Baseline Yields for a C70-based HRIBF

Basic assumptions in calculating baseline yields are provided in bullet form, and explained in subsequent paragraphs.

- Basic Production method is direct 70 MeV proton induced fission on uranium carbide targets
- Target geometries are disks 3 cm diameter by 1.1 cm thick or 5 cm x 1.1 cm (6g/cm^3 UCx density)
- Fission induced by secondary neutrons is included, and plays an important role.
- Maximum beam currents are based conservatively on deposited power densities in similar targets as they are used at HRIBF. The limit is taken to be 88 W/g (15 μA of 50 MeV protons on target).
- Beam assumed to be "painted" almost uniformly across the UCx target face.
- Corresponding maximum beam currents are 82 and 230 μA respectively for 3 cm and 5 cm diameter targets.
- In the baseline beam intensity calculations for the 5 cm target, a conservative estimate taken of 80% of the equal power density limit or 0.8 x 230 = 184 μA estimate.
- In future we expect to develop effective secondary neutron production targets that can withstand 750 μA proton beams for "cold fission" production of n-rich beams by U(n,f).

The IBA C70 is a flexible and powerful machine. This flexibility and the comparatively high beam power available (50 kW) means that it can be used in a variety of ways to produce radioactive species. This note concerns what we believe will be method initially employed at HRIBF to produce neutron-rich species. This should establish an initial baseline for post-accelerated yields that can be used in evaluating the feasibility of early experiments. The baseline method is based firmly on existing techniques and does not utilize the full power of the C70; it leaves substantial scope for improvement as we develop experience with the machine. It is a direct irradiation technique, with proton beam incident on a uranium carbide target with an unusual geometric format – large diameter but relatively small thickness. This format offers two advantages. First the relatively large diameter (we look at 3 cm and 5 cm) allows the effective use of raster-scanning techniques to spread the power deposition in the target. The second advantage is that the target is large enough for the secondary neutron induced fission resulting from the high neutron multiplicity p+U events (ν~10 at 70 MeV) to add substantially to the production of very neutron-rich fission fragments.

The HRIBF has developed reliable and economical uranium carbide targets using the so-called "pressed powder" technique. Targets now in use at HRIBF have a UC density of ~2 g/cm^3, a diameter of 1.4 cm and a volume of about 3 cm^3. These targets are used routinely with 15μA 50 MeV proton beams and have been operated successfully at 20μA (limited by ORIC). The thickness of the target is arranged so that protons emerge, on average, at an energy of about 15 MeV. Thus ~35 MeV is deposited in the target per proton, corresponding (if the irradiation were uniform across the target) to a power density of about 88 W/g at 15μA. Since we do not do a good job of spreading the beam uniformly at IRIS1, the peak power density is probably substantially higher. A mentioned above we have operated at 20μA corresponding to an average of ~120 W/g for uniform irradiation. We have demonstrated that uranium carbide targets with density greater than 6g/cm^3 can be manufactured using the "pressed powder" technique. It has also been shown that the 6 g/ cm^3 target material has release properties as good as that of the 2 g/cm^3 material now used routinely at HRIBF.

The proposed baseline production technique employs thin (1.1 cm), large diameter, disk-shaped targets made of 6g/cm^3 material. The IRIS2 system is designed to raster-scan driver beams over the face of such targets for front-face diameters up to 5 cm. To estimate the maximum beam current of 70 MeV protons such targets can withstand, we take the power density already achieved with 50 MeV proton beams, account for the differences in energy loss and assume uniform on spreading of the beam over the target face. We consider two geometries.

1) 3 cm dia. x 1.1 cm thick; 88 w/g corresponds to 82 μA of 70 MeV p. Total mass 47g.
2) 5 cm dia. x 1.1 cm thick; 88 w/g corresponds to 230 μA of 70 MeV p. Total mass 130g.

To develop a conservative baseline, a limit of 80% of this beam current is taken for the 5 cm targets that are at the limit of the design, assuming e.g., failure to paint the target face uniformly with beam. This also keeps the maximum total power deposited in the 5 cm target below 10 kW. The further conservative assumption of taking 88 W/g (15μA rather than 20 μA at 50 MeV) as the maximum demonstrated power density should also be noted. The current limits used in calculations are therefore 82μA (3 x 1.1 cm) and 184 μA (5 x 1.1).

Effusion simulations indicate that this large-diameter thin target configuration will have favorable release characteristics. Nevertheless, it is possible that the smaller diameter target may have some advantages for very short-lived species. This is why the smaller target is considered in developing baseline numbers. We will investigate this geometry dependence thoroughly over the next two to three years.

In order to calculate post-accelerated beam currents the inputs required besides the driver accelerator beam current, are the in-target production systematics, the species and lifetime dependent conversion of in-target yields to ion-source yields, and post-acceleration efficiency (including charge exchange).

The yields employed in the final calculations are based on experimental proton induced fission-fragment (Z, A) yield systematics developed at ORNL by Kazu Tsukada (Priv. Comm. 1999), largely based on cross sections from the PhD thesis of Yuliang Zhao (Tokyo Metropolitan University, 1996, and references therein). These systematics have been used successfully to predict beam yields for 50 MeV proton beams from ORIC.

Results obtained using proton induced fission calculations by Rubchenya and Aysto (Theoretical Predictions for the Neutron Rich Product Yields, EURISOL Research Report, 2003). In general the Tsukada systematics give somewhat lower yields at large neutron excess than the Rubchenya and Aysto calculations, but in general agree quite well. We use the lower Tsukada yields as a conservative baseline. MCNPX calculations at 70 MeV incident energy do not agree well with either Tsukada or Rubchenya and Aysto, but the problem here may well be operator error.

Isotope production calculations are carried out using standard Monte Carlo particle tracking codes, coupled to a semi-empirical production database. It is important to realize that the secondary neutron-induced fission makes an important contribution for these large targets (it is almost negligible in the small diameter low density targets now in use at HRIBF). The fractional secondary-neutron fission contribution is almost 5% for the 3 cm x 1.1 cm targets and about 8% for the 5 cm x 1.1 cm targets. The impact of secondary fission induced by fission-spectron neutrons on production of very neutron-rich isotopes is, of course, much larger than the 5% and 8% integral fractions would suggest.

The species and lifetime dependence of ion-source yields (i.e decay loss and efficiencies) is calculated using the expressions employed by Lukic (ref. ??), with parameters fit to data obtained at HRIBF where possible and from other ISOL facilities if necessary. This formula describes the yields of HRIBF in its preset configuration very well, when coupled either with Tsukada or Rubchenya and Aysto in-target yields.