Radiopure Oxide Crystals to Search for Dark Matter and Double Beta Decay

Boris V. Grinyov

Institute for Scintillation Materials, Kharkov, Ukraine
(grinyov@isc.kharkov.com)

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Outline

- Introduction (brief about ISMA)
- Motivation
- Improving of $ZnWO_4$, $PbWO_4$ and $PbMoO_4$ scintillators
- R&D of new materials
  - $ZnMoO_4$
  - $MgWO_4$
- Conclusions

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History of Scintillation ISMA

2009 ZnWO4 | **New projects ?!**

- 2007 LGSO
- 2004 dedicated imaging system
- 2000 SPECT
- 1994 CsI(Tl) CRYSTALS of 525 kg WEIGHT
- 1992 PWO
- 1989 CsI(CO_3)
- 1987 UNDOPED CsI SINGLE CRYSTALS
- 1986 $CdWO_4$, $BiGe_3O_{12}$
- 1985 "CRYSTAL" TECHNOLOGY
- 1978 "ROST" TECHNOLOGY
- 1974 ZnSe(Te)
- 1964 CsI(Na)
- 1961 PMMA
- 1959 NaI(Tl)
- 1955 ISC WAS FOUNDED

- 2008 GLAST (Int. NASA)
- 2007 AGILE (EC)
- 2005 NEMO (Int. NASA)
- 2005 OPERA (EC)
- 2000 PiBeta (Switzerland)
- 1998 BaBar (USA)
- 1996 BELLE (Japan)
- 1992-2008 LHC (CERN)

ISMA for International Collaborations

High Energy Physics

CMS

OPERA

PANDA

NEMO

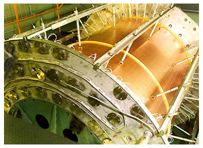
Medium Energy Physics

BELLE (Japan)

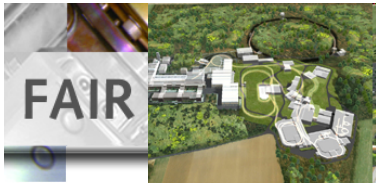
BaBar (USA)

PiBeta (Switzerland)

KEDR

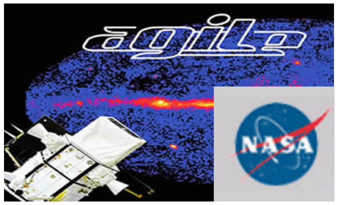


FAIR ?



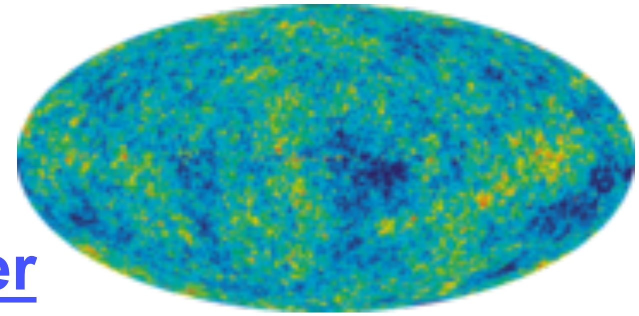
Space Missions

GLAST (USA, Sweden)



AGILE (Italy)

Motivation



Double beta decay

- Nature of neutrino
- Neutrino mass
- Lepton number conservation

Dark Matter

We cannot explain nature of 95% of *the Universe* mass

⇓

new kind of matter (new particles)

Oxide crystal scintillators, in particular tungstates and molybdates, are promising detectors for experiments to search for rare nuclear and sub-nuclear processes such as double beta decay, and dark matter particle interactions. Recently the application of scintillation targets has received a new motivation prompted by the development of cryogenic phonon scintillation detectors

Requirements to scintillators

- a high light output at milli-Kelvin temperature
- an extremely low level of radioactive contamination
- presence of specific nuclei (2β decay)

  (for example $^{64,70}Zn$, $^{180,186}W$, $^{92,98,100}Mo$)

- a variety of elements in scintillation targets (Dark matter)

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ISMA oxide scintillators to search for rare processes

- $CdWO_4$ — 2β $^{106,108,114,116}Cd$, ^{180}W, ^{186}W
- $ZnWO_4$ — 2β $^{64,70}Zn$, ^{180}W, ^{186}W; DM
- $PbWO_4$ — active shield & light guides for $^{116}CdWO_4$
- $PbMoO_4$ — 2β ^{100}Mo
- $CaMoO_4$ — 2β ^{100}Mo; DM
- <u>$ZnMoO_4$</u> — 2β ^{100}Mo, $^{64,70}Zn$
- <u>$MgWO_4$</u> — DM

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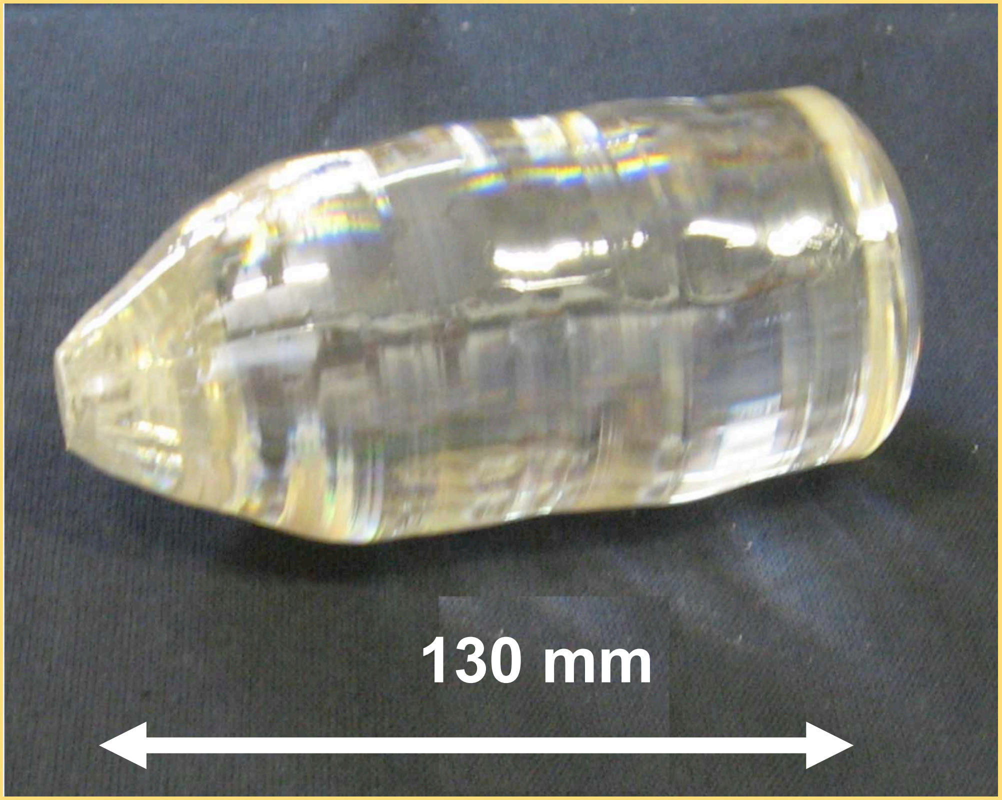
$ZnWO_4$ for 2β and DM



Large volume $ZnWO_4$ crystal scintillators up to ∅50 ×100 mm

$ZnWO_4$ scintillation crystals are promising to search for double beta decay of ^{64}Zn, ^{70}Zn, ^{180}W and ^{186}W

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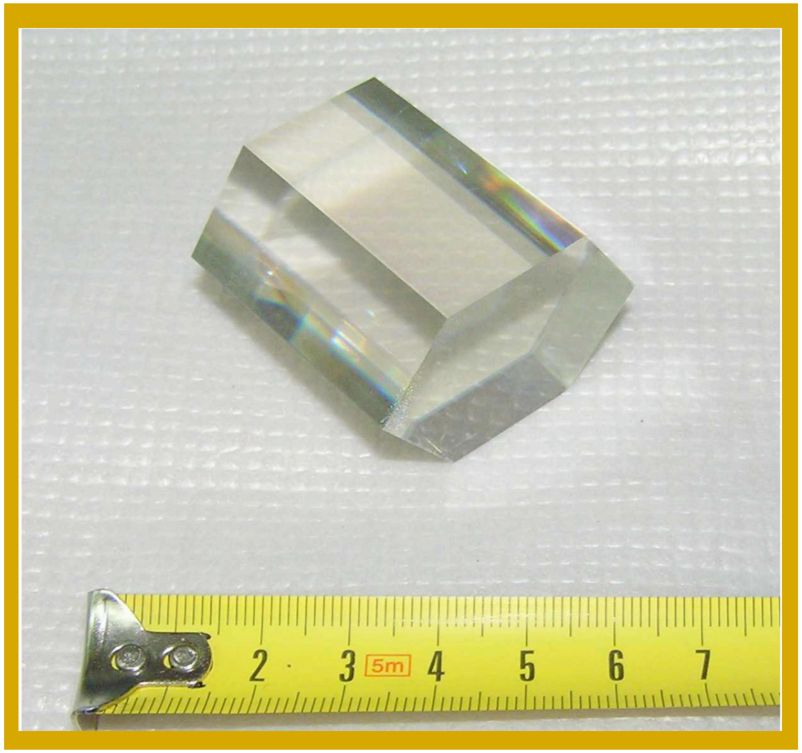
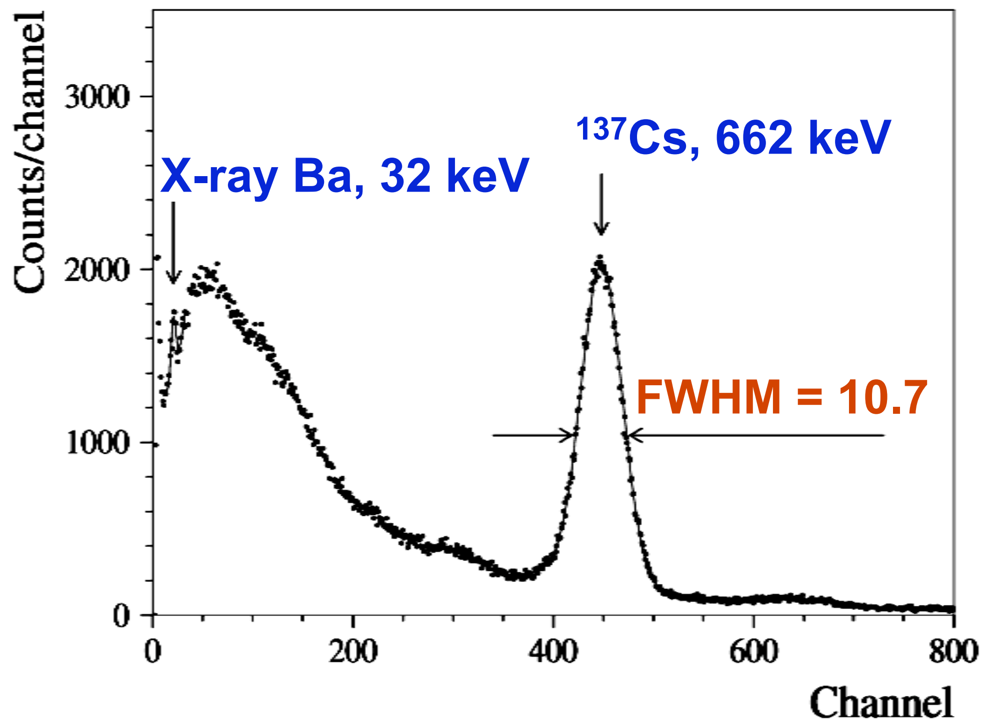
L. L. Nagornaya et al, "Growth of $ZnWO_4$ crystal scintillators for high sensitivity 2β experiments " IEEE Trans. Nucl. Sci. 55 (2008) 1469

The energy resolution of $ZnWO_4$ scintillation elements





The energy resolution of $ZnWO_4$ scintillation elements was 8.5 % with 1 cm^3 sample and 10.7 % with a hexagonal scintillation element 40⬡× 40 mm for 662 keV γ line of ^{137}Cs.

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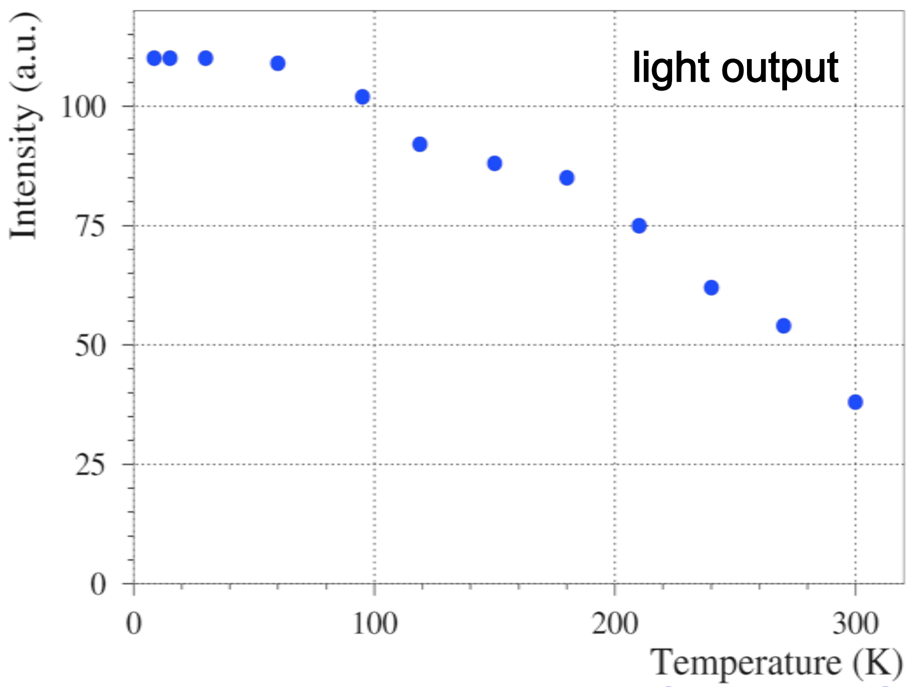
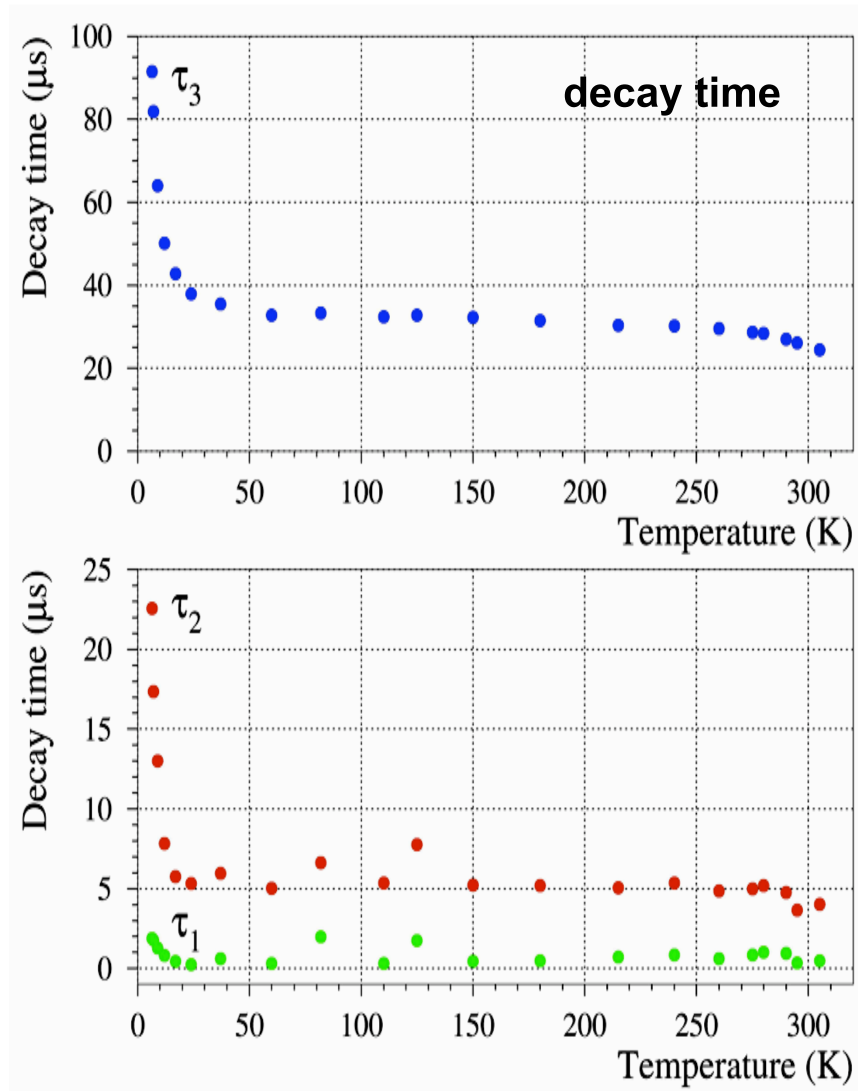
L.Nagornaya et al, "Large volume $ZnWO_4$ crystal scintillators with excellent energy resolution and low background" IEEE Trans. Nucl. Sci. 56 (2009) 994

$ZnWO_4$ temperature dependence of light output and decay time

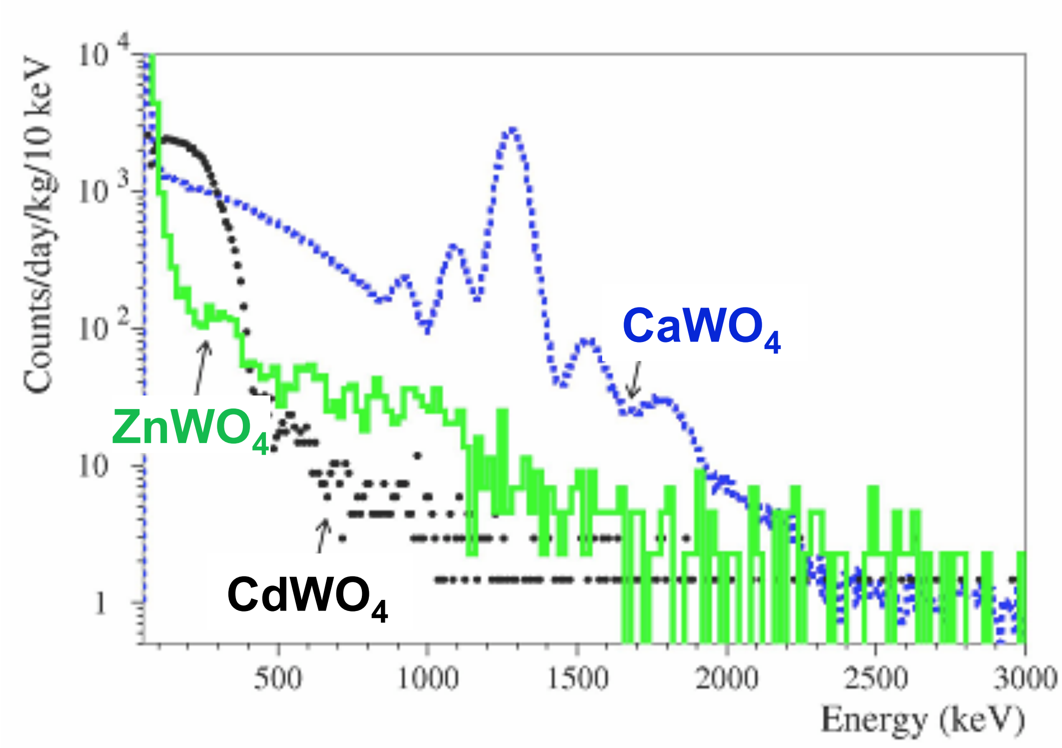




The light output of $ZnWO_4$ demonstrates about three-fold increases and decay time becomes about three times longer with decrease of temperature from 300 K to 7 K.

The relative light output of $ZnWO_4$ at 10 K is 110-115 % that of $CaWO_4$

$ZnWO_4$ - an excellent radiopure



Activity (mBq/kg)

	$ZnWO_4$(1)	$CaWO_4$(2)
^{232}Th	0.0015	0.7
^{235}U	≤ 0.003	1.6
^{238}U	0.002	300
Total α	0.2	400
^{40}K	≤ 0.4	
^{65}Zn	0.5	
^{90}Sr-^{90}Y	≤ 0.4	

The measurements were carried out at Solotvina Underground Laboratory (Ukraine) and Gran Sasso National Laboratories (Italy).

1)P.Belli et al., Nuclear Physics A826 (2009) 256

2)NIMA 538 (2004) 657; APP 23 (2005) 249

$ZnWO_4$ is one of the best candidate as a detector for cryogenic 2β decay and Dark Matter experiments !

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L. L. Nagornaya et al, “Growth of $ZnWO_4$ crystal scintillators for high sensitivity 2β experiments ” IEEE Trans. Nucl. Sci. 55 (2008) 1469

Double beta processes in $^{64,70}Zn$ and $^{180,186}W$ have been searched for with the help of our large volume (0.7kg) $ZnWO_4$ crystal scintillators at the Gran Sasso National Laboratories (INFN, Italy). Total time of measurements exceeds 10 thousands hours. New improved half-life limits in ^{64}Zn have been set about 7×10^{20} yr. The different modes of 2β processes in ^{70}Zn, ^{180}W, and ^{186}W have been restricted at the level of 10^{17}-10^{20} yr.

P. Belli, et al "Search for 2β decay of Zinc and Tungsten with the help of low-background $ZnWO_4$ crystal scintillators" Nuclear Physics A826 (2009) 256

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$PbWO_4$ и $PbMoO_4$

For the first time, $PbWO_4$ scintillation crystal had been developed by us for studies in the field of high energies. Possible applications of this crystal include studies of double beta-decay and searches for dark matter and its use as a protective filter from PMT radioactivity.

L. Nagornaya et al, "Fast scintillators based on large "heavy" tungstate single crystals," in *Proc. "Crystal 2000" Int. Workshop*, Chamonix, France, 1992, pp. 367–374.

F.A.Danevich et al., "Application of $PbWO_4$ crystal scintillators in experiment to search for 2β decay of ^{116}Cd", NIMA 556(2006)259.

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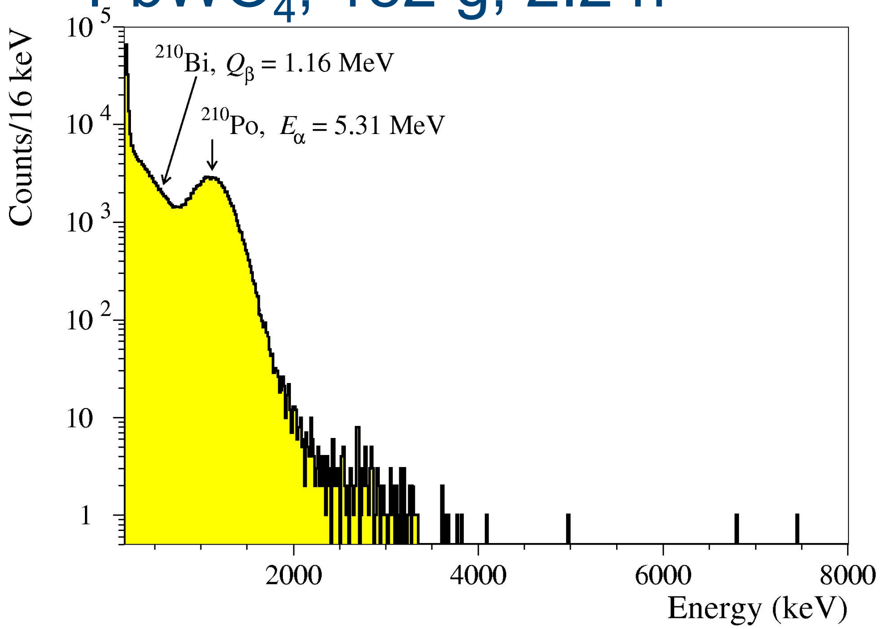
$PbWO_4$ и $PbMoO_4$

$PbWO_4$, 182 g, 2.2 h



Chain	Nuclide	Activity (mBq/kg)
^{232}Th	^{228}Th	≤13
^{238}U	^{226}Ra	≤10
	^{210}Po	$(53-79)\times 10^3$

The radioactive background level of these crystals is rather high and is determined by the presence of ^{210}Po. ISMA carries out works on purification of archaeological lead for growth of lead tungstate crystals with low radioactive background.

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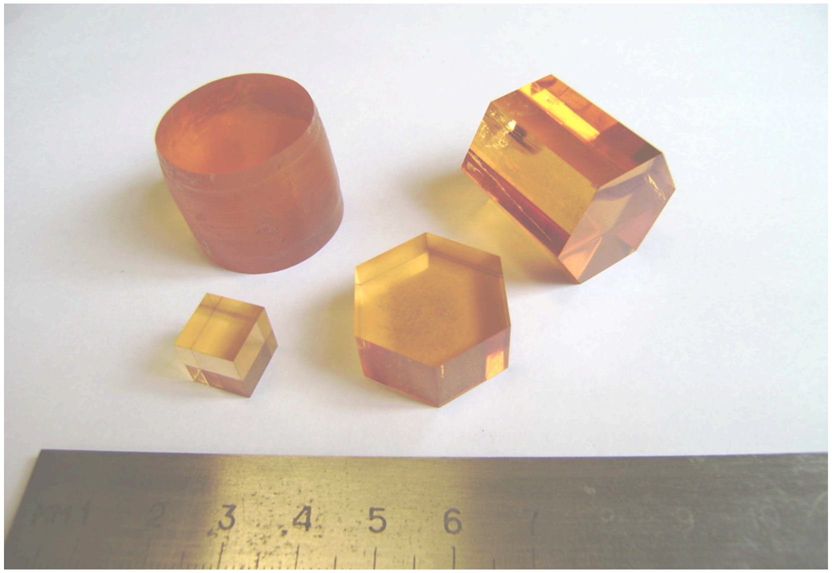
F.A.Danevich et al., “Application of $PbWO_4$ crystal scintillators in experiment to search for 2β decay of ^{116}Cd”, NIMA 556(2006)259.

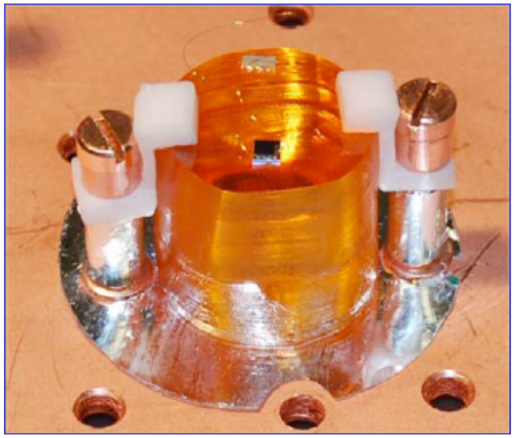
$ZnMoO_4$ – a detector to search for 2β decay ^{100}Mo



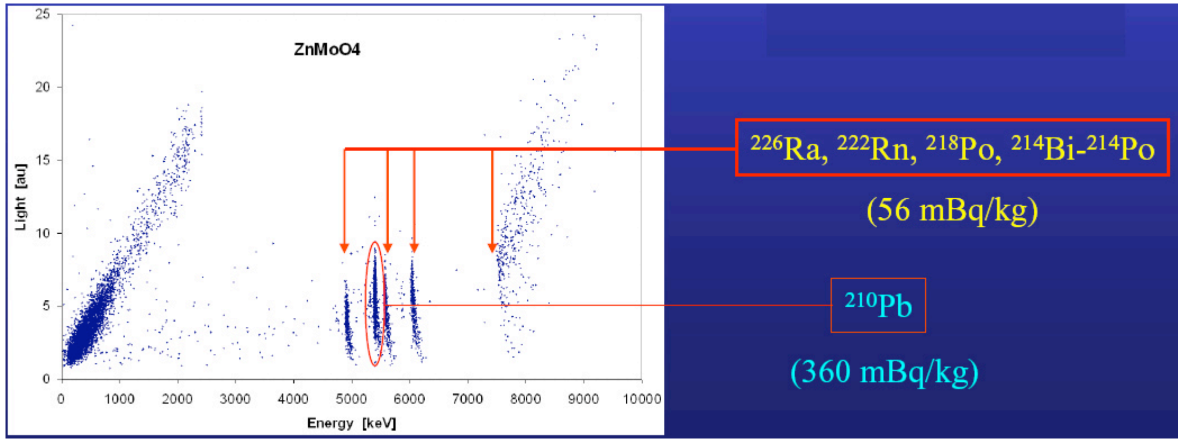
Large volume $ZnMoO_4$ crystal scintillators up to ∅ 40 ×70 mm

L.Nagornaya et al, “Tungstate and Molybdate Scintillators to Search for Dark Matter and Double Beta Decay ” IEEE Trans. Nucl. Sci. 56 (2009) 2513

The measurements of $ZnMoO_4$ at milli-Kelvin temperature



$ZnMoO_4$ crystal mounted on copper cryostat.



Scatter plot of the light signal versus heat signal for background exposition with $ZnMoO_4$ crystal.

Contamination by ^{210}Po (suppose in equilibrium with ^{210}Pb) is 360 mBq/kg, activity of ^{226}Ra was determined as 56 mBq/kg by analysis of α events in the data.

(Stefano Pirro, INFN - Sezione di Milano Bicocca I-20126 Milano - Italy)

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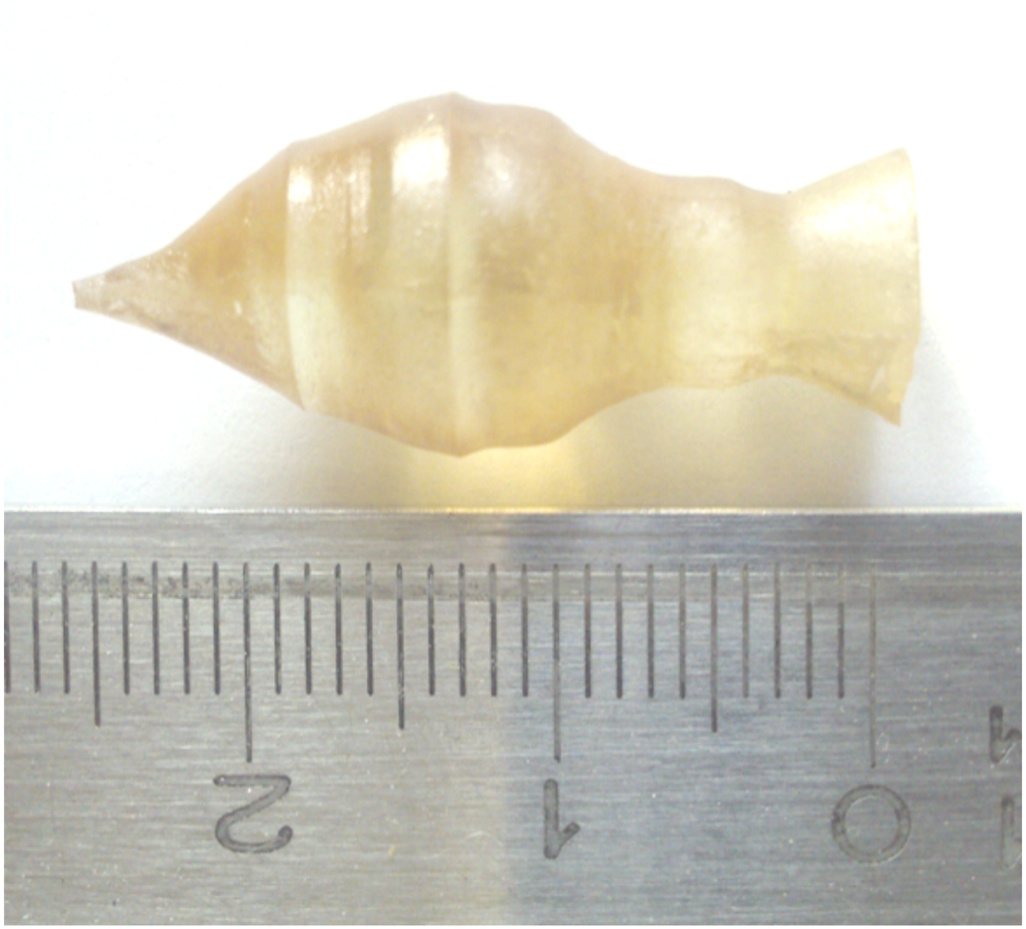
$MgWO_4$ crystals for Dark Matter search



While experiments searching for 2β-decays require certain elements in a detector, cryogenic dark matter experiments require a variety of scintillation targets to verify the nature of a detected signal

The main difficulty of crystal growth from the melt is the presence in $MgWO_4$ of a phase transition below the melting point. Magnesium tungstate crystals of a few cm^3 volume were grown for the first time by pulling the seed from the melted flux solution

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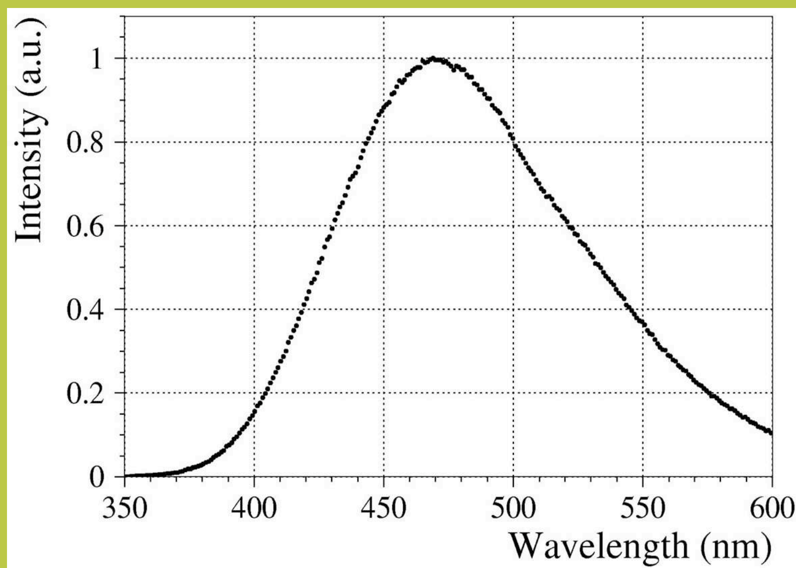
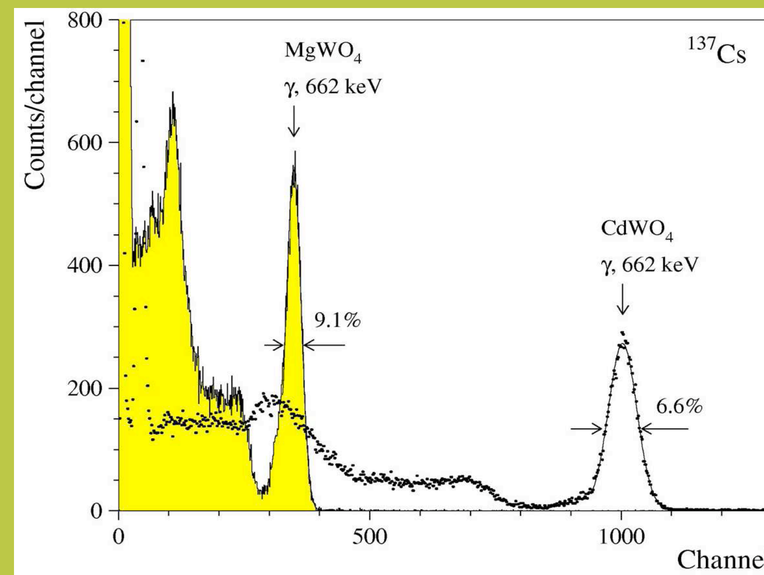
F.A.Danevich et al, “$MgWO_4$–A new crystal scintillator”,Nuclear Instruments and Methods in Physics Research A608(2009)107–115

XRL and Energy spectra of 662 keV ^{137}Cs γ-rays measured for $MgWO_4$





The crystal shows intense luminescence under X-ray excitation. The broad emission band exhibits maximum at 475 nm.

The relative photoelectron yield found to be 35% that of $CdWO_4$ and 27% that of NaI(Tl).

The energy resolution of a small sample magnesium tungstate crystal scintillator giving 9.1 % for the 662 keV γ-quanta of Cs

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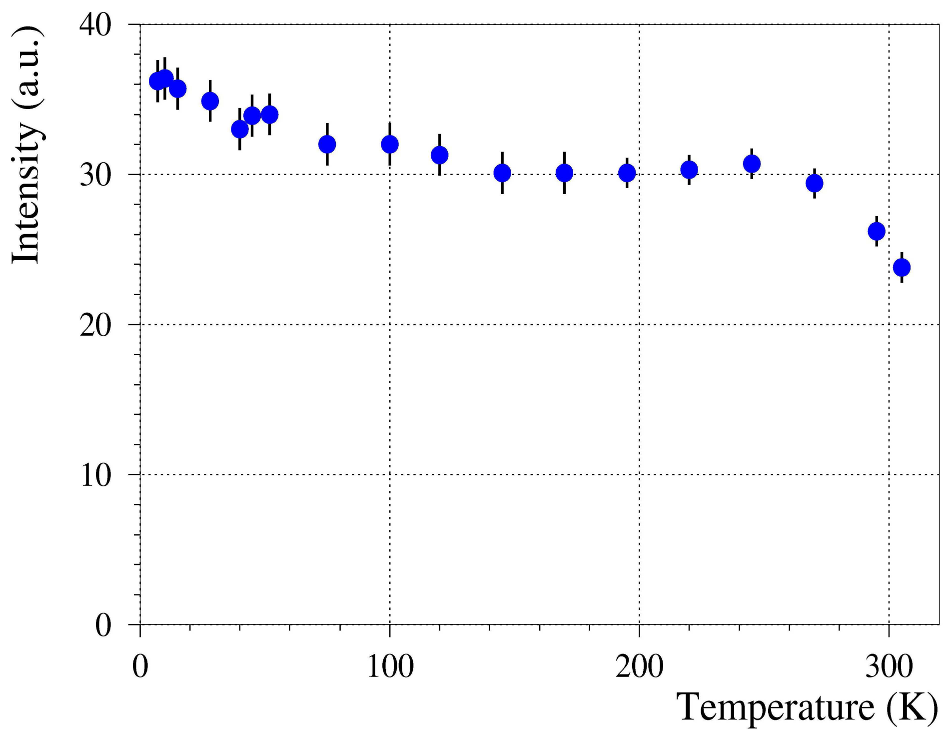
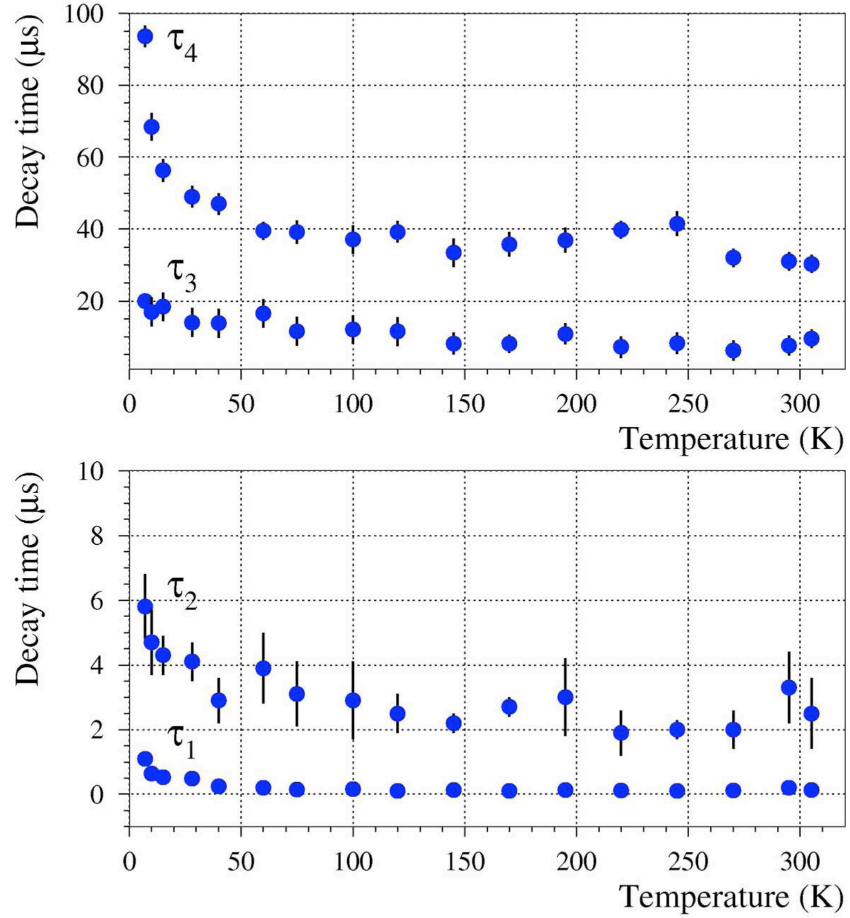
Temperature dependence of the LY and the decay time of the $MgWO_4$ scintillator





The relative scintillation efficiency is 33% of $ZnWO_4$ at T = 7 K

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Conclusions

- Large volume high quality radiopure $ZnWO_4$ crystal scintillators were developed for 2β and dark matter experiments
- Radiopure $PbWO_4$ and $PbMoO_4$ scintillators are developing using archaeological lead with low radiation background.
- $ZnMoO_4$ crystal scintillators ~50 cm^3 of volume were developed for high sensitivity cryogenic 2 β experiment
- $MgWO_4$ crystal scintillators a few cm^3 were grown for the first time. A good target for cryogenic dark matter experiments!

Thank you for your attention!