

## Background

The design of the MYRRHA/XT-ADS, the European eXperimental Accelerator Driven System for the demonstration of Transmutation, includes a high power windowless spallation target operating with liquid LBE (Lead-Bismuth Eutectic) that will be irradiated with a 600 MeV proton beam at currents of up to 2.5 mA. When considering such a high power windowless target design, a number of questions need to be addressed, such as the stability of the free surface flow and its ability to remove the power deposited by the proton beam by forced convection, the compatibility of a large hot LBE reservoir with the beam line vacuum and the outgassing of the LBE in the spallation target circuit. These issues have been studied during previous experiments supported by numerical simulations. Another crucial point in the development of the spallation target is the demonstration of the safe and stable operation of the free LBE surface during irradiation with a high power proton beam. As a first step in this program, the WEBExpIrr (Windowless target Electron Beam Experimental Irradiation) experiment was set up.

## Objectives

The purpose of the WEBExpIrr experiment was to investigate the influence of LBE surface heating caused by a charged particle beam in a situation representative of the MYRRHA/XT-ADS. More in particular, we wanted to assess possible free surface distortion or shockwave effects in nominal conditions and during sudden beam on/off transient situations, as well as possible enhanced evaporation.

## Principal results

An experiment (TT-1000 Rhodotron) was conceived at IBA (Ion Beam Applications s.a., Louvain-la-Neuve), a 7 MeV electron accelerator which produces beam currents of up to 100 mA. Due to the small penetration depth of the 7 MeV electron beam and the high beam currents available, the TT-1000 allows to imitate the high power deposition at the MYRRHA/XT-ADS LBE free surface. Moreover, the use of an electron beam allows avoiding the experimental difficulties that arise when employing a high energy proton beam in view of materials activation and the production of radioactive isotopes. The geometry and the LBE flow characteristics in the WEBExpIrr setup were made as representative as possible of the actual situation in the MYRRHA/XT-ADS spallation target. The table below shows a comparison between the beam and target properties for both the XT-ADS and WEBEXPIR case. Taking into account the different beam profiles, an electron beam current of at least 100  $\mu$ A was needed during the WEBEXPIR experiment in order to get the same surface heating (less than 2 mm below the surface) at the position of the beam spot.

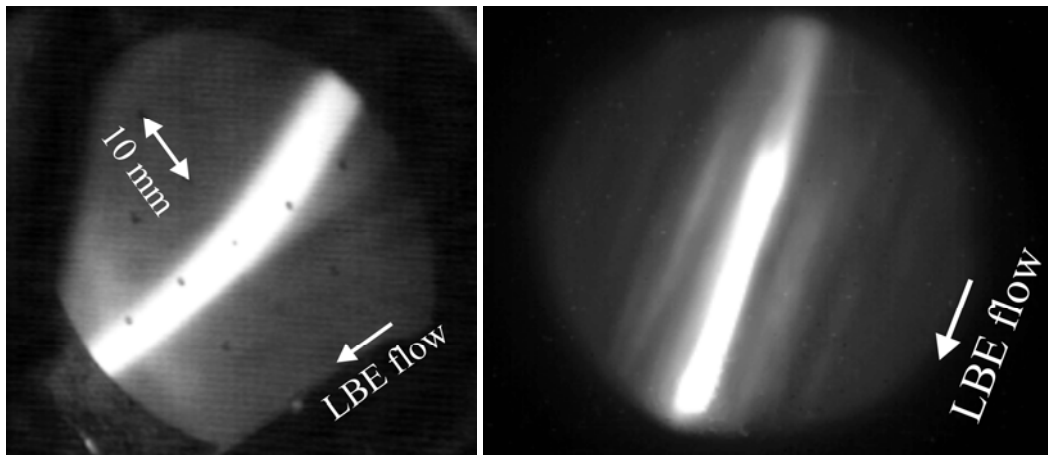
	XT-ADS target	WEBEXPIR target
Target material	LBE	LBE
Beam energy	600 MeV p	7 MeV e <sup>-</sup>
Average power deposition < 2 mm	1.8 kW/mm/mA	2.2 kW/mm/mA
Flow velocity	2.5 m/s	2.5 m/s
Beam shape	~ Gaussian (10 mm FWHM) painted along annulus (54 mm $\varnothing$ )	~ Gaussian (3 mm FWHM $\perp$ flow, 10 mm FWHM // flow)
Beam current	2.5 mA	<b>0.1 mA</b>

The distribution of the current along the beam profile was determined prior to the actual irradiation experiments. For this purpose a stack of electrically insulated collimators with decreasing diameters was mounted at the exit of the 270° bending magnet. The fraction of the beam current caught by each of the collimators was read out. The remaining fraction of the beam was deposited in a water cooled beam dump. Since the profile of the beam might change as a function of the total beam current, the beam profile was measured for currents of 100  $\mu$ A up to 4 mA. Apart from this, the beam position and profile were also visually checked by inserting an Al<sub>2</sub>O<sub>3</sub> coated and water cooled copper support in the electron beam at the position of the beam interaction point. The interaction with the 7 MeV electrons produces visual radiation which can be detected with an optical camera as can be seen in the figure below. The combination of both measurements resulted in a beam profile with an average full width at half maximum (FWHM) of 10 mm in the direction parallel and 3 mm perpendicular to the LBE flow.

An optical camera was positioned both nearly perpendicular and parallel to the LBE surface, focussing on the beam interaction point. Visual images were recorded for beam currents of 100  $\mu$ A up to 5 mA. No obvious distortion of the LBE surface was detected for any of the beam currents.

An infrared camera was positioned perpendicular to the LBE surface, focussing on the LBE surface just downstream of the beam interaction point. The camera was used to measure the surface heating of the LBE for beam currents of 100  $\mu$ A up to 7.5 mA. Temperature increases at the LBE surface of over 250 K have been observed.

The enhanced evaporation of the LBE as a result of surface heating by the electron beam was measured with a shieldless Bayard-Alpert vacuum gauge positioned close to the beam interaction point. The increase in pressure was monitored for beam currents of 100  $\mu$ A up to 10 mA. Even at 10 mA, the pressure in the interaction chamber stayed well below  $10^{-4}$  mbar which is the vacuum pressure level required in the MYRRHA/XT-ADS spallation target design. At currents above 5 mA, pressure spikes were observed which can possibly be attributed to evaporation of LBE droplets that are hit by the electron beam. Surface samples were taken at a number of cold positions in the interaction chamber for off-line determination of the amount of LBE condensation. Apart from solid droplets, which are due to spitting of the turbulent LBE flow, no LBE condensation was found.



*Beam profile on the  $Al_2O_3$ -surface (left) and LBE surface heating at 1.5 mA beam current observed with the infrared camera (right)*

The aim of the WEBEXPIR experiment was to check for any LBE surface distortion or enhanced evaporation as a result of surface heating with a 7 MeV electron beam in conditions representative of the MYRRHA/XT-ADS spallation target. Various tests have been carried out at electron beam currents of up to 10 mA, which corresponds to up to 100 times the nominal beam current necessary to reproduce surface heating in representative conditions. No significant shockwave effects or enhanced LBE evaporation were detected. As a first conclusion it can be stated that the WEBEXPIR free surface flow was not disturbed by the interaction with the electron beam and that the vacuum conditions stayed well within the design specifications of the MYRRHA/XT-ADS.

In the meantime, the WEBExplr loop has been reassembled at SCK•CEN for use in a number of LBE flow experiments. Recently, a project for measuring the reflectivity of a turbulent LBE surface for laser light has been started at the WEBEXPIR loop. The results of these measurements will be used for the design of the MYRRHA/XT-ADS LIDAR system, which will monitor the level of the free LBE surface in the target nozzle. The loop has also been used for testing an electromagnetic flow meter, developed by FZR (Forschungszentrum Rossendorf, DE).

### Future work

A detailed analysis of the measurements and the results obtained during the WEBEXPIR experiment will be reported in a forthcoming publication. The reassembled WEBEXPIR loop will be used in future LBE flow experiments at SCK•CEN for the optimisation of the spallation target nozzle design.

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### Main reference

Jan Heyse, Hamid Ait Abderrahim, Thierry Aoust, Marc Dierckx, Kris Rosseel, Paul Schuurmans, Katrien Van Tichelen, Arnaud Guertin, Jean-Michel Buhour, Arnaud Cadiou, Michel Abs, Benoit Nactergal, Dirk Vandeplassche, "WEBExplr: Windowless target Electron Beam Experimental Irradiation", Proceedings of the Fifth International Workshop on the Utilisation and Reliability of High Power Proton Accelerators, Mol, Belgium, 6-9 May 2007.