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4 ROD RFQ INJECTORS FOR THE GSI LINAC ⁺

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Abstract

A 4-Rod RFQ is being built as a part of the new "High Charge State Injector" for the UNILAC at GSI - Darmstadt[1,2]. It will accelerate heavy ions from an ECR ion source with charge to mass ratio of $q/u \geq 0.117$ (U^{28+}) from 2.5 keV/u to 300 keV/u which corresponds to an energy gain of 2.5 MeV/q. The 4-Rod RFQ will be 2.9 m long with a tank diameter of 35 cm and will operate at 108.5 MHz with a duty cycle of up to 50% .
The status of the project and first results are presented. In addition work on a high current prototyp accelerator designed for U^{2+} (25 emA), 2.5 to 25 keV/u, and an operating frequency of 27 MHz is reported.

Introduction

The GSI is extending its accelerator facility by a heavy ion synchrotron SIS and a storage ring ESR[3,4,5]. Figure 1 shows a layout of the new GSI accelerator complex. The SIS which will be operational this year is a 18 Tm synchrotron which is designed to accelerate all elements up to uranium to energies above 1 GeV/u .
To fill the SIS to its space charge limit and to use the full potential of the new GSI accelerator complex a new high current injector is planned which should accelerate up to 25 emA U^{2+} ions with a small duty cycle of 1% .These values are thought to be achievable goals concerning ion source and RFQ technology [6].
A gas stripper at 216 keV/u produces a reasonable fraction of the necessary charge state of U^{10+} for acceleration in the Wideroe. The gas stripper at 1.4 MeV/u between the Wideroe and the Alvarez part of the UNILAC then strips to U^{28+} for postacceleration and injection into the SIS.
For much lower currents (design value e.g. 5 eμA instead of 25 emA) but with a duty cycle of up to 100% the development of new sources[7,8] for highly charged heavy ions as well as rf preaccelerators [9,10] enable direct acceleration of U^{28+} ions.
Therefore, for the UNILAC experimental program with low beam currents but a duty cycle of 25% a second new injector will be built in the stripper hall of the GSI [1,2].
This high charge state injector will consist of the combination of an ECR ion source , a 4 Rod RFQ, which is shown schematically in fig. 2, and an IH structure [11,12].
Without any stripper U^{28+} ions extracted from the ECR source will be accelerated to 300 keV/u and to 1.4 MeV/u respectively, thus replacing the Wideroe /Stripper part of the UNILAC which is then being dedicated to short pulse high current acceleration for SIS injection.

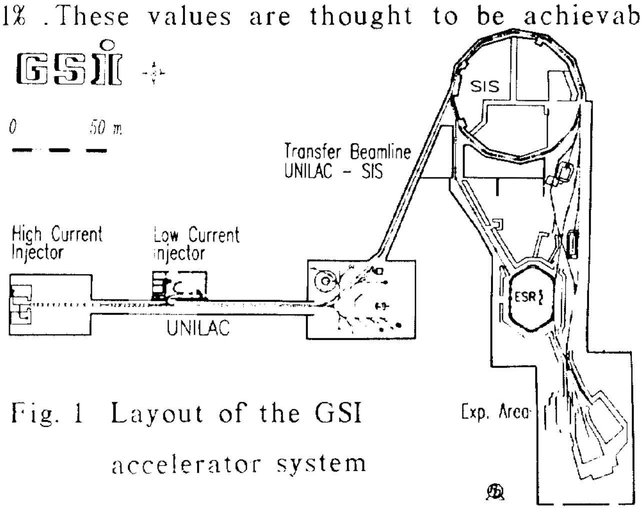

Fig. 1 Layout of the GSI accelerator system

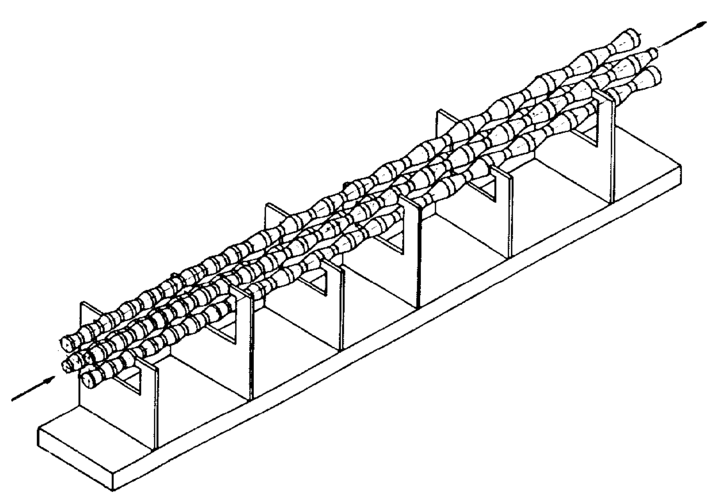

Fig. 2 Scheme of the 4 Rod RFQ structure

⁺ supported by the BMFT and the GSI

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Now only the poststripper part of the UNILAC (Alvarez, Single Gap Resonators) has to be operated in a time sharing mode. With this system, beams with different ions, currents and energies are provided independently for the old experimental hall and the SIS on a pulse to pulse basis (50Hz).

High current injector RFQ-U2

The time sharing operation of the poststripper part of the UNILAC can be simplified if the bunch frequency is 27 MHz instead of 13 MHz as previously planned due to the reduced space charge forces. The stripper position has been changed to 216 keV/u corresponding to an accelerator voltage of 25 MV to get a reasonable fraction of the beam with the design charge state of U^{10+} for the Wideroe. Detailed studies of beam generation, sources of emittance growth, and application of new RFQ design procedures, resulted in higher current limits giving safety margins and shorter RFQs even at the doubled frequency of 27 MHz [13,14,15]. A 27 MHz 4 Rod RFQ-U2 structure with spiral shaped stems as developed in Frankfurt is an alternative to the 13 MHz Split Coaxial structure [16]. First high power experiments with this structure have been successful[15], showing electrode fields higher than three times the value given by Kilpatrick criterion for the sparking limit [17]. Figure 3 shows a scheme of the basic cell of this structure.
Now a prototype 4 Rod Spiral RFQ accelerator designed for the bunching and acceleration of a 25mA U^{2+} beam from 2.5 keV/u to 25 keV/u (length appr. 4.5 m) will be built and tested [15]

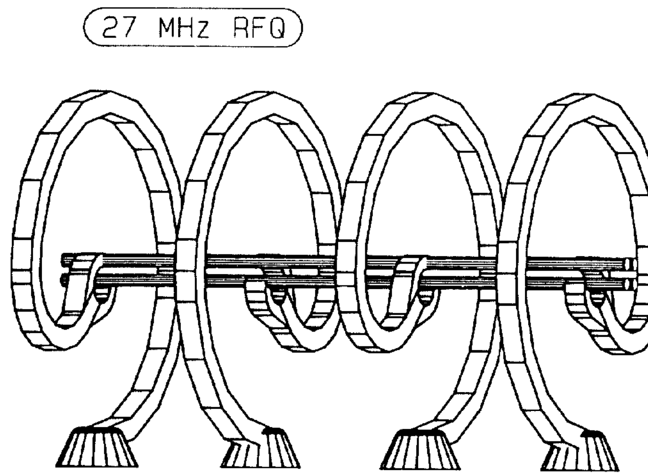

Fig. 3 Scheme of the low frequency Spiral RFQ

to study in more detail the emittance growth and beam loss source in the crucial first part of a heavy ion high current RFQ.

The high charge state Injector

The high charge state, low current injector is a system consisting of an ECR ion source followed by an RFQ and an IH accelerator as shown in Fig. 4 .
It is designed to deliver U^{28+} at 1.4 Mev/u without an additional stripper. The design current of 4μA should be achieved with minimum emittance growth. The new injector linac will have 50% duty cycle (100Hz, 5msec pulses). Because of the pulse structure of the UNILAC (50Hz) each other pulse will be used in the stripper hall for low energy experiments. The ECR ion source will deliver U^{28+} at

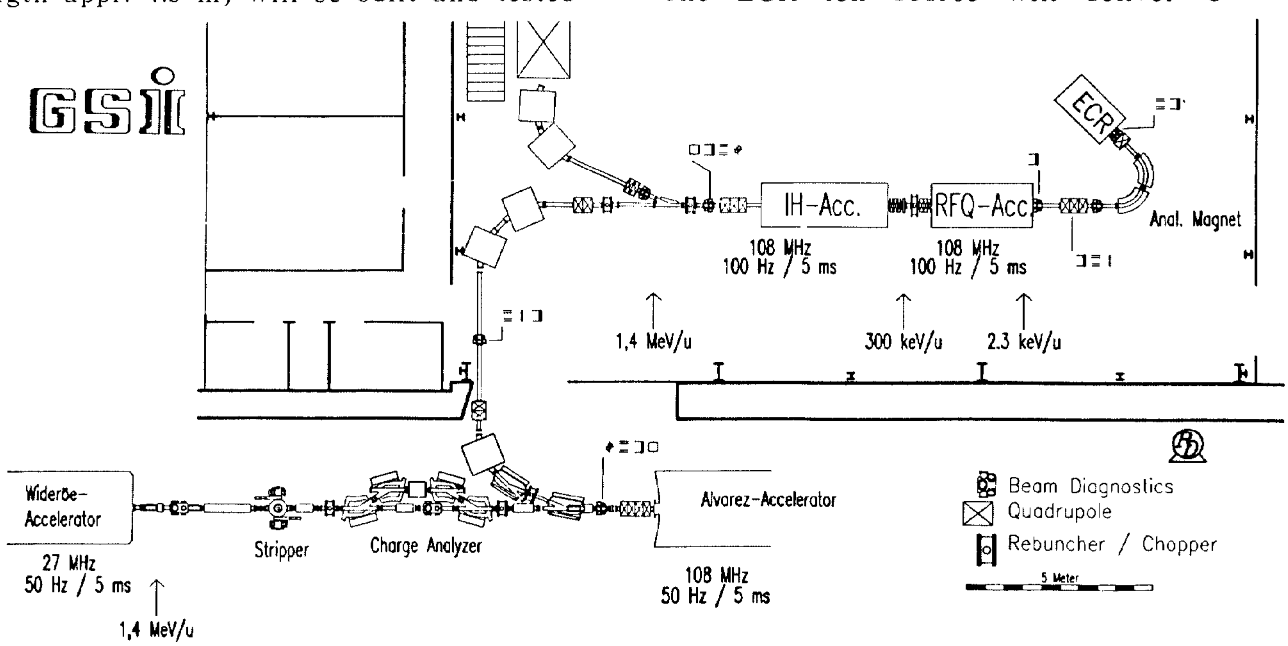

Fig. 4 Layout of the new high charge state injector

sufficiently high intensities at an energy of 2.5 keV/u. The LEBT section [18] has to provide mass separation and matching to the RFQ entrance. The 4 Rod RFQ will be designed and built at the Institut für Angewandte Physik, Frankfurt. The final energy of 300 keV/u is sufficient for injection into the following IH structure, which accelerates up to 1.4 MeV/u .

The high charge state RFQ-U28

Acceleration of the heavy ion beam from 2.5 keV/u to 300 keV/u is being done with a 4Rod RFQ [19,20] . It employs circular rod electrodes and a linear array of straight radial stems as resonant structure. It should be especially well suited for heavy ion acceleration at low frequencies.

After successful operation with protons at DESY [20] a heavy ion RFQ is now being completed for the CRYRING project at MSI in Stockholm [21]. The design of the GSI RFQ follows this development but the parameters have now been stringened. At the same operational frequency of 108 MHz and final energy the injection energy has been lowered from 10 keV/u to 2.5 keV/u as well as the specific charge (from q/m = 0.25 to q/m = 0.117). The structure length has been doubled and as most difficult task the duty cycle has been increased from 0.1 % to 50%. This together requires changes in the particle dynamic design as well as in the mechanical layout.

The particle dynamics design was made for a compromise of minimum longitudinal and radial emittance growth and good transmission at this very low injection energy of 2.5 keV/u which is the same as for the high current injector at 27 MHz. Following a new design procedure [14] a RFQ with a length of 2.9 m was designed with an electrode voltage of U_Q = 80kV, a minimum aperture of 3.0 mm, and a maximum modulation of 2.1 . Fig. 5 shows the RFQ parameters along the structure.

Tests of this design have been done with PARMTEQ [22,23] confirming the beam parameters and determining the matching parameters and emittance growth. The results show that radial and axial emittances are favourably low which should be a good base for further injection into the IH structure.

Starting with a normalized input emittance of 0.5π mm mmrad from the ion source, the radial emittance growth is 20%, the transmission 95% and the longitudinal emittance is as small as 40π $^{\circ}$ keV/u or 0.25 MeVnsec. Figure 6 shows PARMTEQ results, in Table 1 some characteristic parameters of the RFQ-U28 are given.

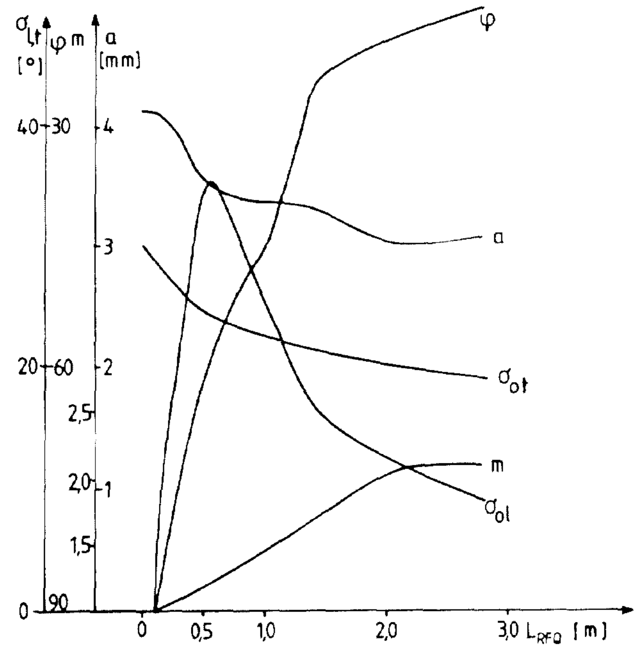

Fig. 5 Beam dynamics design for RFQ-U28

The beam dynamics design was also aiming for a structure as short as possible. This is very important for the mechanical design but mainly for rf power consumption and rf-stability reasons [24].

As an example for the rf optimisation fig. 7 shows the shuntimpedance R_p , the ratio of power loss in the electrodes to total rf- losses N_{el}/N and the length of the radial stems L_S as function of the number N_S of radial electrode support stems . A value of R_P = 180 kΩm seems to be achievable corresponding to a peak power consumption of 100 kW for the design electrode voltage of U_Q= 80 kV.

Choice of higher ion currents of e.g. U^{25+} ions requires a voltage of U_Q= 90 kV and a rf power consumption of N= 130 kW peak power. The transmitter presently available for driving the RFQ may restrict the duty cycle for this case to less than 50%. The power loss on the electrodes would be 20% of the total power which is a safe value for the design chosen.

The mechanical design has been changed to improve cooling e.g. direct cooling of the rod electrodes. The tank itself will be of a coffin like design to facilitate alignment, installation, and maintenance. Fig. 8 shows a scheme of the tank for RFQ-U28. Like the CRYRING RFQ it will be metal sealed to allow good vaccuum and even moderate baking. Figure 9 shows a view of the CRYRING- RFQ which can be considered as a 1:1 model for the RFQ- U28 for GSI.

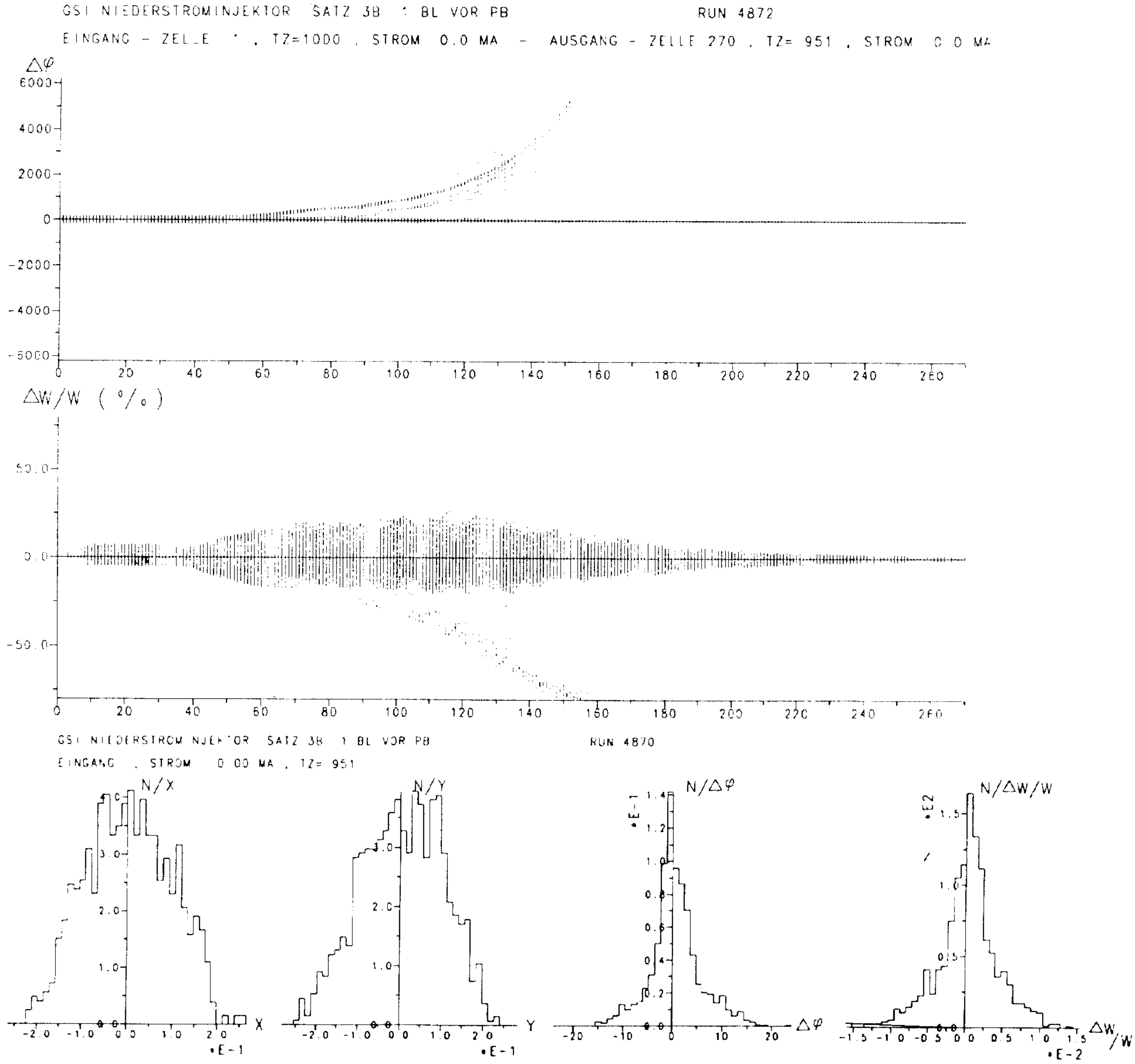

Fig. 6 Results of PARMTEQ simulations

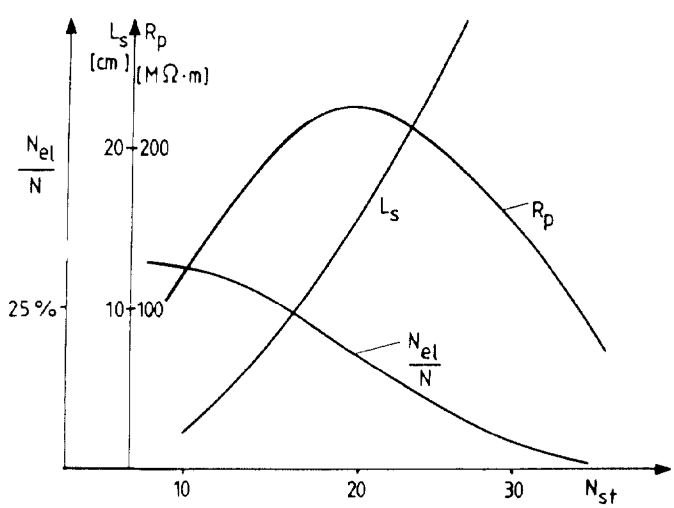

Fig. 7 Impedance R_p, fraction of elctrode losses and stem length L_s as function of the number of supporting stems N_{st}.

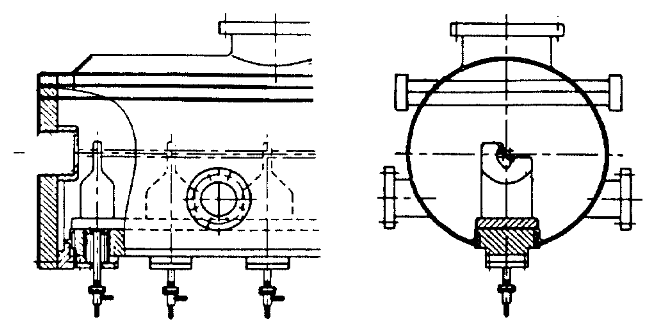

Fig. 8 Mechanical layout of RFQ U28

Status

The beam dynamic design, the mechanical design and model measurements are almost completed. The RFQ U28 tank is out for offers and details of the cooling and the tuning devices are being designed. The RFQ like the rest of the U28 injector will be manufactured and assembled in summer and fall 1989 so that first beam tests can be done at the end of this year.

Acknowledgements

The RFQ-U2 and RFQ-U28 are part of a collaboration of which the RFQs are only a small part. I thank my collegues for support and help. I am especially grateful to N. Angert, J. Klabunde, H. Deitinghoff, T. Weis and J. Friedrich.

Injection energy	2.5 keV/u
Final energy	300 keV/u
Charge to mass ratio	28/238 - 1
Frequency	108.5 MHz
Duty cycle	25% - 50%
Repetition rate	50Hz - 100 Hz
Electrode voltage	80 kV
Aperture	3.0 mm
Modulation	1 - 2.1
Length	2.9 m
Rf-power (for U^{28+})	100 kW
Tank diameter	35 cm
Radial acceptance (norm.)	0.8 πmm mrad
Input emittance (norm.)	0.5 πmm mrad
Output emittance (norm.)	0.6 πmm mrad
Longitudinal emittance (95%)	0.25 πMeVnsec

Table 1 Parameters for RFQ U28

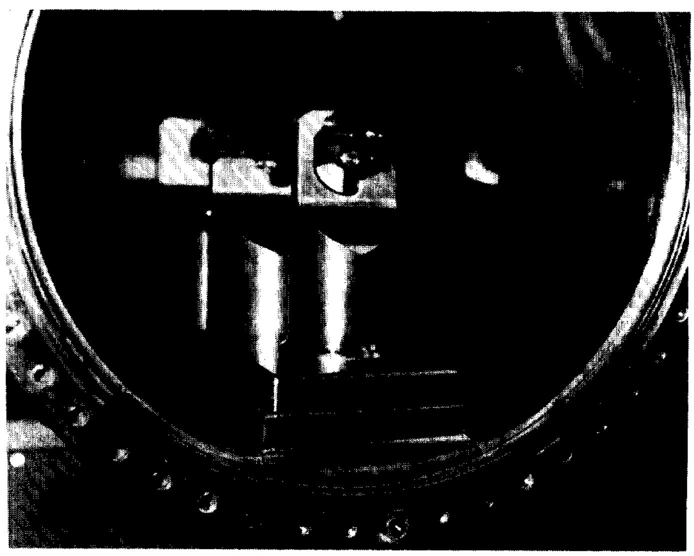

Fig. 9 View of a heavy ion 4Rod RFQ

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