Summary of $PbWO_4$ properties and manufacturing process

To grow crystals as the initial materials were used WO_3 and PbO powders of purity 99.99%. Best quality $PbWO_4$ was grown from a 50%–50% mixture of lead oxide (PbO) and tungsten oxide (WO_3) which melts congruently at 1123°C, without a phase transition during cooling. Note, the analysis revealed that crystals with poor radiation hardness have a non-optimal Pb/W ratio !

The standard method to grow $PbWO_4$ crystals is the *Czochralski* one in a platinum crucible. This method was used in Russia and Czech Republic. Raw materials (mixture of PbO and WO_3) were first melted in a platinum crucible from which up to three ingots of 2 kg of polycrystalline $PbWO_4$ were grown. This polycrystalline $PbWO_4$ was then used as starting material for crystal growth in a second stage. During the second stage the doping of the crystal with La, Lu, Gd, Nb or Y at concentrations from few tens of ppm to ~100-200 ppm was performed. This drastically can change scintillation properties and radiation hardness of the crystals. Best timing and high light yield were achieved with combined double doping La and Y-ions on the level of < 20 - 100 ppm, or triple doping of Mo, Cd and Sb.

Radiation hardness and recovery of the crystals also depends on the type and concentration of doping material. After ~50-100 krad accumulated dose for about one month out of beam the La-doped crystals will almost completely recover, whereas Nb-doped crystals will only recover 30% to 40% of the initial damage.

Note that all of the characteristics above are dependent on the exact production technology and may vary from company-to-company, or even within the same company from batch-to-batch. One should thus carefully study the product quality (light yield, timing, radiation hardness and UV recovery) and do some prototyping before one can procure the full quantity of the required blocks for the detector. It is also important to know if the company will (is able to) perform quality control measurements before delivery to be sure that all parameters of the crystals are within required limits?

Rough $PbWO_4$ requirements for NPS:

- ***Sufficient light yield: > 10-15 phe/MeV***
- ***Uniformity of light yield and decay time : within +-10%***
- ***Short decay time: 90% of the light within 100 ns***
- ***Limited light yield loss under irradiation: < 10% at dose ~50 krad***
- ***Precise geometric dimensions: tolerance +-1mm in length,+- 50um in lateral***
- ***The surfaces must polished: roughness < ±0.05um***
- ***No cracks prolonging deeper than 0.5 mm***
- ***Transmission (20 cm):>35% at 360nm;>60% at 420nm,>70% at 620nm***