Development of Novel Luminescent Coatings for the ESS Target

Proposal 1604
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on behalf of the collaboration
Overview

- Presenting the scientific case
  - 3 Beam Imagine Systems (BIS) for the ESS, short comparison to existing SNS system
  - Some of the main challenges to be overcome
- Coating development
  - Scientific goals & additional investigations planned
- Experimental setup at HiRadMat
- Handling & Safety
**Proton Accelerator**
- Energy: 2 GeV
- Rep. rate: 14 Hz
- Current: 62.5 mA

**Target Station**
- Rotating W target
- He-gas cooled
- 5 MW average power
- 42 beam ports

**General introduction skipped**
Assumed to be known at CERN

**Neutron Instruments**
- Construction budget contains 16 instruments
- Committed to deliver 22 instruments by 2028

**Total cost:** 1,843 M€ (2013)
ESS Beam Parameters

- Beam highly focused in accelerator
- Fast rastering magnets expands the beam onto the proton-beam window and the 200 × 100 mm beam entrance window on the target wheel

**Beam Monitoring System essential for the safe operation of the ESS**
Failure in rastering needs to be spotted before the next pulse (≤ 70µs)

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**Proton beam parameters**
- Proton energy: 2 GeV
- Average power: 5 MW
- Peak power: 125 MW
- Beam pulse: 2.86 ms
- Repetition rate: 14 Hz
- Protons per pulse: ≈ 1 × 10^{15}
- Protons per second: ≈ 1.5 × 10^{16}
- Bunches per pulse: ≈ 1 × 10^6
- Beam size on target: 13.5 × 5 mm
- Beam footprint on target: 180 × 64 mm
- Protons per mm² (per pulse): ≈ 1 × 10^{11}
- Protons per mm² (per bunch): ≈ 1 × 10^{9}
Existing Beam Imaging System at SNS

System installed during last months of construction. No space originally foreseen.
Existing Beam Imaging System at SNS

Left: Target vessel before coating. Middle: Target vessel with mask and bond coating. Right: Target vessel during coating with luminescence powder.

Luminescence picture soon after target installation. One can see the effect of the fibre bundle on the picture quality.
New ESS Beam Imaging System

- Monolith vessel
- Neutron moderator
- Rotating target wheel (tungsten blocks inside steel vessel, He cooled, 5 tons total)
- Luminescence coating

Beam Instrumentation Plug (BIP) including two Optical Imaging System

Beam Window (vacuum separation)

Proton pulse, 2.8ms, 2 GeV, 125 MW peak

A third imaging system will monitor the beam on the tuning dump.
Challenge 1: Radiation Damage of Coating

- At SNS, the light yield drops to < 10% within days of operation. Dependent on coating technique.
- Significant higher neutron flux at ESS! (and protons)
- ESS target exchange only every 5 years, compared to 6 months at SNS

Light yield at SNS due to radiation damage

Ruby: 694 nm

Alternative lines might be a solution

Reduced light yield with increased radiation damage (mainly neutrons) for different wavelengths
Challenge 2: Temperature of Coating

Temperature map of ESS target surface: **190°C** peak, 20°C change during pulse

- Current coating loses light yield with raising temperature, due to competing non-emitting processes.
- Conflicts with expected operational temperature of close to 200°C
- Very little luminescence left, very short decay time
- Effect could be dependent on coating technique!
Challenge 3 : The Optical System

- 2 optical systems purely based on mirrors, to accept wide wavelength range. No image degradation due to optical fibres.
- Resolution of \( \leq 1\text{mm} \) required.
- Close to 15 meter total path, \( \varnothing \leq 10\text{ cm} \), BIP must still provide adequate shielding.
- Measure beam size on target in real time.
- Inhibit following pulse if abnormal situation is detected.

The optical paths of the two BIS extend several meters to an accessible room.
Status of coating development

- Existing coating used at SNS barely suitable for ESS
  - Radiation levels & operational temperature could reduce the light yield beyond usability at full operation

- New coating must: withstand extrem ESS radiation conditions, have a short decay time to visualise rastering, be able to separate light from proton pulse or background, separation from luminescence induced in environment (residual gas, He-atmosphere)....

- **Search for new material urgent!**
  (coating of target wheel in 2018, beam on target in 2019)

- A 2 m² curved surface needs to be coated. We need to develop an industrial coating technique, preferable in Europe, base on commercial available powered. Reproduce-able for many years.

- **Existing coating suitable for commissioning phase** (search could continue for next target (≈ 5 years), but intermediate loss in monitoring feared)
Why is this HiRadMat measurement important

- Even with identical powder composition, different coatings behave very differently under intense radiation.
  - e.g. the powder particle size and the spraying technique have a great effect on the 10%-tail, currently used for imaging after initiate irradiation. Effect needs to be understood

- First comparison measurement of fresh samples with new / old coating techniques using high energy proton beams

- Reference measurement for all future materials & coating techniques
Part of a wider analysis

- Laser induced check of **light yield** (when possible)
- **Spectral analysis** of possible materials
- **Heating** stage (electrical, compatible with test beam), under construction at UiO
- Irradiation from **proton beams & spallation products**
- Irradiation by fast/thermal neutrons (research reactors) to simulate **radiation damage** caused by neutrons
- (Re-) Examination of **crystal structure** after each step
Experimental Setup

- We can re-use existing screen testing setup, without any modifications
- Our samples are dimensioned to fit in the vertical mount provided
- We can profit from experience gained during previous HiRadMat tests
- Comparison to already tested materials
  - In addition to the tested AWAKE setup, we want to install 3 radiation hard optical fibres (incl. one spare, + mounts), 20 m long, bringing luminescence light to tunnel TT61

- **2 portable spectrometer** (ThorsLab CCS100 & CCS175) and one standard laptop (remote connection) temporarily installed in TT61

- We need **2 trigger signals** with variable delay to trigger spectrometer
Experimental Setup

HiRadMat measurement setup

Please see talk from Edda & Marlene
Sample description

- Dimensions: 15 x 30 mm (to fit on existing experimental setup)

- Proposed substrate: 0.5 mm Al plates

- Bond coating: ≤ 45 µm of 95% Ni with 5% Al (might disappear)

- Luminescence Coating: 50-150 µm $\text{Al}_2\text{O}_3$ with 1.5% $\text{Cr}_2\text{O}_3$
  (some Cr diffused into Alumina, some stay in Cr0-Cluster)

- Samples for this test use original SNS powder, sprayed in different thickness and technique (at USA and Sweden)

- Later experiments: different coating materials. Pre-selection of candidate powders currently ongoing!
Proposed Beam Parameters

- We would like to simulate the number of protons per mm$^2$ during one ESS pulse: $\approx 1 \times 10^{11}$

- 3 different intensities: nominal intensity + one above + one below. (0.5 / 1 / 1.5 $\times 10^{11}$)

- 10 consecutive shots per intensity per sample

- Spot size: 1 mm$^2$

- 6 Samples: $6 \times 3 \times 10 = 180$ pulses

- Estimated time needed: 2 shifts
Safety and radiation protection aspects

- **Radiological risk:**
  - The coatings are practically identical to screens commonly used for beam setup at various beam lines at CERN without observing any problems. No radiological risk is expected.

- **Contamination Risk:**
  - No release of the coating of screen material expected. For comparison, at SNS the identical coating is exposed to: 7 $10^8$ pulses of 940 MeV protons with peak areal density of about $10^{10}$ p/mm$^2$ (per pulse), 600 ns pulse length. Total irradiation dose leads to a few DPA of displacement damage. No release of coating material ever observed.

- **Post-irradiation plan:**
  - After an appropriate cool-down period, the screen samples will be visually inspected (BI lab in building 867) for structural damage. Finally the screen samples will be returned to the Oslo University institute for further analysis.

- **Operational Procedures:**
  - We follow all procedures already in place for existing setup. Operated from the CCC with help of AWAKE experts et al. Stepper motor, OD filter wheels and the camera read-out will be controlled using the standard BTV FESA application. Connection to laptop computer & spectrometer via remote connection.
Backup Slides
Rotating target wheel (tungsten blocks inside steel vessel, He cooled, 5 tons total)

Neutron moderator

Monolith vessel

Beam Instrumentation Plug (BIP) including Optical Imaging System

Optical Path

Beam Window (vacuum separation)

Proton pulse, 2.8ms, 2 GeV, 125 MW peak

Luminescence coating
Backup Slides : ESS

ESS long pulse potential

Brightness (n/cm²/s/ster/Å)

x10¹⁴
λ=1.5 Å

ESS 5 MW
2015 design
thermal moderator

ESS 5 MW
2013 design (TDR)

ISy TS1
128 kW

ISy TS2
32 kW

SNS
1.4 MW

JPARC
300 kW

ILL 57 MW

Possibilities for pulse shaping

0 1 2 3 4
0 1 2 3 4 5 6 7 8

time (ms)
Backup Slides: ESS

- New design concept is simpler, more manufacturable, and has lower temperatures and stresses
  - Tungsten stress < 100 MPa
  - Tungsten temp < 400 °C

TDR design (2013): Plate geometry with “S” flow

New baseline design (2015): Brick geometry with highly parallel flow

~ 7000 \(10 \times 30 \times 80 \text{ mm}^3\) tungsten bricks

80 MPa

Stress After a Pulse
Monte Carlo Simulation
Energy Deposition in ESS Target Coating

- **Proton Beam Window**: Dominated by proton induced displacement damage, ~ 90 particle µA/cm², Goal: 1 year lifetime

- **Tuning dump**: Wide range of beam parameters, 20 GJ conservative estimate of annual energy to dump, Coated dump: goal of life of the facility

No rastering of beam on target surface included in simulation