EURISOL 100 KW TARGET STATIONS OPERATION AND IMPLICATIONS FOR ITS PROTON DRIVER BEAM*

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Abstract

EURISOL, the next European radioactive ion beam (RIB) facility calls for the development of target and ion source assemblies to dissipate deposited heat and to extract and ionize isotopes of interest efficiently. The EURISOL 100 kW direct targets should be designed for a goal lifetime of up to three weeks. Target operation from the moment it is installed on a target station until its exhaustion involves several phases with specific proton beam intensity requirements. This paper discusses operation of the 100 kW targets within the ongoing EURISOL Design Study, with an emphasis on the requirements for the proton driver beam.

INTRODUCTION

EURISOL, the next generation European RIB facility, plans to operate four target stations in parallel, three 100 kW direct targets and one 5 MW spallation neutron source with one proton linac driver. The predicted increase in yields compared to current RIB facilities is 1 to 3 orders of magnitude. The EURISOL driver beam baseline is a 1 GeV, 5 mA proton beam. This primary proton beam is to be shared between the four target stations. A further consideration is that most targets will need to be segmented into sub-units to manage heat dissipation [1].

The nature of primary beam sharing has a direct impact on target design, operation and lifetime. Whether the primary beam is pulsed or continuous, splitting it in time to accommodate the four targets implies that each target would be subjected to a pulsed beam, whose pulse width and repetition cycle have to be optimized in view of efficient RIB production and target lifetime. By experience, the lifetime of a target is maximum through the use of a continuous wave (cw) driver beam. Pulsed-beam induced instantaneous heating induces fatigue and hence sintering in the target material and will have to be addressed in the case of a pulsed beam incident on a target or its sub-unit.

HIGH POWER TARGETRY

High power targets are a key component of facilities requiring high intensities of a given observable produced either via a single or multi-step process through the interaction of a high energy projectile with the target material. Such facilities are radioactive ion beams facilities, spallation neutron sources and existing neutrino factories.

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This section summarizes the current state of the art of high power targets. A distinction is made between different types of targets namely direct targets (<100 kW) and double-stage spallation neutron targets (> 1 MW).

At CERN-ISOLDE, the driver beam is provided by the proton synchrotron booster which also serves as an injector to the proton synchrotron. The PS booster beam is pulsed, each 1.2 s pulse consists of four bunches with a 230 ns width and a bunch-to-bunch spacing of 572 ns, measured between consecutive bunch peaks. The maximum number of protons per bunch is 1.2×10^{13} but since the four bunches within a pulse do not all reach this maximum, the number of protons per pulse is limited to 3.2×10^{13}. During a normal physics run, ISOLDE gets half the pulses from the PS booster. With 1.4 GeV protons, the instantaneous bunch power is 11.7 GW, more than six orders of magnitude higher than the average power on target of 3 kW. Targets generally last a couple of weeks at most.

The TRIUMF-ISAC proton cyclotron, with a cyclotron frequency of 23 MHz and beam energy of 500 MeV, is designed for a maximum intensity of 100 µA [2]. Even though the primary proton beam is close to cw, the challenge of reaching the design intensity of 100 µA on targets is a tough one, with the main difficulty being the power dissipation within the target and the required cooling of targets [3]. A fine balance between power dissipation and cooling is a necessity to maintain the target at an optimum temperature and promote the fast release of short half-life nuclides. Direct targets at ISAC have been exposed to up to 25 kW of beam power depending on the type of target [4]. They are the current operational record holders for direct targets that produce RIBs and serve as a model for the development of targets beyond 25 kW. Progress towards the 100 µA design intensity has occurred in a staged manner, starting with 1-3 µA in 1998 [5] and reaching the current limit of 50 µA. Metal foil targets are considered to be at the limit of proton beam intensity with the current target design, with Nb and Ta foils being exposed to 30 µA and 40 µA respectively in 2001. Oxide targets were represented by a $CaZrO_3$ pellet target, which was operated with up to 2 µA of proton beam intensity. Innovations in the fabrication of compound carbide targets have allowed these to reach maximum intensities of 40 µA, 45 µA, 50 µA for TiC, SiC and ZrC respectively during 2002-2003. Targets at ISAC can remain operational for up to 3 months (6.2×10^{20} protons).

Megawatt pilot experiment (MEGAPIE) is an initiative to design, build, operate and explore a liquid lead-bismuth spallation target for 1 MW of beam power, taking advantage of the existing spallation neutron facility SINQ at PSI, Switzerland [6]. The MEGAPIE 1 MW target is designed to accept a proton beam with an energy of 575 MeV and intensities up to 1.74 mA and starts taking protons end July 2006 [7]. The protons are accelerated in a separated sector cyclotron whose cavities operate at 50.63 MHz [8]. The time between pulses is 19.75 ns and the bunch width is 0.3 ns. Issues associated with the liquid metal target under heavy proton irradiation include liquid metal corrosion, embrittlement of the beam window and hydrogen retention in the case of helium production. The beam window material, T91 steel, will be exposed to the high power proton beam and flowing liquid metal. Without considering the effect of the liquid metal and taking into consideration the effects of radiation damage alone, the lifetime of the target window was estimated to be 3-6 months during nominal operation.

At the spallation neutron source (SNS) at the ORNL, the 1 GeV, 1.4 MW proton beam is pulsed, with a typical pulse width of < 1 μs and a 60 Hz repetition rate [9]. The major issue with this liquid mercury target is withstanding the effects of the intense heating of the liquid metal. The rate of temperature rise is ~107 K/s during the very brief pulse and the mercury undergoes a large pressure increase. The SNS target beam window is expected to be replaced every two weeks during nominal operation. This facility has just started taking its first protons and will provide valuable information on target lifetime in the near future.

TARGET OPERATION

The direct targets for EURISOL are foreseen to have a finite lifetime of up to three weeks. Their operation from the moment they are coupled remotely onto a target station until their removal once they are spent involves several stages (Fig. 1).

The first stage consists in vacuum-pumping and progressively heating the target. A stable beam with tracer elements pre-loaded into the target allows to check the functionality of the ion source and to assess and tune the transmission efficiency from the target station to the experimental area.

The protons are switched on to perform a proton beam scan, where the best position for the proton beam on the target is found. The target is characterised by measuring yield and release properties for relevant isotopes. For a facility with a cw driver beam, this can be achieved with short bursts (~ms) at reduced beam intensity. The burst width and time between consecutive bursts would be determined by the release, effusion, diffusion and half-life of the particular isotope to be analysed.

Target characterisation would be followed by a gradual increase in driver beam current up to the nominal operational current for that target. As the beam current is increased, it heats up the target so that external heating must be reduced and target cooling optimised to keep the target temperature constant. The target would then be handed over to the users who might have special requirements for the driver beam current.

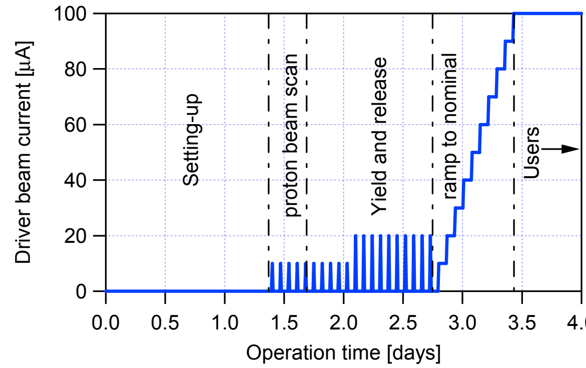

Figure 1: Target operation stages including setting-up, proton beam scan, yield and release measurements, ramping up to nominal current and handing over to users.

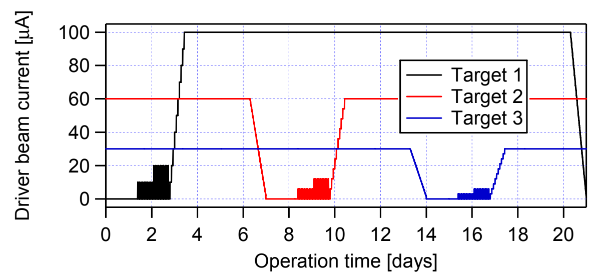

Figure 2: Driver beam current over a three-week period for different nominal intensities at each of the three target stations.

At EURISOL, up to three direct targets will be operating in parallel. Any combination of the three targets at any one of the three stages of operation described must be possible. The driver beam therefore has to be flexible enough to accommodate this versatility of target operation (Fig. 2).

EURISOL DRIVER BEAM

The debate about the driver beam time structure centres around whether it should be continuous or pulsed. A pulsed beam has benefits such as higher instantaneous RIB intensities which can be beneficial for some experimental setups, since the decay losses are kept to a minimum and the higher instantaneous heating enhances diffusion of the isotopes from the target matrix [10]. Another benefit of a pulsed driver beam is the better selectivity in the case where a contaminant has a significantly shorter half-life allowing the suppression of the contaminant through appropriate timing of a 'beam gate'. The major drawback of a pulsed beam is that it induces thermal stresses that affect the lifetime of the target and become a limiting factor for its operation.

The length of time a given target spends 'online' at existing facilities is driven by cost, user requirements or incurred damage during irradiation. Defining a basis for comparing the lifetime of targets at different facilities is an exercise that can therefore only be approximate.

Table 1: Proton beam and target lifetime parameters: l_p is the pulse (or bunch) length, τ_p is the time between consecutive pulses, T is the operation temperature of the target, τ_{rel} is the relaxation time. The lifetime quoted is either by experience (ISOLDE, ISAC) or estimated (MEGAPIE, SNS).

	Proton beam parameters					Target lifetime parameters			
	f [Hz]	l_p [s]	τ_p [s]	P_{avg} [kW]	P_{peak} [kW]	T [°C]	τ_{rel} [$\times 10^{-6}$ s]	R_{value} [τ_{rel} / τ_p]	Lifetime [wks]
ISOLDE	0.42	230×10^{-9}	2.4	3	11.7×10^{6}	2000	1.2	5×10^{-7}	1
ISAC	-	-	-	25	25	2000	2.4	-	12
MEGAPIE	50.63×10^{6}	0.3×10^{-9}	19.5×10^{-9}	1000	66×10^{3}	< 400	47	2410	> 12
SNS	60	$< 10^{-6}$	16.7×10^{-3}	1400	24×10^{6}	< 90	81	4.85×10^{-3}	2

Table 1 lists proton beam and target lifetime parameters. The relaxation time, τ_{rel}, is the ratio of the critical length (given by the proton beam FWHM) to the speed of sound in the target material. Thermal and mechanical shocks are enhanced if the length between pulses is much bigger than the relaxation time. The R_{value} which is the ratio between τ_{rel} and τ_p is a measure of the susceptibility of a target to pulsed-beam induced fatigue, the greater the R_{value}, the greater the lifetime of a given target. As expected, those facilities that employ a cw driver beam (ISAC, MEGAPIE) have targets with longer lifetimes.

The design study for the EURISOL driver accelerator is being carried out by a dedicated task group whose authority will decide the final proposal for the driver accelerator. The following paragraphs report an exercise in the use of the Super Proton Linac (SPL) at CERN [11] for the purposes of EURISOL. This exercise is not meant to be suggestive of the applicability of SPL for EURISOL and as will be seen, the SPL proposes a pulsed beam.

The SPL is an interesting study case because the pulse microstructure is known. An option of switching between targets within a pulse was proposed by the SPL study group. The 3.5 GeV SPL beam would operate at 50 Hz (40 mA) with a pulse length of 0.82 ms. Each pulse is composed of a 0.71 ms (1.78×10^{14} particles) long fraction for the EURISOL high-power target, a 0.1 ms gap to switch the beam to a different beam line, and a 14 μs (3.6×10^{12} particles) long fraction for a low-power target (see Ref. [10]). This time structure allows to supply in parallel two or more (with more gaps in the bunch train) target stations with each pulse, keeping the repetition rate for all target stations at 50 Hz. The bunch centres are spaced by 2.84 ns and carry 0.71×10^{9} particles each. The total length of the single bunches is approximately 0.15 ns. Another option to share the SPL beam between different target stations is to use H^- laser stripping.

The EURISOL proposal is H^- magnetic stripping of a fraction of the primary beam to H^o and separation of the two resulting fractions [12]. The H^o can then be stripped through a carbon foil to H^+. The primary target can thus be split and steered to feed a number of targets.

SUMMARY

One driver beam is foreseen to feed three 100 kW direct target stations and one 5 MW two-stage spallation neutron target at EURISOL. The sharing of this driver beam between targets must be achieved in such a way that the targets are not exposed to highly pulsed beams which would affect the target lifetime. It is therefore highly desirable to have a driver beam operating in continuous mode down to the level of the target sub-units mounted to each target station.

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