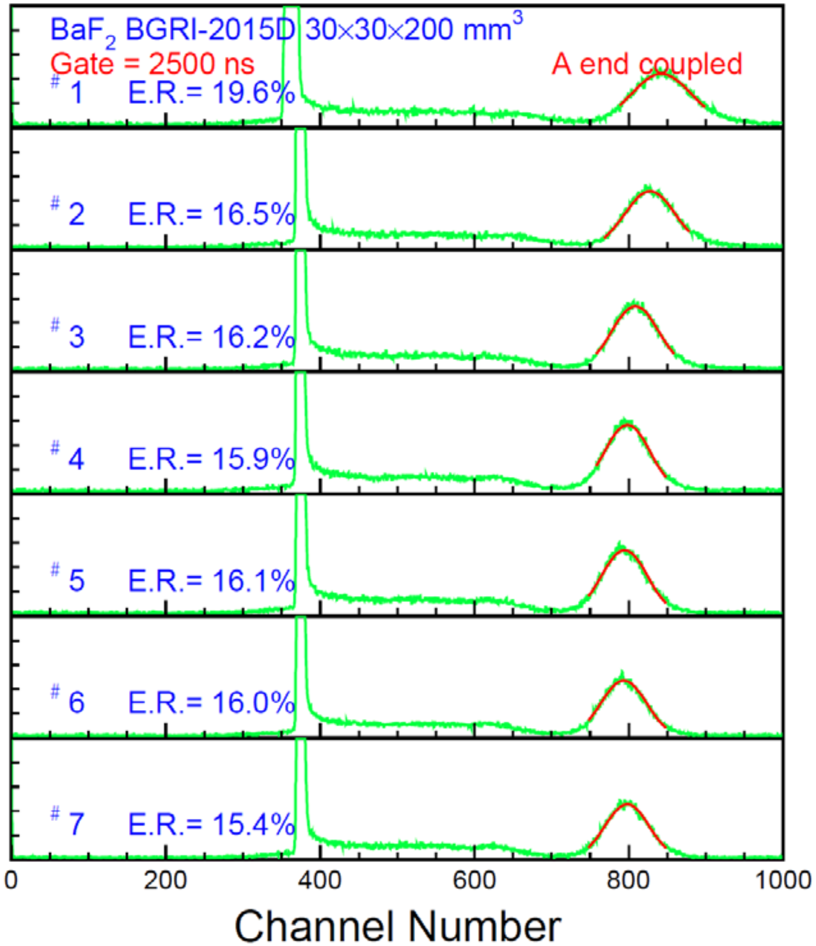


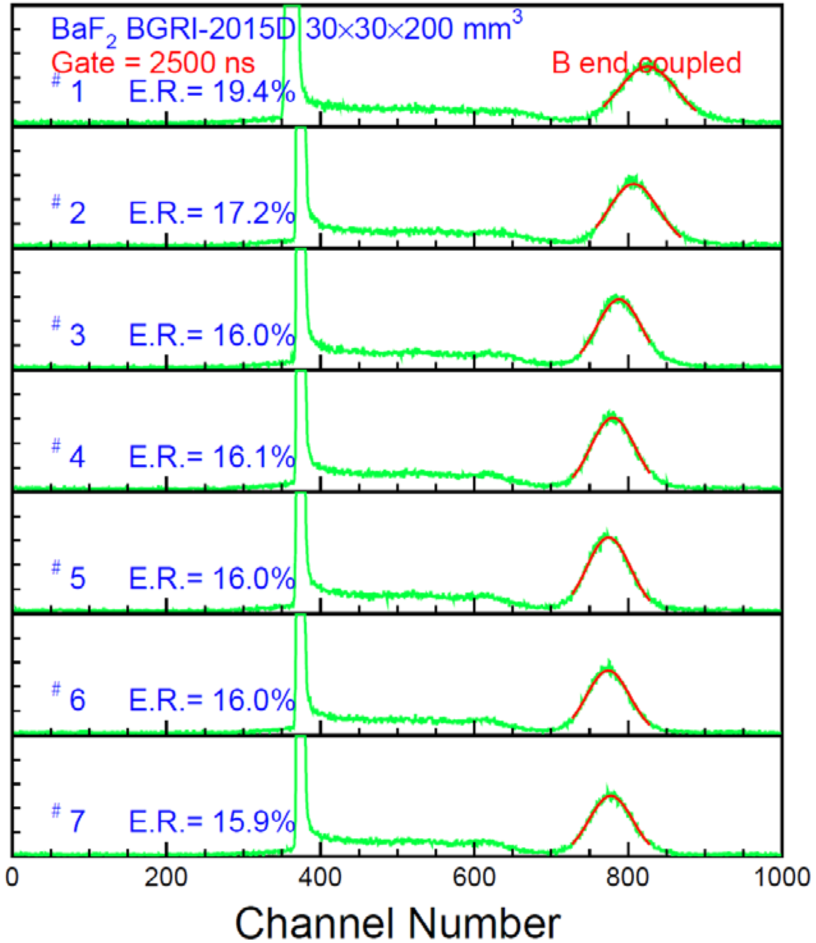
# Pulse Height Spectra: BGRI-2015D

Gate: 2500 ns

Ave ER= 16.5%

Ave ER= 16.7%

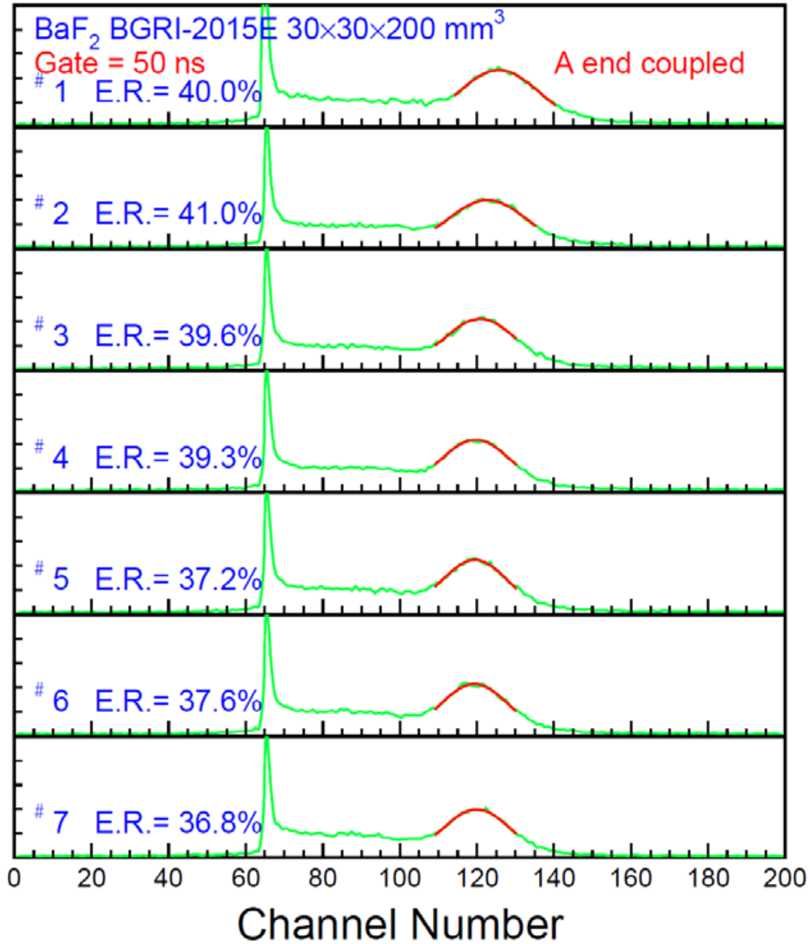


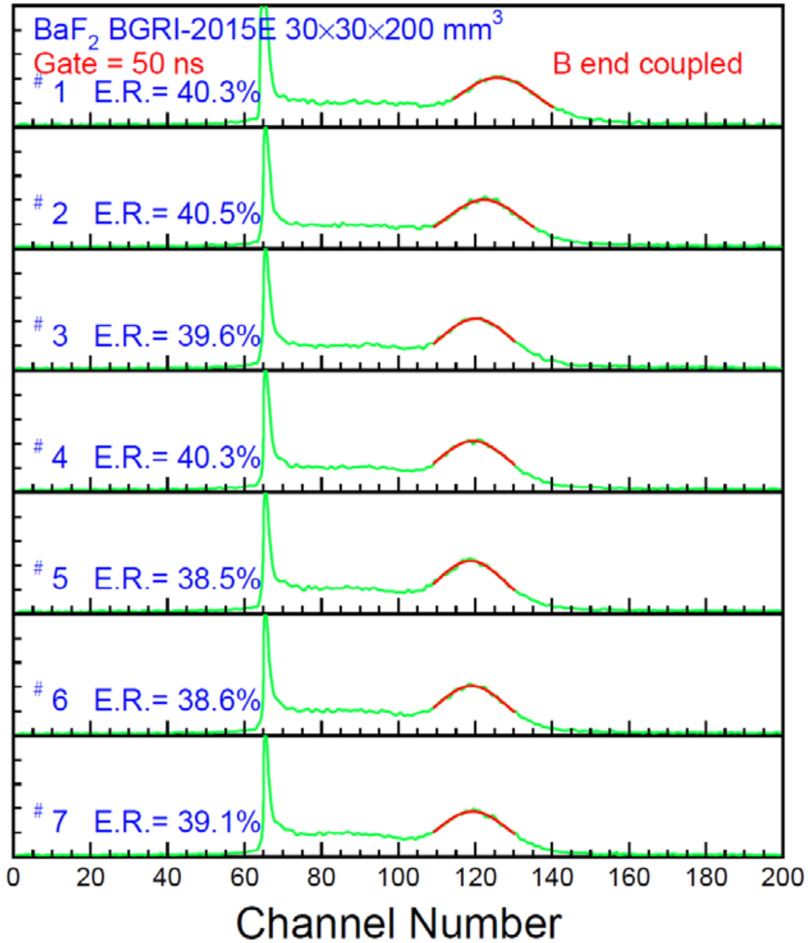
# Pulse Height Spectra: BGRI-2015E

Gate: 50 ns

Ave ER= 38.8%




Ave ER= 39.6%

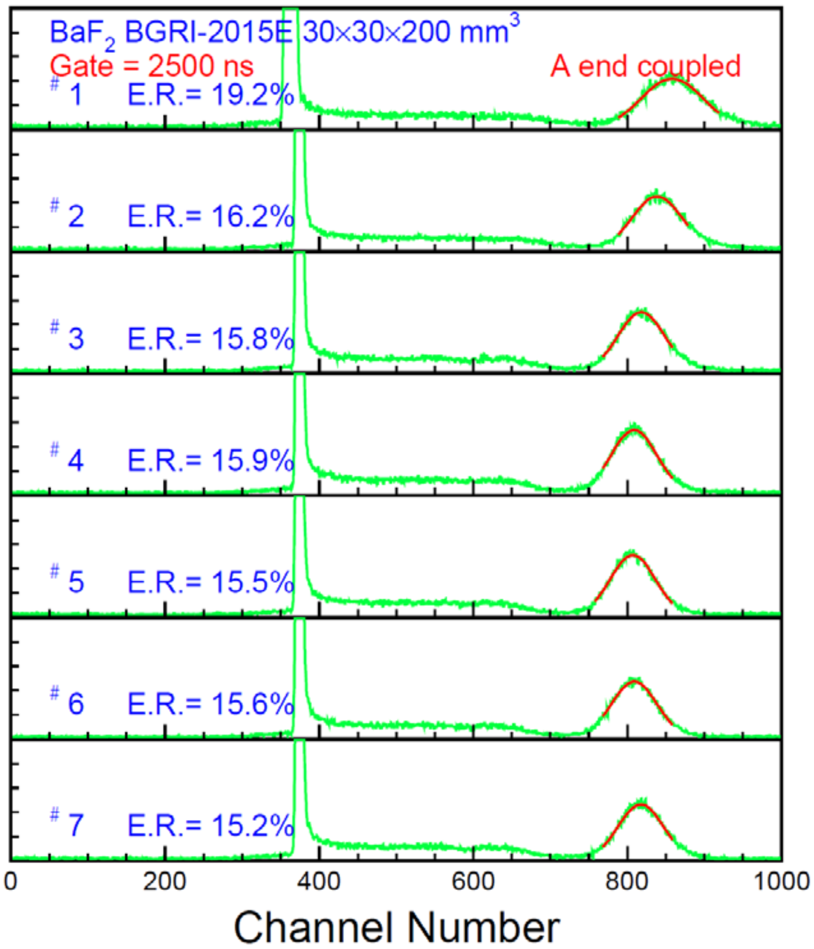


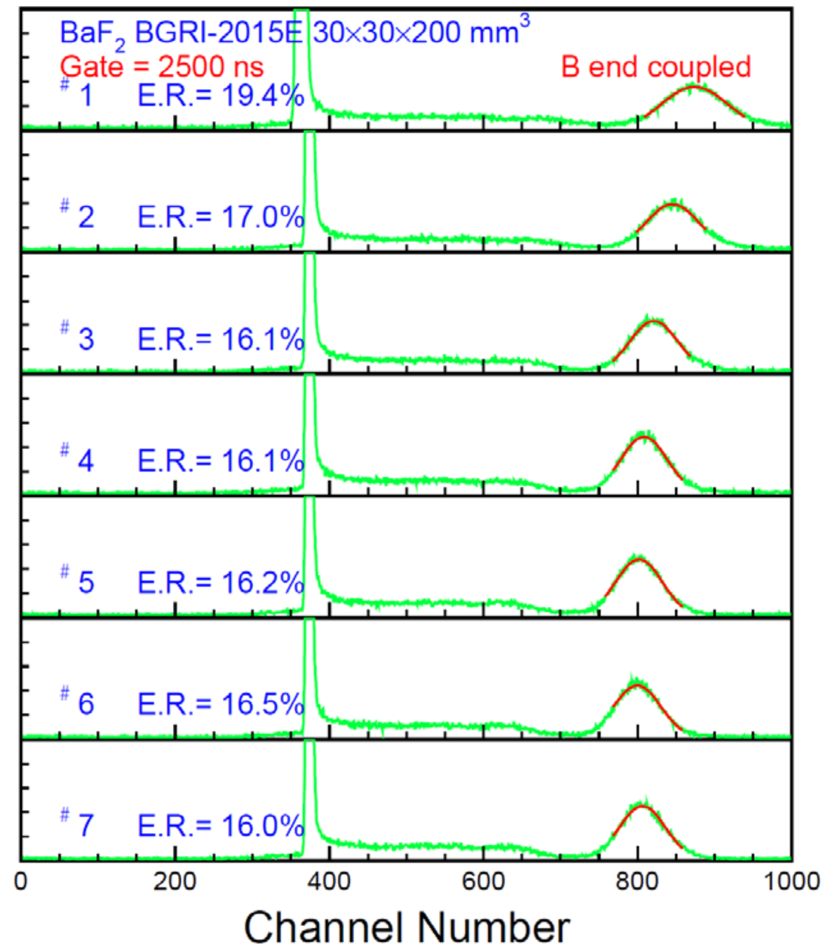
# Pulse Height Spectra: BGRI-2015E

Gate: 2500 ns

Ave ER= 16.2%

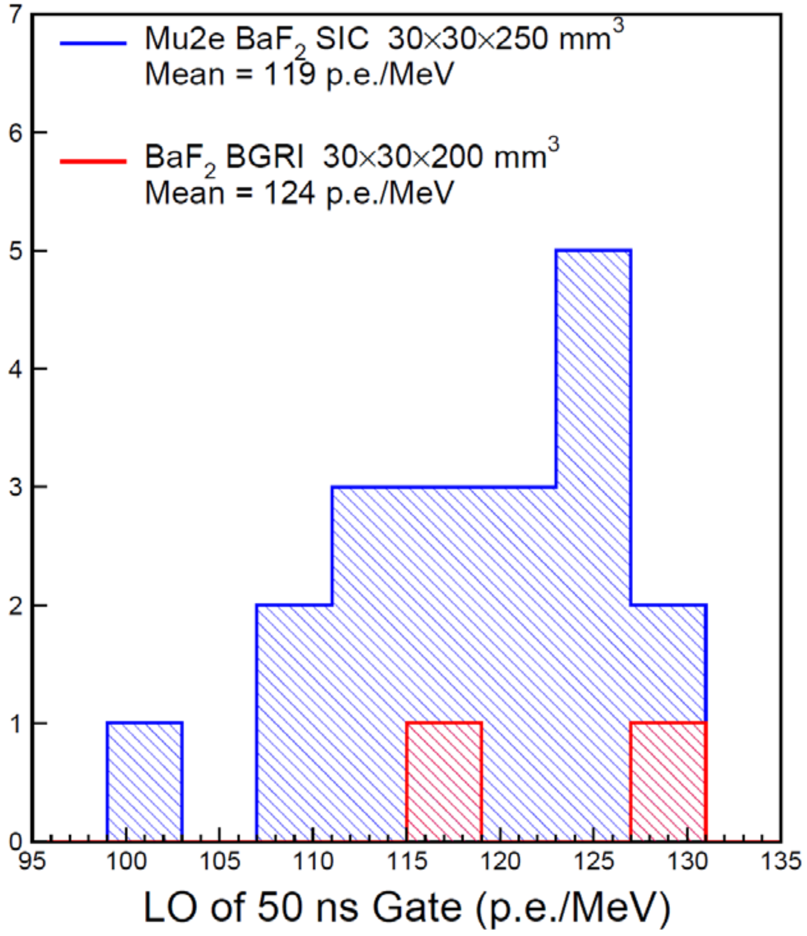
Ave ER= 16.8%

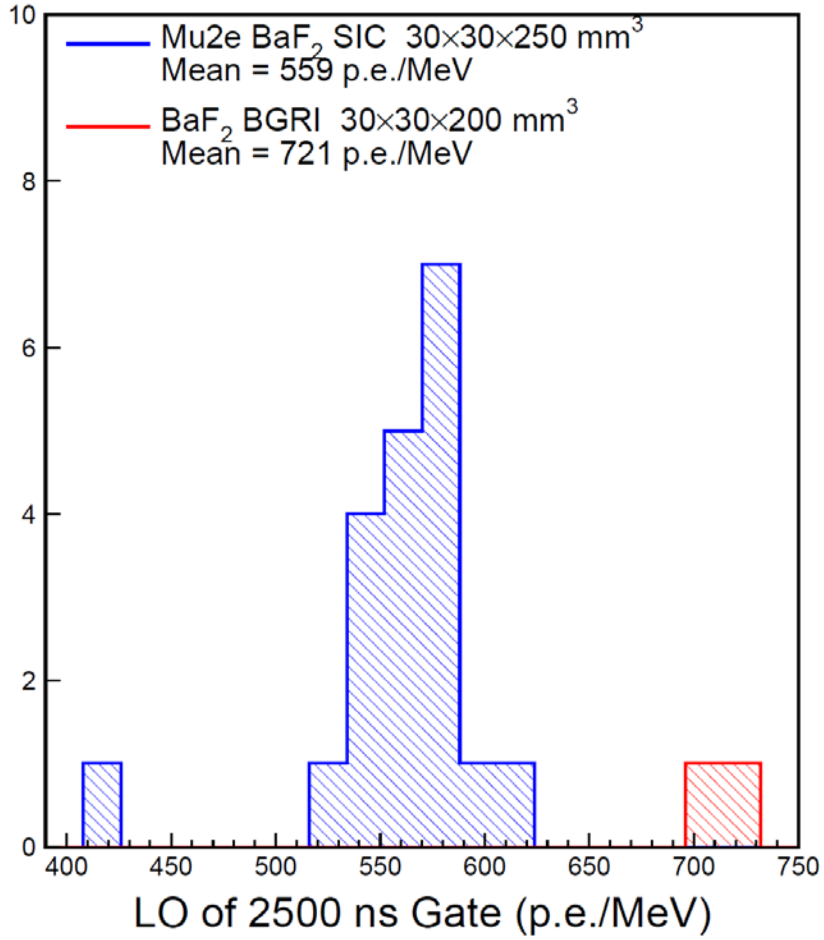


# Comparison of Light Output

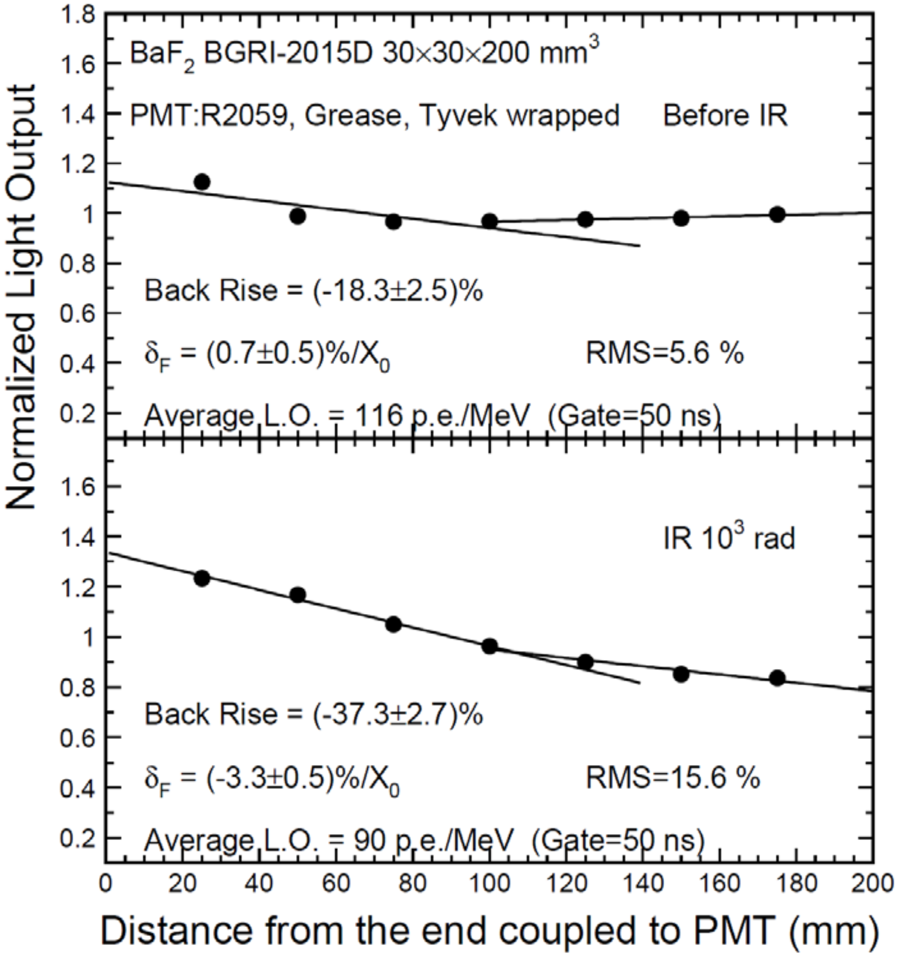
All samples wrapped with two layers of Tyvek paper

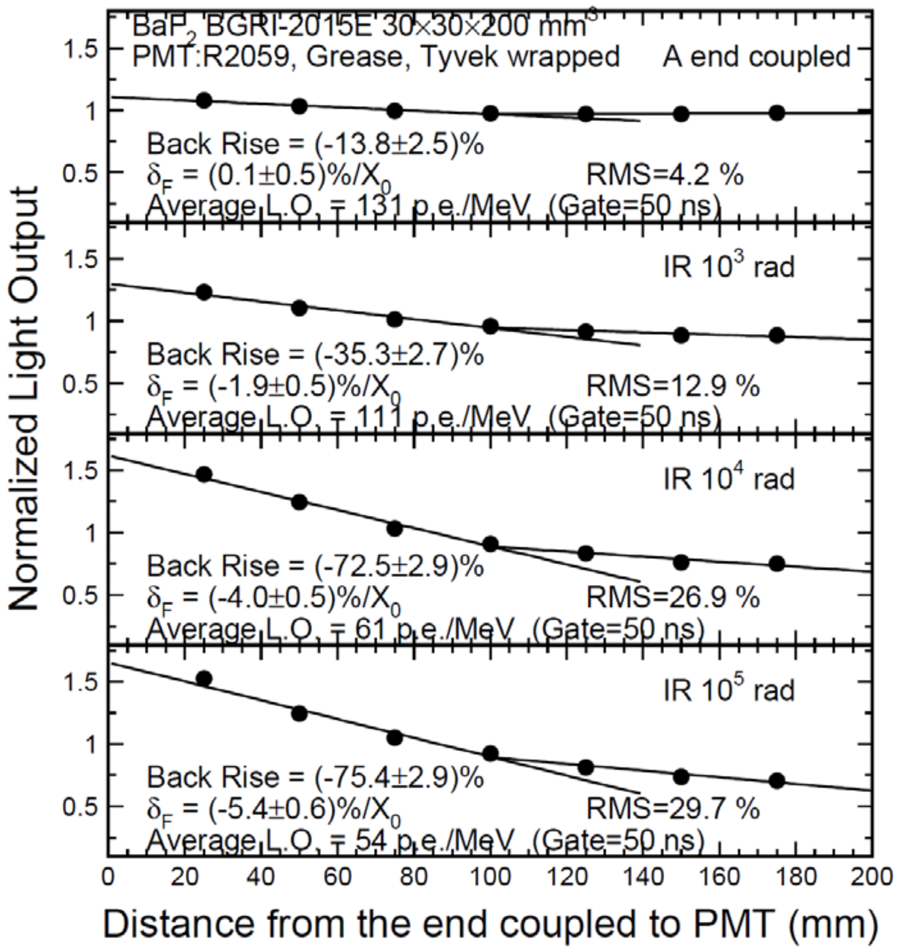


# LRU Before and After Gamma-ray Irradiation

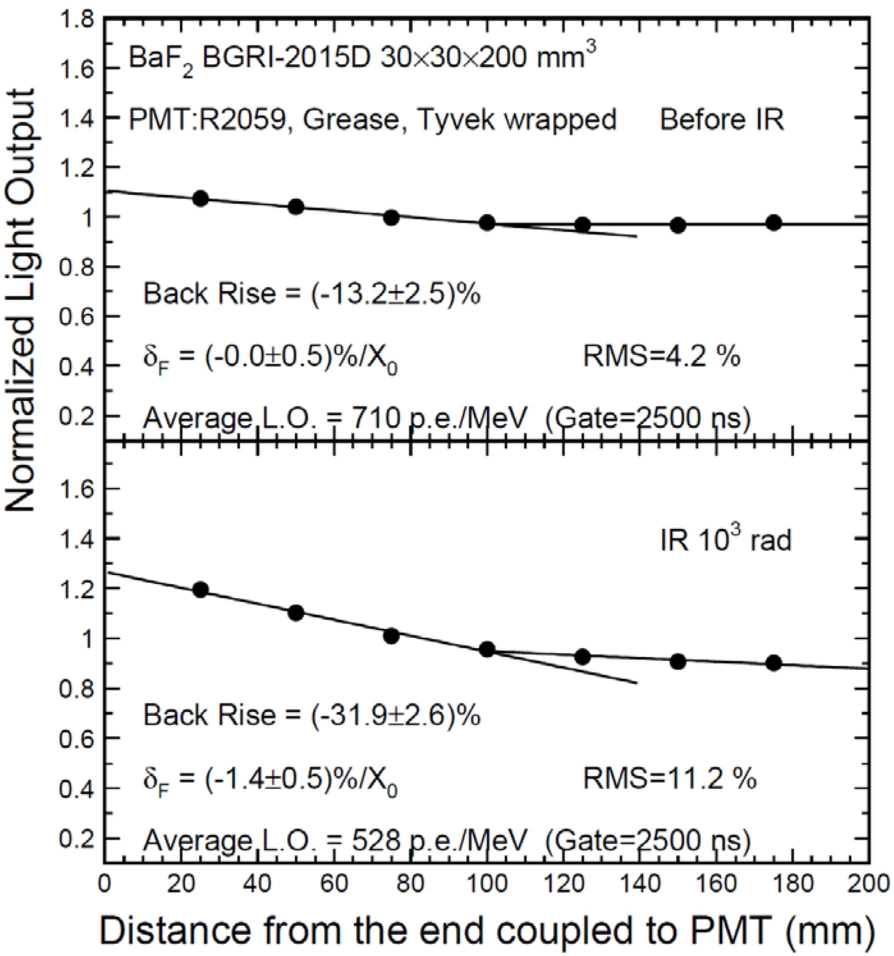
Gate: 50 ns

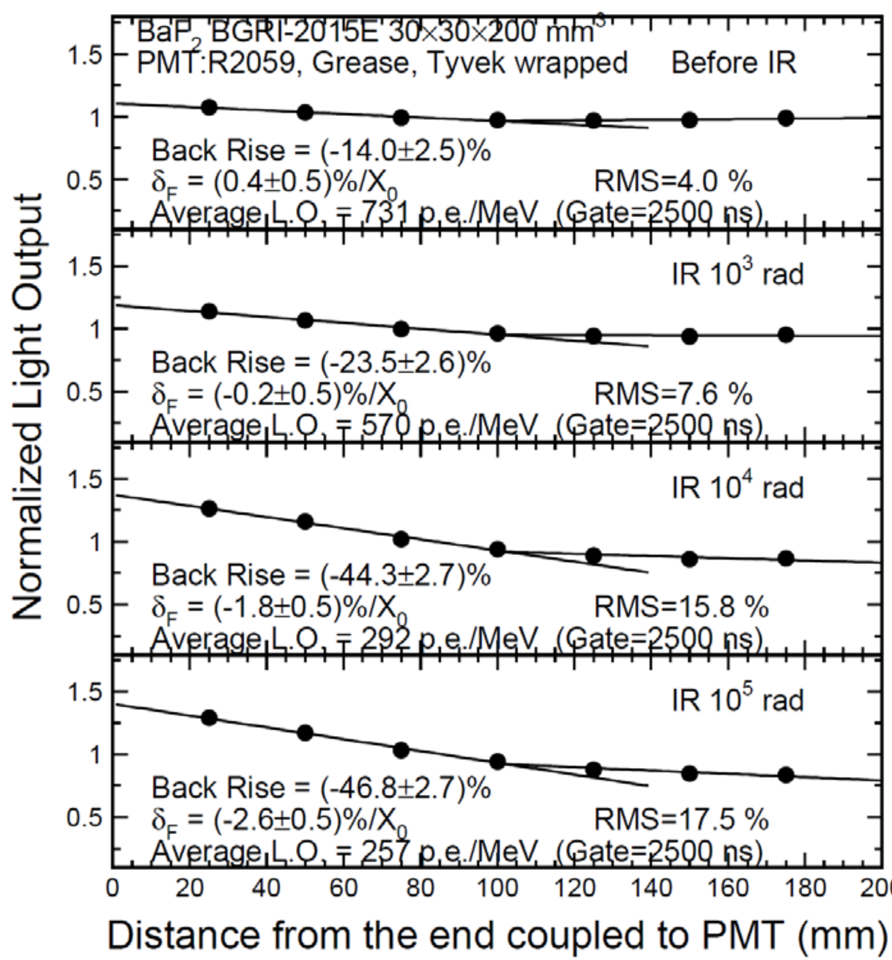


# LRU Before and After Gamma-ray Irradiation

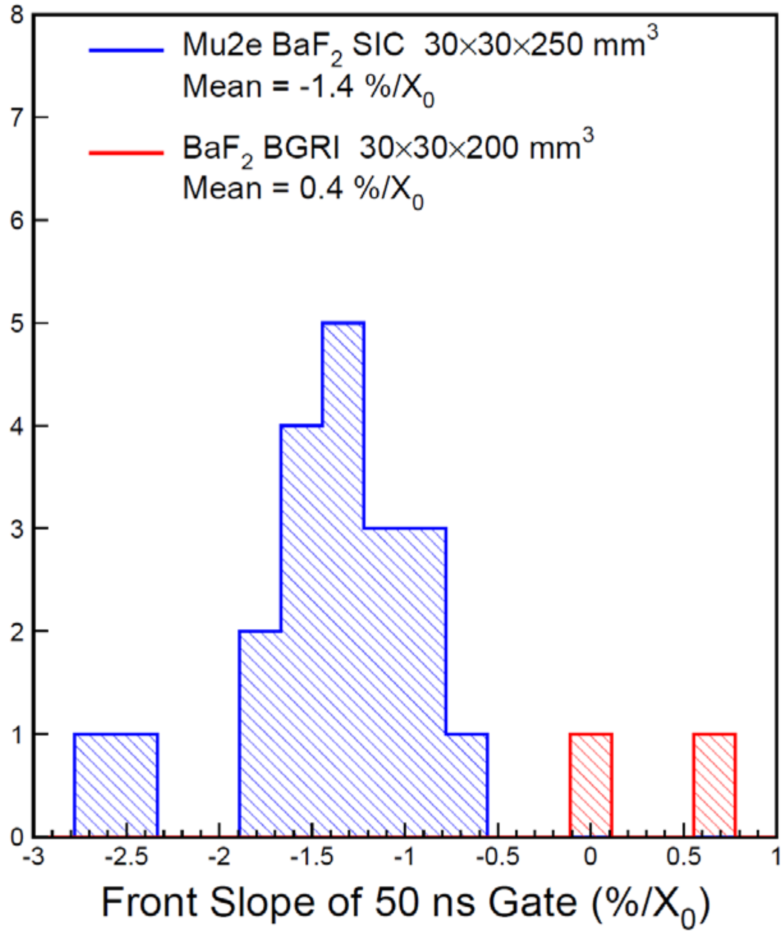
Gate: 2,500 ns

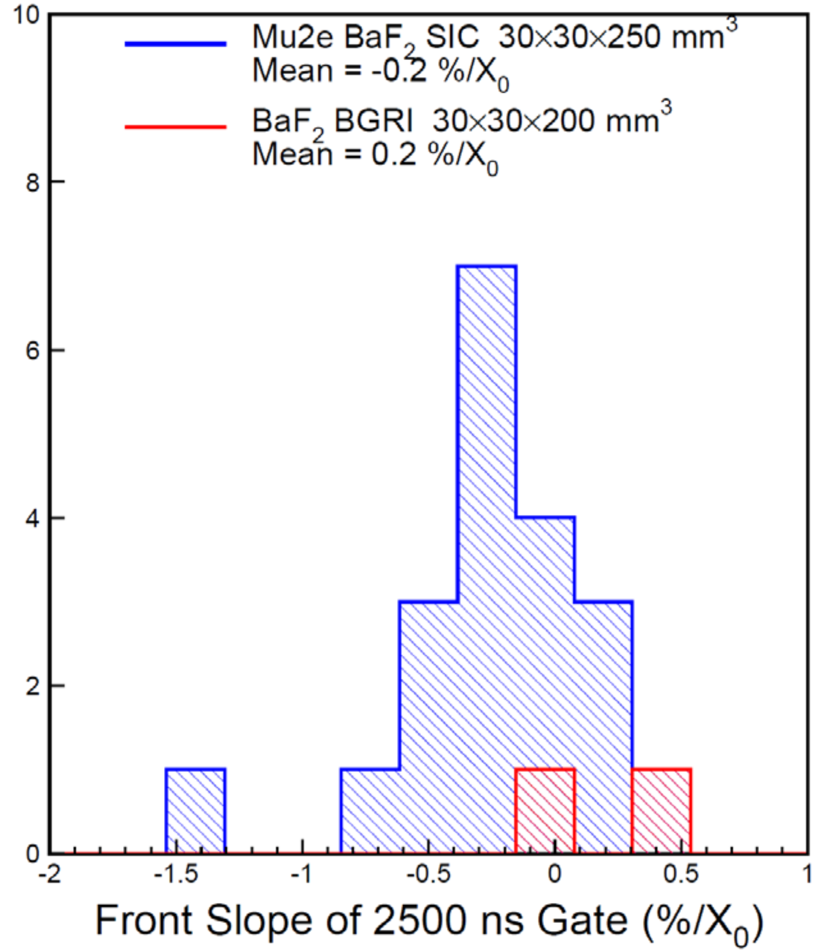


# Comparison of Front Slope

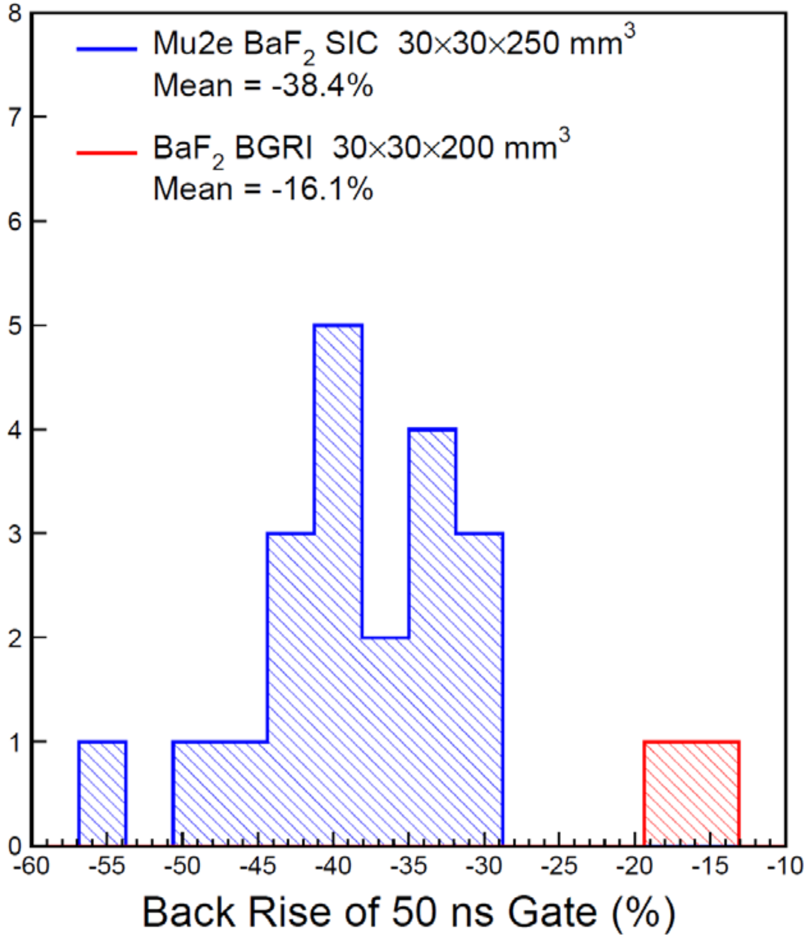
All samples wrapped with two layers of Tyvek paper

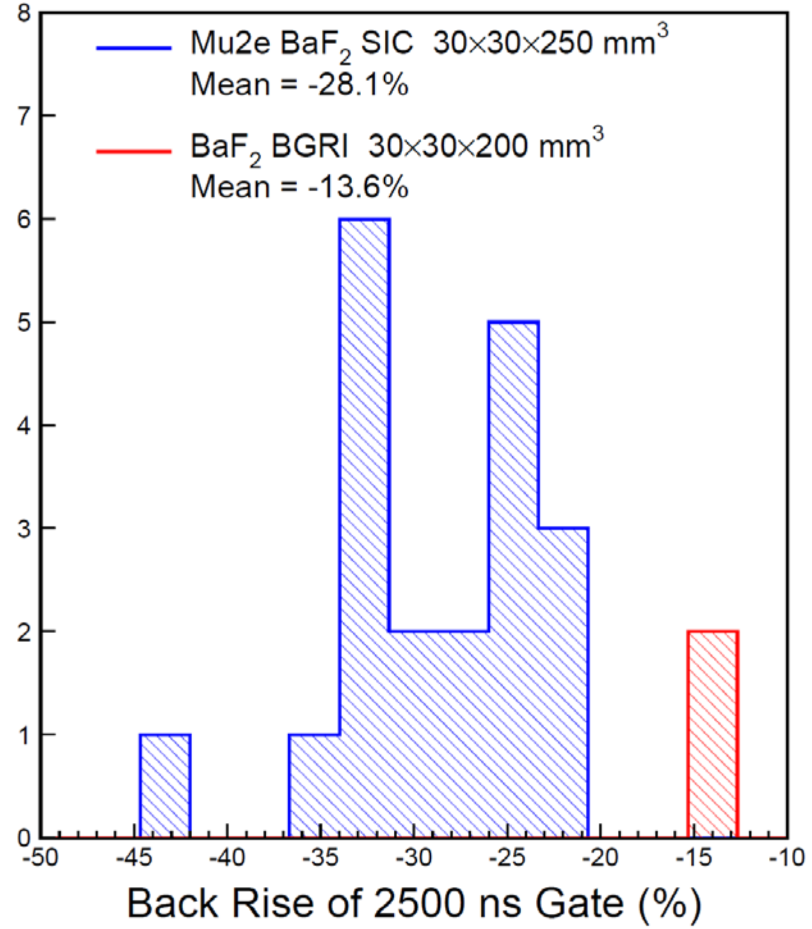


# Comparison of Back Rise

All samples wrapped with two layers of Tyvek paper



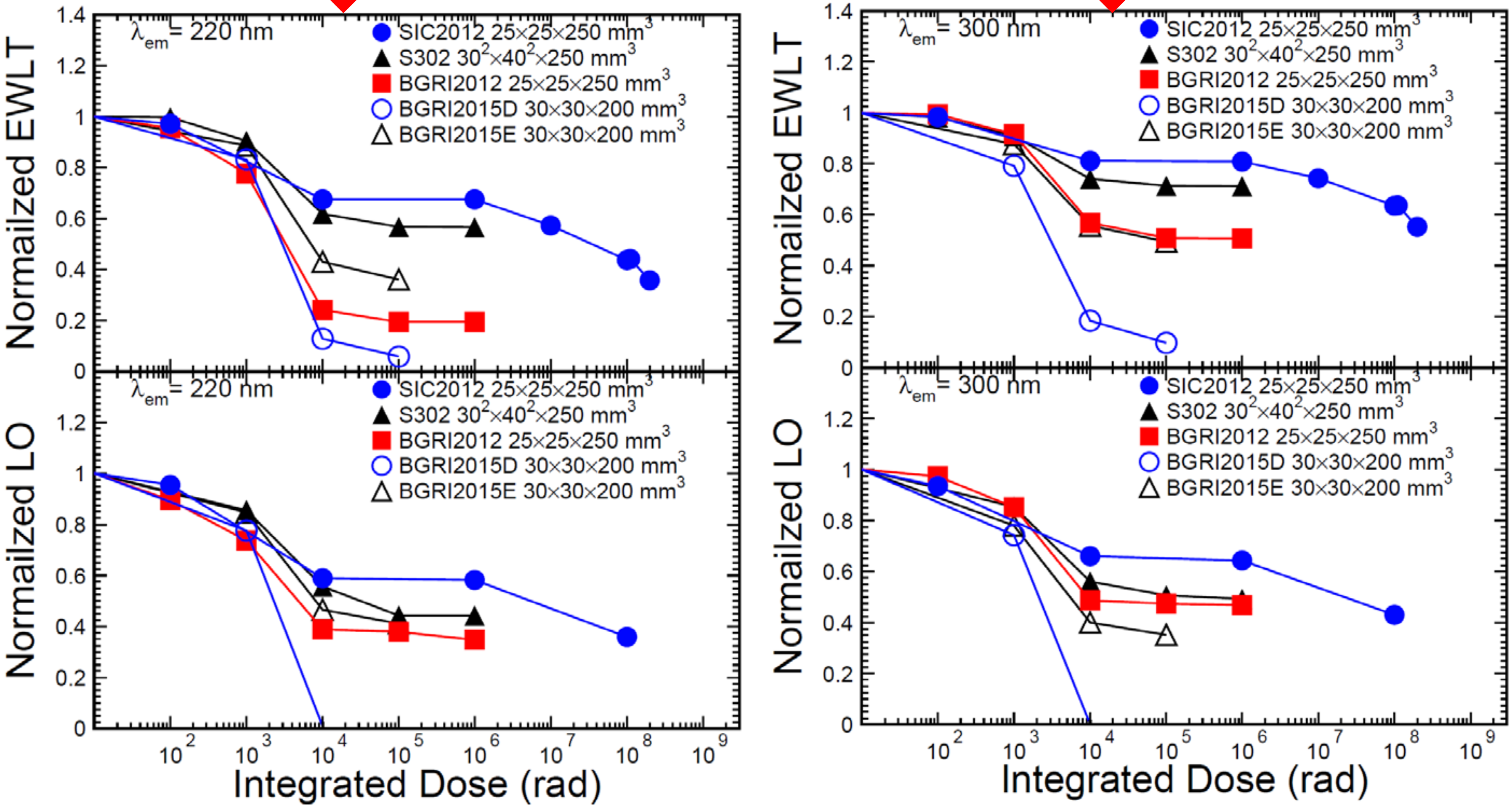



# Summary: Initial Properties

| ID | Average of 20SIC Crystals | BGRI2015D | BGRI2015E |
|---|---|---|---|
| Dimension | 30x30x250 | 30x30x200 | 30x30x200 |
| T@220 nm (%) | 85.5±0.2 | 87.9±0.2 | 85.0±0.2 |
| T@300 nm (%) | 91.3±0.2 | 92.9±0.2 | 92.5±0.2 |
| EWLT of Fast Component (%) | 86.1±0.2 | 89.0±0.2 | 86.9±0.2 |
| EWLT of Slow Component (%) | 91.1±0.2 | 92.4±0.2 | 92.4±0.2 |
| LO 50 ns Gate (p.e./MeV) | 119±1 | 116±1 | 131±1 |
| Back Rise 50 ns Gate (%) | -38.4±2.5 | -18.3±2.5 | -13.8±2.5 |
| $\delta_F$ 50 ns Gate (%/$X_0$) | -1.4±0.5 | 0.7±0.5 | 0.1±0.5 |
| RMS 50 ns Gate (%) | 13.6 | 5.6 | 4.2 |
| LO 2500 ns Gate (p.e./MeV) | 562±6 | 710±7 | 731±7 |
| Back Rise 2500 ns Gate (%) | -28.1±2.5 | -13.2±2.5 | -14.0±2.5 |
| $\delta_F$ 2500 ns Gate (%/$X_0$) | -0.2±0.5 | 0±0.5 | 0.4±0.5 |
| RMS 2500 ns Gate (%) | 9.3 | 4.2 | 4.0 |

# Summary: Radiation Damage in EWLT and LO

Radiation hardness of two new BGRI samples are compatible with BGRI2012




Fast Component

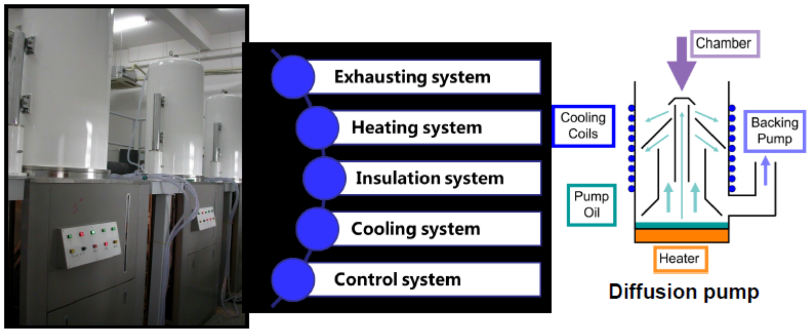
Slow Component

# Summary

- Longitudinal transmittance, light output and light response uniformity of two 20 cm long BGRI samples are better than twenty 25 cm long SIC crystals, and much better than an early sample BGRI2012.
- This difference seems caused by different crystal length: 20 cm versus 25 cm.
- Radiation hardness of two BGRI samples was measured up to 100 krad. It is worse than SIC2012, and is compatible with BGRI2012, indicating improvement is needed by controlling oxygen contamination.
- BGRI is working in two directions: test alternative raw material suppliers and improving vacuum in furnaces.
- SICCAS decided to pursue non-vacuum growth in January with limited progress achieved so far.
- Additional vendors are important.

# SICCAS: Non-Vacuum Growth

## Problems and limitations of growth in vacuum

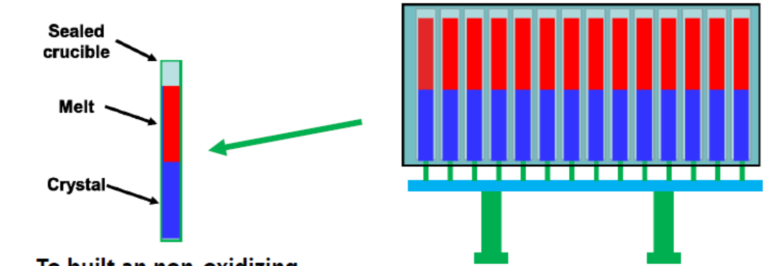


Diffusion pump

- Complicated and expensive growth system
- Poor efficiency (6 ingots from single growth per furnace)
- No incentive to invest



## New Facility to be built to meet the M2e requirements




To built an non-oxidizing atmosphere inside Pt crucible

Modified multi-crucibles Bridgman Method developed in SICCAS

- ✓ No pump system
- ✓ No circulating water system
- ✓ Easier to operate

A general method to cost-effectively grow BGO/PWO/CsI:Tl/$PbF_2$ etc.

**A very promising alternative method to be pursued for $BaF_2$ growth.**

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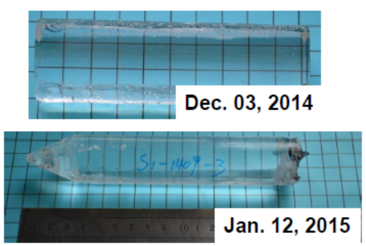
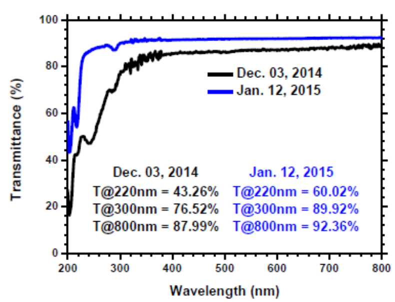
## Progress on growth $BaF_2$ in non-vacuum atmosphere

### Before the visit



Two crystal boules grown in non-vacuum atmosphere before the visit



Optical Transmittance of $BaF_2$ crystals

- Crack-free, clear crystal boule can be grown
- Great progress, but more R&D work is needed

SICCAS 中国科学院上海硅酸盐研究所

## Progress on growth $BaF_2$ in non-vacuum atmosphere

### After the visit


Three crystal boules grown in non-vacuum atmosphere at March. 26, 2015

- Crack
- Fully oxidized
- No carbon and gas inclusions
- Wrong improvement direction

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