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MAFF – The Munich accelerator for fission fragments

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Abstract. At the new high flux reactor FRM-II in Munich the accelerator MAFF (Munich accelerator for fission fragments) is under design. In the high neutron flux of 10^{14} n/cm^2 s up to 10^{14} neutron-rich fission fragments per second are produced in the 1 g U-235 target. Ions with an energy of 30 keV are extracted from the ion source. In the mass seperator two isotopes can be selected. One of the beams is used for low energy experiments, the other one is injected into an ECRIS (or EBIS) for charge breeding to a $q/A \geq 0.16$. A gas filled RFQ cooler is used for emittance improvement. The subsequent LINAC delivers beams with an energy ranging from 3.7 MeV/u to 5.9 MeV/u. New IH structures are being developed at the Munich tandem laboratory. A small storage ring is planned in a further stage to recycle the fission fragments. A thin target foil can be placed into this ring, e.g., for synthesis of super-heavy elements. The through-going beam tube has been installed in the heavy water tank of the reactor. Tests of the target ion source in a special oven to test long term stability and safety tests were in progress.

Keywords. Research reactors; linear accelerator; beam transport; particle sources and targets; ion sources.

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1. Introduction

All over the world facilities for radioactive ion beam (RIB) production are planned or were recently completed. Two different methods are used. In projectile fragmentation a thin production target is bombarded with high energetic projectiles. The radioactive ions leave the production target with high energy. The following mass separator and a cooler ring as an option delivers the ions to the experiment. In the isotope separation on line (ISOL) production method the radioactive nuclei are produced almost at rest. After the ionization a post accelerator increases the energy in the region of the Coulomb barrier. With this method good beam quality is available. At ISOLDE at CERN different thick production targets are hit by protons with an energy of 1.0 GeV or 1.4 GeV. A broad range of neutron- and proton-rich nuclei is produced via fragmentation and spallation. Here the high energetic protons are directly used to produce the desired nuclei. In the indirect method secondary particles like fast neutrons, thermal neutrons or bremsstrahlung-photons are generated and then an intense source of neutron-rich fission fragments is obtained by fissioning uranium or thorium targets. The Munich RIB project MAFF will be of this type. Here the very intense neutron flux of the new research reactor FRM-II will be used for

Table 1. Yields of prominent isotopes at MAFF compared to SPIRAL and ISOLDE. The primary beams are 10 μA of 1.15 GeV ^{12}C for SPIRAL, 2.5 μA of 1 GeV protons (or 600 MeV protons for the SC respectively) for ISOLDE.

Isotope	Prod. rate (s^{-1})	Half-life (s)	Release (%)	Ioniz. (%)	MAFF (s^{-1})	SPIRAL (s^{-1})	ISOLDE (s^{-1})
^{78}Zn	$2.3 \cdot 10^{9}$	1.47	36	10	$8 \cdot 10^{7}$	$2 \cdot 10^{6}$	$1 \cdot 10^{6}$ SC
^{91}Kr	$3.3 \cdot 10^{12}$	8.6	89	15	$4 \cdot 10^{11}$	$2 \cdot 10^{9}$	$2 \cdot 10^{9}$
^{94}Kr	$1.1 \cdot 10^{11}$	0.2	16	15	$3 \cdot 10^{9}$	$3 \cdot 10^{7}$	$4 \cdot 10^{6}$
^{97}Rb	$3 \cdot 10^{10}$	0.17	10	80	$2 \cdot 10^{9}$	$5 \cdot 10^{8}$	$3 \cdot 10^{8}$
^{132}Sn	$7 \cdot 10^{11}$	39.7	89	10	$6 \cdot 10^{10}$	$6 \cdot 10^{6}$	$8 \cdot 10^{7}$ SC
^{142}Xe	$5.2 \cdot 10^{11}$	1.24	7	25	$1 \cdot 10^{10}$	$6 \cdot 10^{7}$	$2 \cdot 10^{8}$
^{144}Xe	$9.3 \cdot 10^{9}$	1.15	7	25	$2 \cdot 10^{8}$	$1 \cdot 10^{6}$	$5 \cdot 10^{6}$
^{144}Cs	$4.3 \cdot 10^{11}$	1.0	47	80	$2 \cdot 10^{11}$	$2 \cdot 10^{10}$	$3 \cdot 10^{10}$

fissioning a uranium target of about 1 g U-235. High beam intensities in neutron-rich nuclei are expected (see table 1).

An advantage of using thermal neutrons instead of fast neutrons is to avoid the unwanted production of 227-Ac and 226-Ra. For these nuclides only very low production levels are allowed by safety regulations.

2. The research reactor FRM-II

The new high flux reactor FRM-II is completed but the final authorization for commissioning is not yet given. At a thermal power of 20 MW the maximum neutron flux will be $8 \cdot 10^{14}$ n/cm^2 s. In the first stage about 20 experiments will be set up in the reactor hall and the neutron guide hall. One of them is the MAFF fission fragment accelerator (figure 1). The U-235 target is placed close to the reactor fuel element in in-pile position of the heavy water moderator tank. The fission fragments are ionized (1^+) and extracted through the reactor beam tube. In a mass pre-seperator the low energy beam (30 keV) is separated. The emittance improver and a high-resolution separator is used to prepare the ions for the acceleration in the LINAC. The LINAC and the charge breeding device (an EBIS or an ECRIS) will be placed outside the reactor in an external hall. The experiments with the high energetic radioactive ions are set up in this hall, too.

3. The MAFF ion source

The most important part of MAFF is the target/ion source. A through-going tube is installed in the heavy water moderator tank of the FRM-II. In the middle of this tube the uranium target is placed in a thermal neutron flux of $\approx 10^{14}$n/cm^2 s. Thus only 1 g U-235 is sufficient for a fission rate of 10^{14} s^{-1}, corresponding to a thermal power of 3 kW. The temperature of the target reaches $\approx 2400\,^\circ$C in equilibrium of thermal heating and radiation cooling (figure 2).

The U-235 is dispersed in a porous graphite matrix which is enclosed in a rhenium cylinder (60 mm long, 15 mm in diameter). To protect the rhenium container from chemical

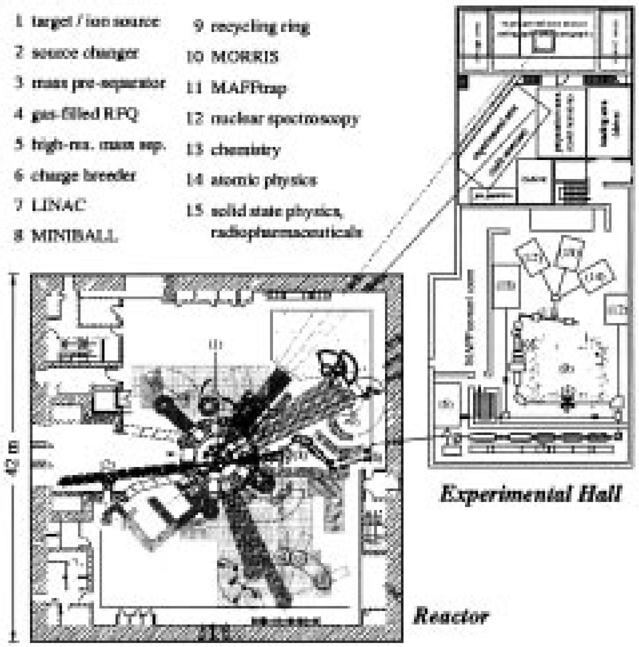

Figure 1. The components of MAFF in the FRM-II building and the external hall.

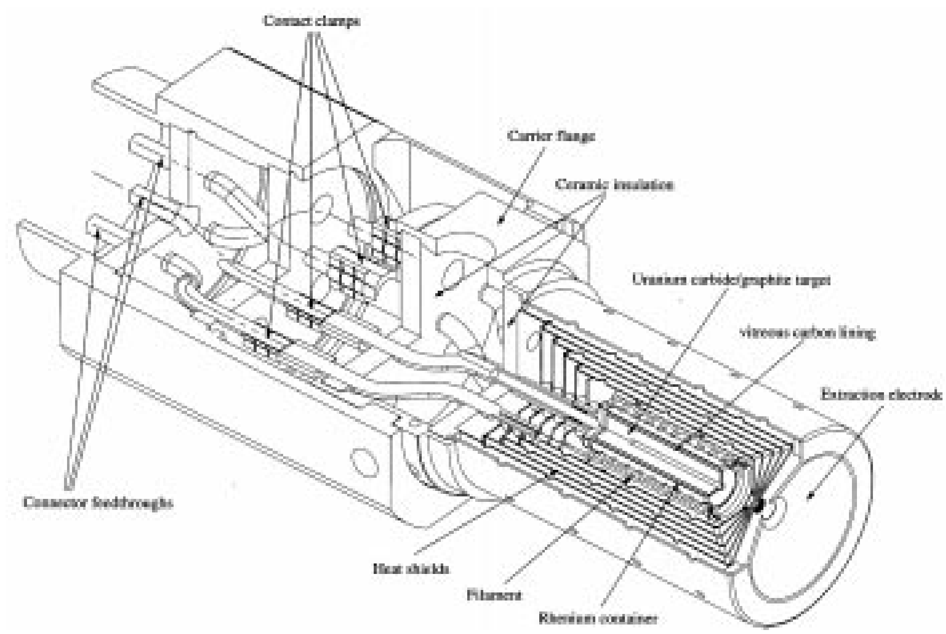

Figure 2. Schematic drawing of the target/ion source unit.

attack of UC_2 or the fission products a thin layer of vitreous carbon separates the uranium-doped graphite matrix from rhenium. The high operating temperature guarantees short diffusion time of the fission products before they reach the exit hole of the rhenium container and are ionized at the hot metallic surface. The small size of the target also leads to high extraction efficiencies. The heating filament around the rhenium container will keep the temperature constant in spite of the uranium burn-up of approximately 20% during one reactor cycle of 52 days, which is also the expected operational lifetime of the target. The additional heat shields are only required in test runs when the target contains a significantly reduced uranium load of only a few milligrams. In the first step only surface ionization will be used, but later resonant laser ionization also will be applied which allows to ionize many metallic elements and is also element specific, thus reducing the background.

The ion source unit is mounted on a trolley which is inserted into the through-going reactor beam tube from the source changer side. From the beam extraction side another trolley carrying the ion optical system is inserted. Therefore the ion source unit is mechanically independent of the ion optical system which facilitates the target changing procedure.

A considerable portion of the fission fragments will leave the target without being ionized. In order to keep these radioactive gases in a well-shielded environment, helium-cooled cryo-panels at 15 K are installed close to the ion source. The condensed radioactive gases will decay after a relatively short period of time to non-volatile elements, thus remaining adhered permanently to the cryo-panels.

4. Low energy beam line

After leaving the reactor beam tube, the ion beam passes the mass pre-separator, a combination of electrostatic deflector and dipole magnet with a system of slit diaphragms. This broad range low resolution separator retains all undesired masses and splits the beam in the sense that one mass of the light and one of the heavy wing of the fission distribution can pass simultaneously and later on be used independently. A subsequent gas-filled RFQ reduces the energy spread of the beam and improves its emittance. At present we are investigating whether alternatively a rf jet cell with electromagnetic ion funnel [1,2] could perform this task with the additional advantage of insensitiveness to plasma formation in the buffer gas and almost 100% transmission. In the following high resolution dipole magnet mass separation is possible before the beam is used for low-energy experiments and post acceleration, repectively.

5. High energy beam line

One of the two beams leaves the reactor building and is transferred to the adjacent experimntal hall where it is accelerated in a compact LINAC of about 20 m length to its final energy between 3.7 and 5.9 MeV/u, sufficient for experiments at the Coulomb barrier. In order to obtain efficient acceleration in the LINAC, charge breeding of the single charged ions to a charge-to-mass ratio $q/A \geq 0.16$ is required. This $1^+ \rightarrow n^+$ conversion can be performed by either an electron beam ion source (EBIS) or an electron cyclotron resonance ion source (ECRIS) [3]. Due to the expected high beam intensities at MAFF (up to 10^{10}–10^{12} ions/s) the ECRIS is at present the favored device. Electron beam ion sources

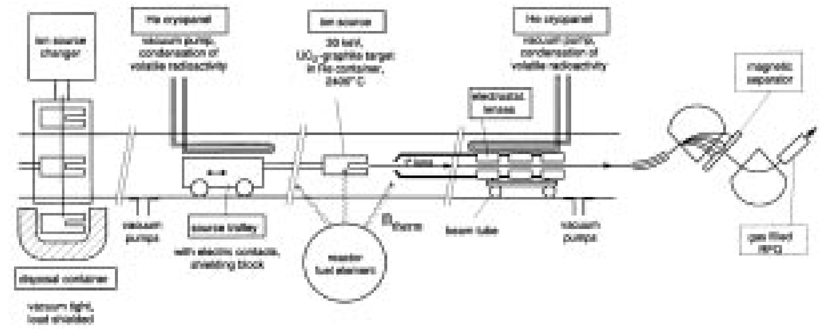

Figure 3. The in-pile part of MAFF.

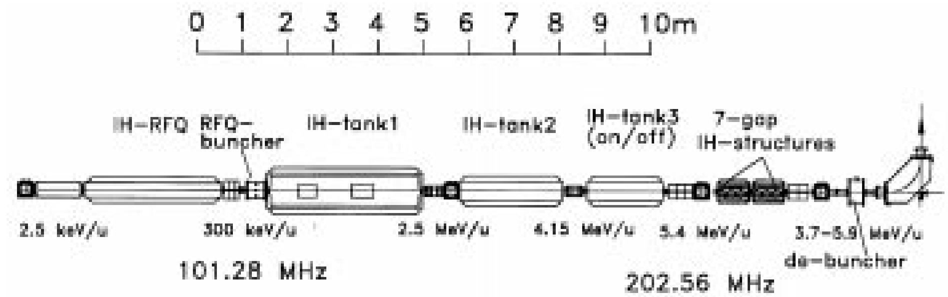

Figure 4. The MAFF linear accelerator.

usually achieve shorter breeding times and superior beam qualities than ECR sources and operate inherently on bunched beams, but they are space charge limited to beam intensities up to 10^8 s^{-1} [4–8]. ECR sources on the other hand are able to handle beam currents up to 10^{12} s^{-1} with charge breeding times and efficiencies dependent on rf frequency and power. They usually run in cw mode, but beam bunching is also possible with an extraction efficiency of $\approx$50% of the cw value [9].

In order to determine the optimum charge breeding system for the next generation RIB facilities and also for MAFF, an EU RTD network 'charge breeding' has been established [10]. In this framework very promising results were obtained with the new PHOENIX ECR, e.g. for indium a gross breeding efficiency (sum over all charge states of up to 70% could be achieved with 11% in the optimum charge state (20^+), breeding times comparable to those of an EBIS and manageable beam intensities of up to 10^{12}–10^{13} ions/s [11,12]. The performance of ECR sources for low beam intensities on the other hand remains to be demonstrated, as due to the much higher residual gas pressure (10^{-6}–10^{-5} mbar) in an ECRIS compared to an EBIS (10^{-11}) mbar the ions undergo transfer collisions. The MAFF LINAC is designed for a 10% duty factor and final energies between 3.7 and 5.9 MeV/u with an energy spread of less than 0.2% at the target. It consists of a RFQ accelerator, three IH structures and two 7-gap IH resonators. The lay out is shown in figure 4. In order to reduce the length of the accelerator, the frequency is increased from 101 MHz to 202 MHz after the first IH resonator. The beam energy variation will be done by switching on or off the third IH resonator and using the 7-gap resonators for acceleration or deceleration.

This MAFF LINAC is very similar to the REX-ISOLDE LINAC in the front part. REX-ISOLDE has been set up last year at CERN and so completly new design is not necessary.

6. Present activities

The in-pile parts of MAFF are now tested in a special vacuum furnace which allows continuous heating up to a temperature of 2500°C and extended periods of time (>1000 h). These heating tests are necessary to assure a sufficient mechanical stability and chemical compatibility of the used materials under operating conditions [13,14]. Also the doping of graphite with uranyl nitrate is investigated to verify a homogeneous UC_2 distribution in the target. Soon the complete preparation and assembly of the production target including the welding of the rhenium container will be possible in the hot lab of the Sektion Physik. The ion optics of the source will be tested with stable isotopes at the Ion Source Lab of the Munich tandem accelerator. Moreover, a test tube is being set up which simulates the whole through going reactor beam tube. This set up aims at the determination of the system performance of the target/ion source, its ion optical characteristics and the temperature distribution. The efficiency of the cryo-panels will also be tested here. Detector systems for first experiments at the low energy beam are becoming available. The MINIBALL Ge-cluster detector is already built. It will allow gamma spectroscopy with high granularity and position resolution. Moreover MAFFTRAP is being built, a SHIPTRAP-like system for the investigation of fusion reaction products at the high energy beam. But this set up can also be used to examine exotic nuclei at the low energy beam.

7. The schedule of MAFF

Due to its possible implications on the safety of the FRM-II, an authorization procedure is required for MAFF which cannot start before the commissioning of the reactor. An approval of concept, however, has already been obtained in September 1999. The low energy beam is expected to be operational within three to four years after the start-up of the FRM-II. Two years later the high-energy beam also may become available, provided adequate funding of all component is sanctioned.

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