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AGOR Status Report

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The Netherlands

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AGOR Status Overview

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- Introduction
- Operation
- Reliability issues
- Plans for the future

AGOR Introduction

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- Superconducting AGOR cyclotron is a multi-particle, variable energy AVF-cyclotron
- French-Dutch collaboration built 1987 – 1994
- Operational since 1996
- Magnetic field (1.7 to 4 T) produced by two superconducting main coils, fifteen trim coils and three fully saturated iron pole sectors
- Three external ion sources (two ECR sources for heavy ions, multi-cusp source for protons) are axially injected

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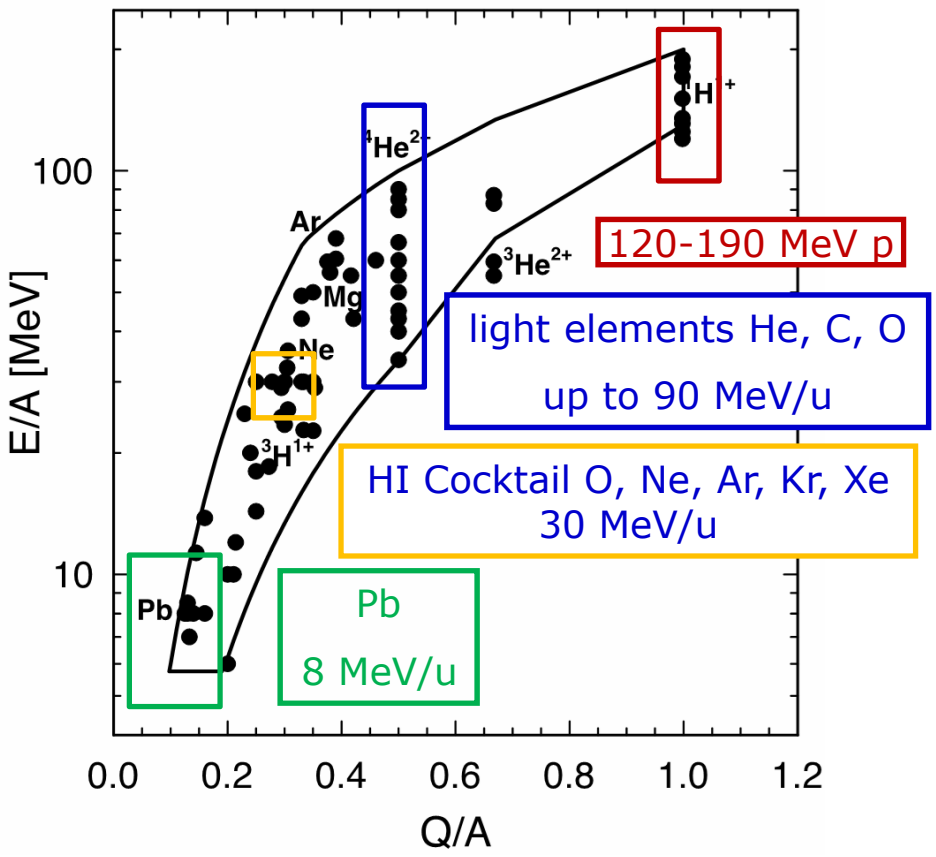
- AGOR can deliver beams of all elements
- From 1996 – 2013 beams mainly used for research in nuclear physics (light ions) and on fundamental symmetries (heavy ions)
- Since 2014 the emphasis has shifted towards biomedical research, detector development and radiation hardness testing



AGOR Operation

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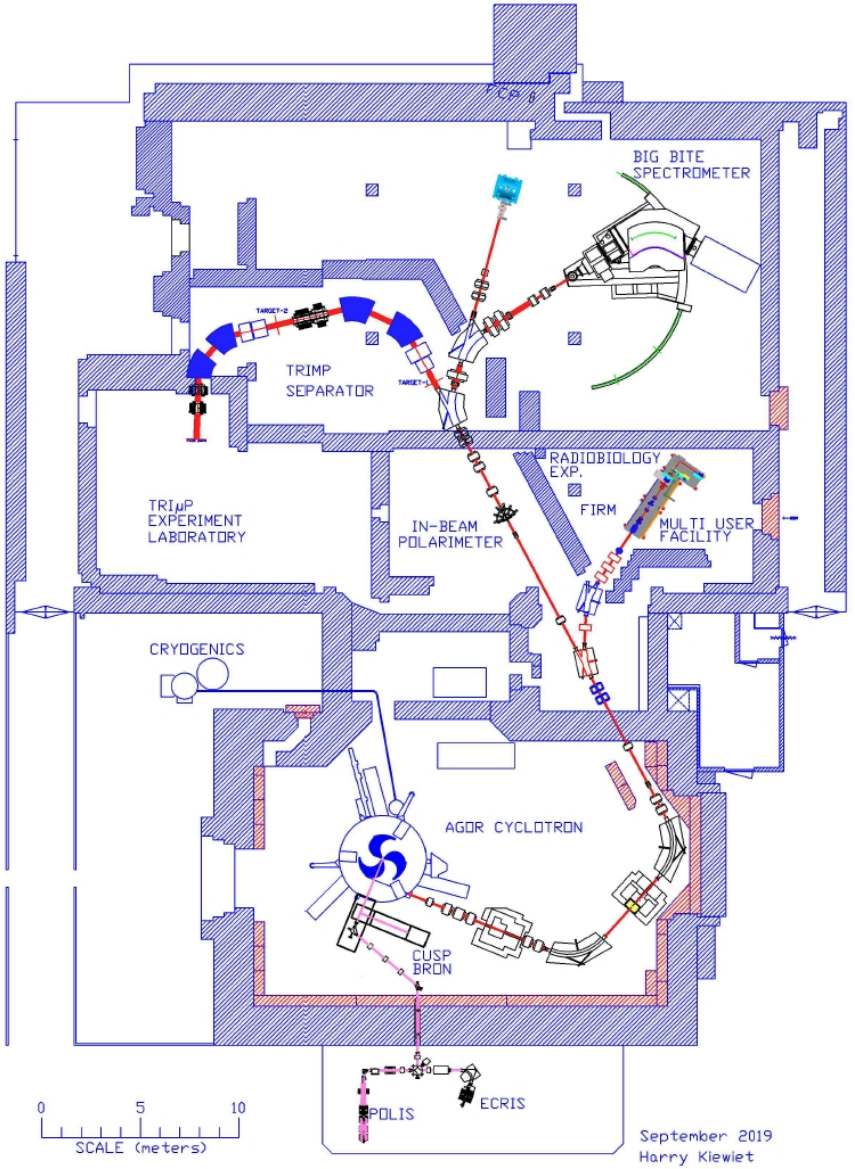
- Operational 120 hours/week, 26 weeks/year to meet current demand
- With shift from fundamental physics to radiation biology and physics and technology of particle therapy the number of individual experiments increased while their duration has decreased
- Over the past few years proton beams provided for over 80% of beam time



AGOR Reliability Issues

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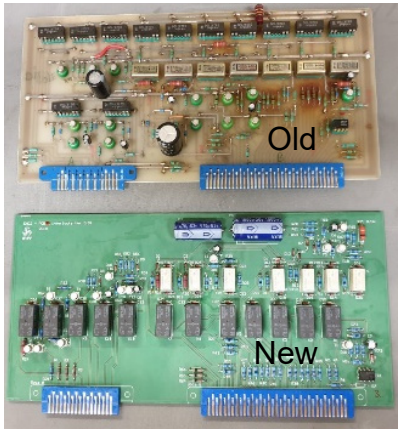
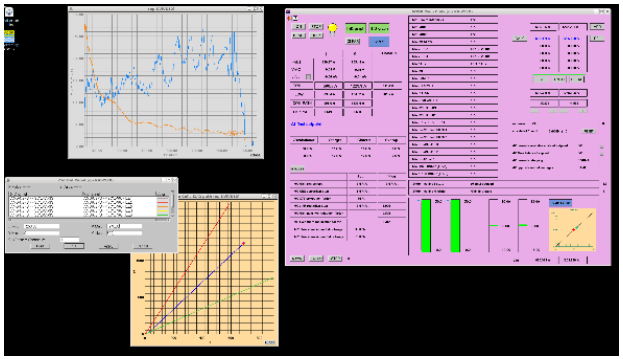
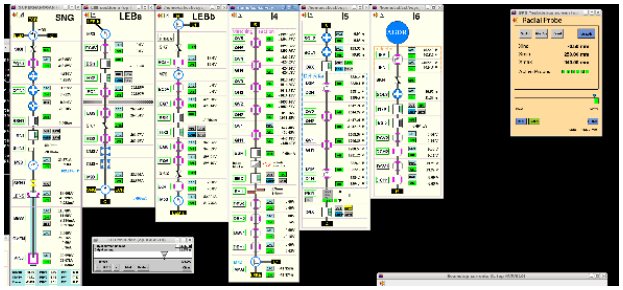
- After nearly 25 years of operation reliability issues have been encountered in certain sub-systems
- Mainly from a lack of availability of spare parts and components or wear and tear
- Have started a program (across several years) to gradually replace all PLC's (vacuum, cryogenics, cooling) and phase out BITBUS (power supplies, beam diagnostics)
- The low-level electronics (amplitude, phase and tuning regulation) and the position control of the RF-cavities require overhaul to replace obsolete components







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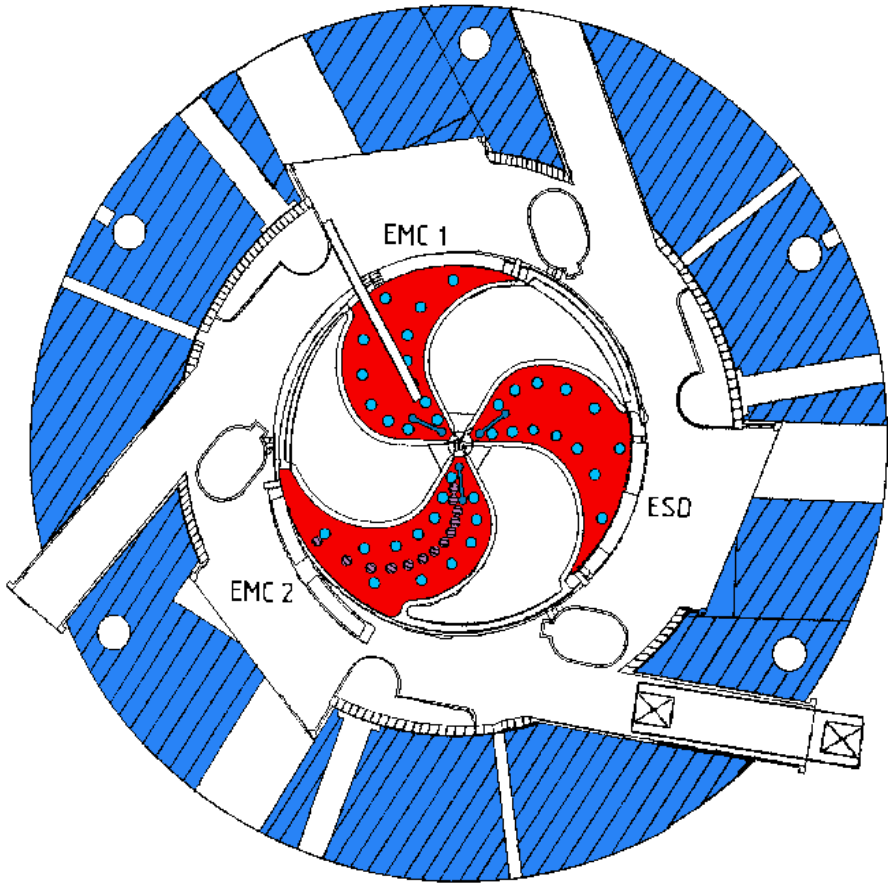
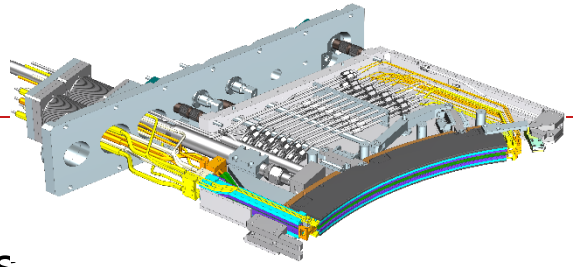
- The extraction system of the AGOR cyclotron consists of the electrostatic deflector (ESD), a room temperature electromagnetic channel (EMC1) and two superconducting electromagnetic channels (EMC2 and QPOLE)
- ESD operates at moderate voltage (V≤50 kV) and field strength (E ≤ 10 MV/m) – very reliable
- EMC1 has been found to be less reliable



AGOR Reliability Issues



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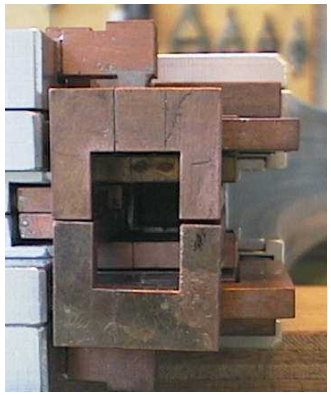
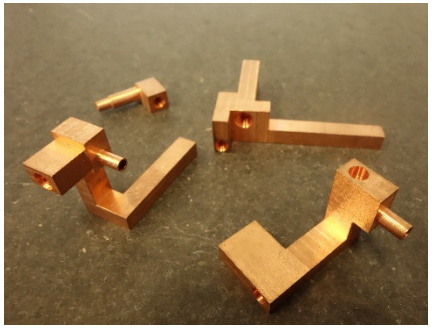
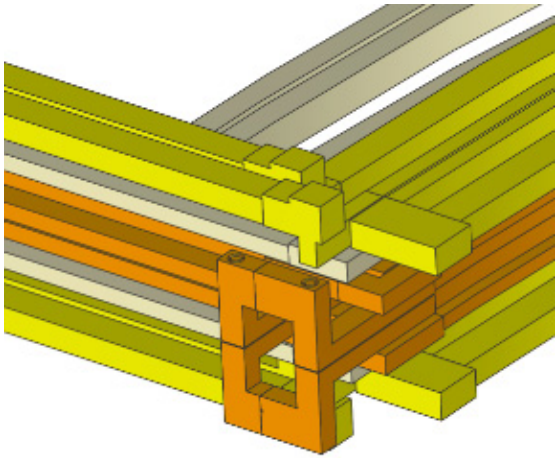
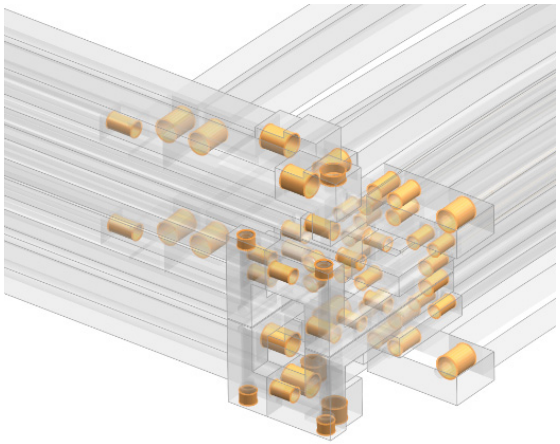
- EMC1 operates at high current densities (up to 140 A/mm^2) and small winding dimensions (3x4mm^2) with a cooling channel
- Total power dissipation in the channel is 80 kW in less than 2 kg of Cu
- Results in high flow velocities for cooling
- Erosion of the copper at the location of the sharp bends!









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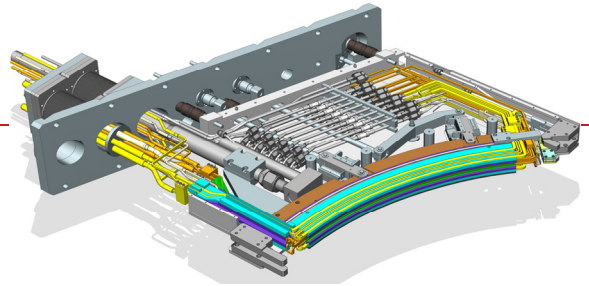

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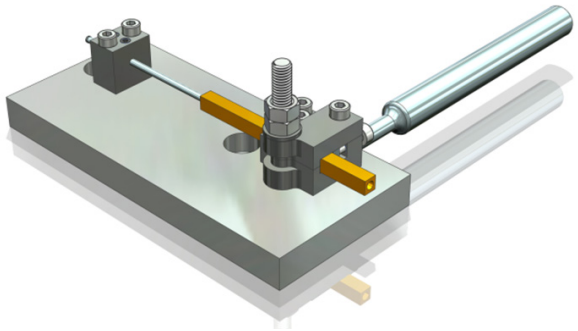
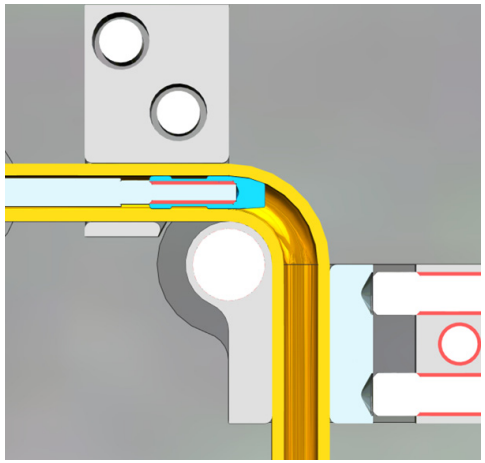
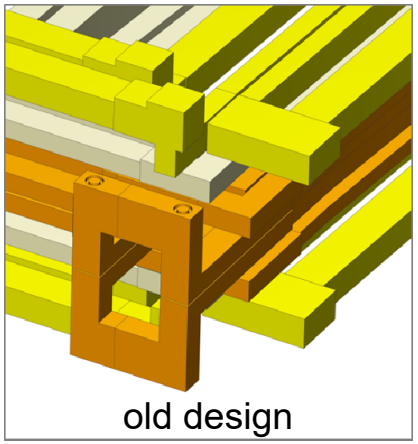
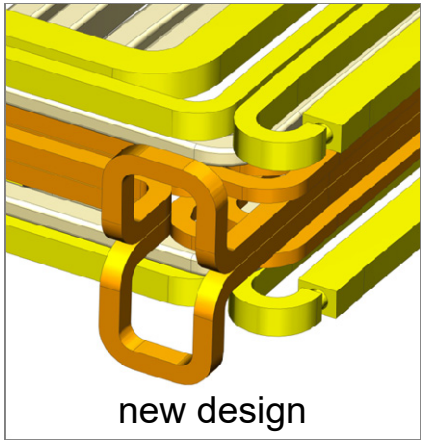
- To avoid this the channel has been completely redesigned in-house using a bending technique



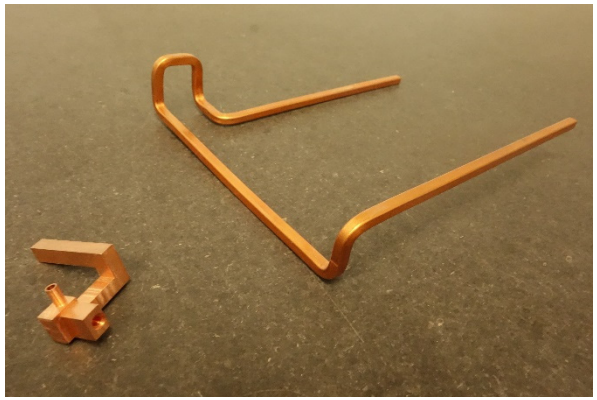


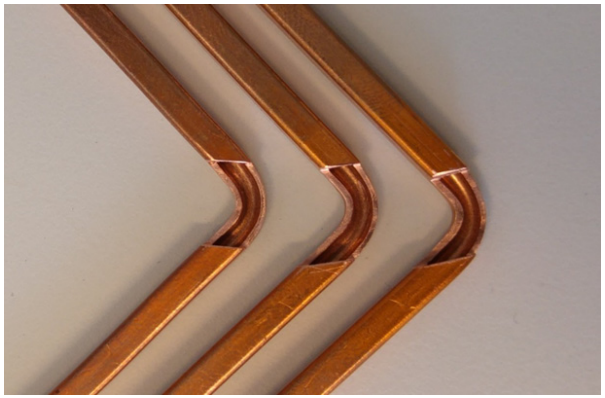


old design



new design





AGOR Reliability Issues

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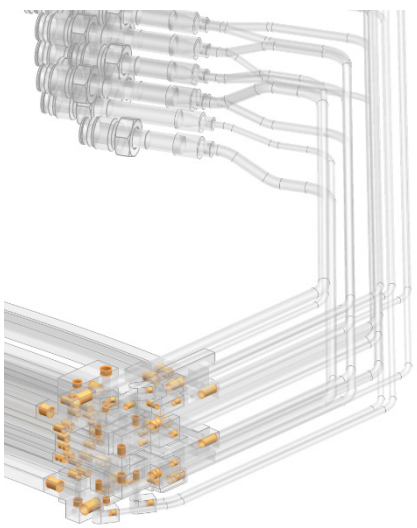
- An additional benefit of the new EMC1 design is a reduction of the number of brazings by a factor of four
- The new EMC1 is under construction in our workshop and will be commissioned in 2020



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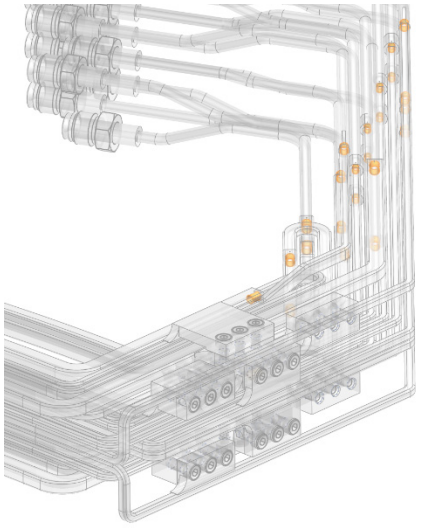
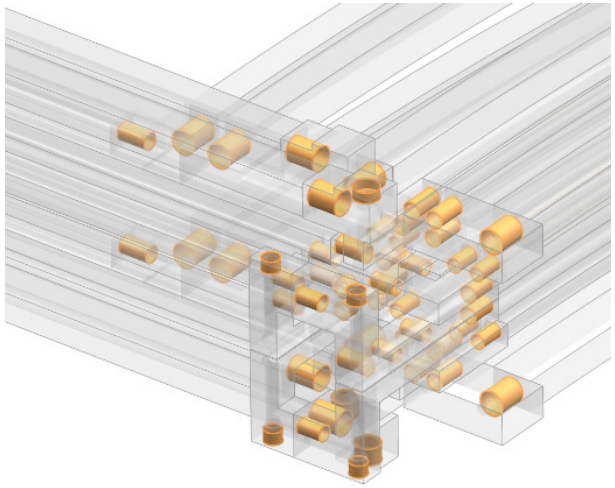


new design



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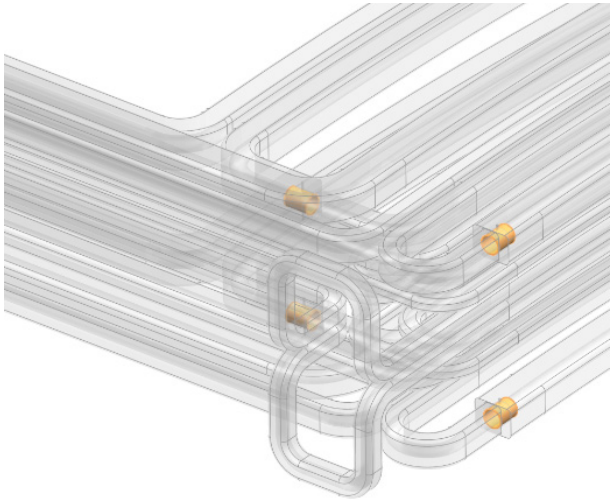

new design

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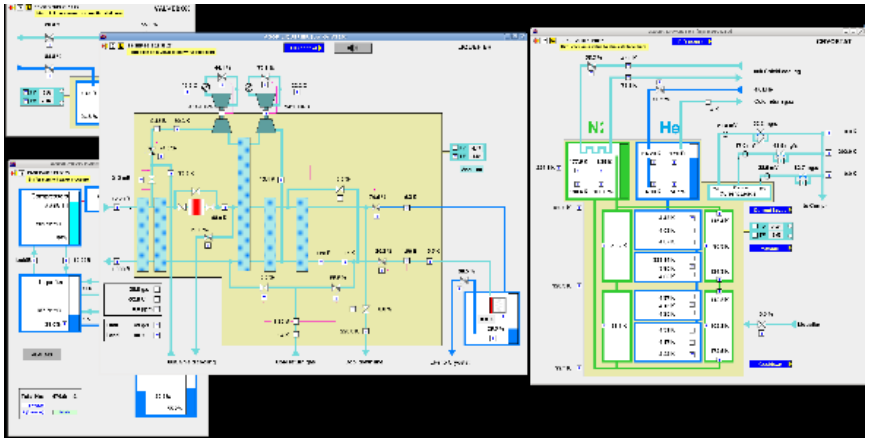
- Main coils and the two superconducting extraction channels are cooled by a Linde TCF-50 cryoplant
- Reliable system overall but over the past year we experienced a transient instability during filling of any of the three cryostats (lasted days or weeks)
- No sign of excessive heat loss in transfer lines or cryostats
- After most recent maintenance cycle, during which all transfer lines were warmed up and evacuated, the problem has seemed to have disappeared



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- At the end of 2018, we installed a new Kaeser helium compressor and upgraded the cryogenic control system
- Operates at variable frequency
- Resulted in an energy savings of 15% for the accelerator facility as a whole
- Payback for investment in about six years
- Heat recovery system provides about 75% of heat needed for building

AGOR's plans for the future

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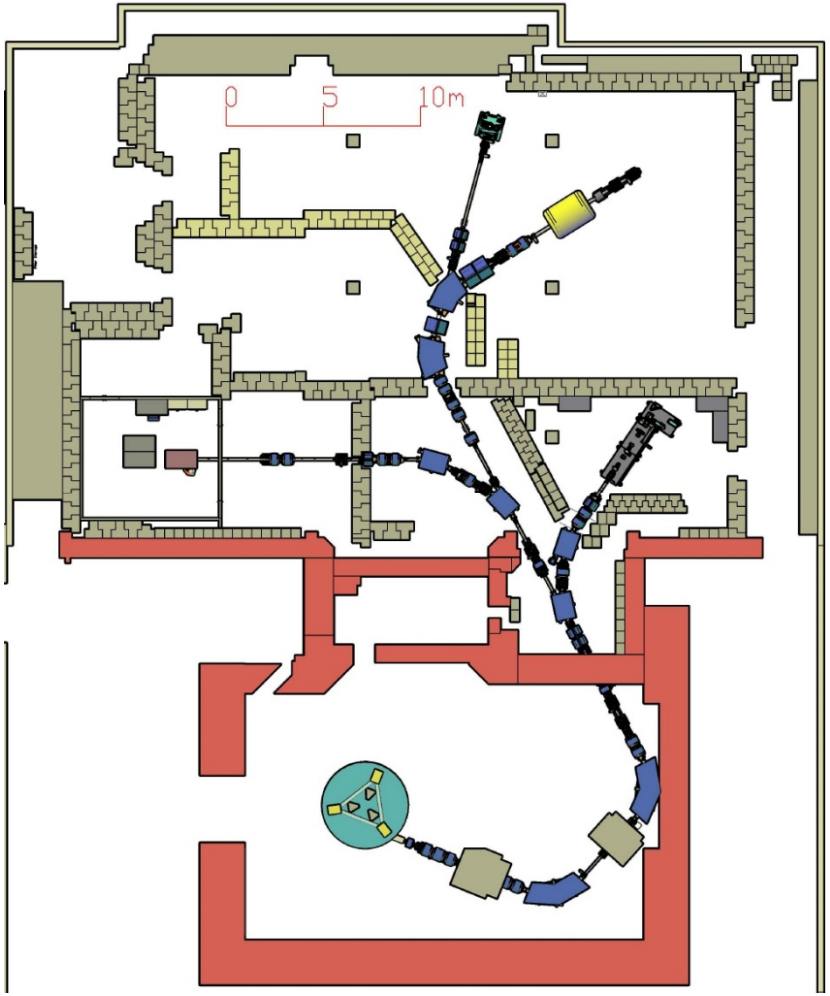
- In 2018 funding has been obtained for further expansion of the biomedical research as well as for a project investigating the properties of neutron-rich heavy nuclei
- Two new experimental platforms will be installed at existing beam lines
- The BBS magnetic spectrometer used for nuclear structure research and the TRIμP fragment separator are being decommissioned



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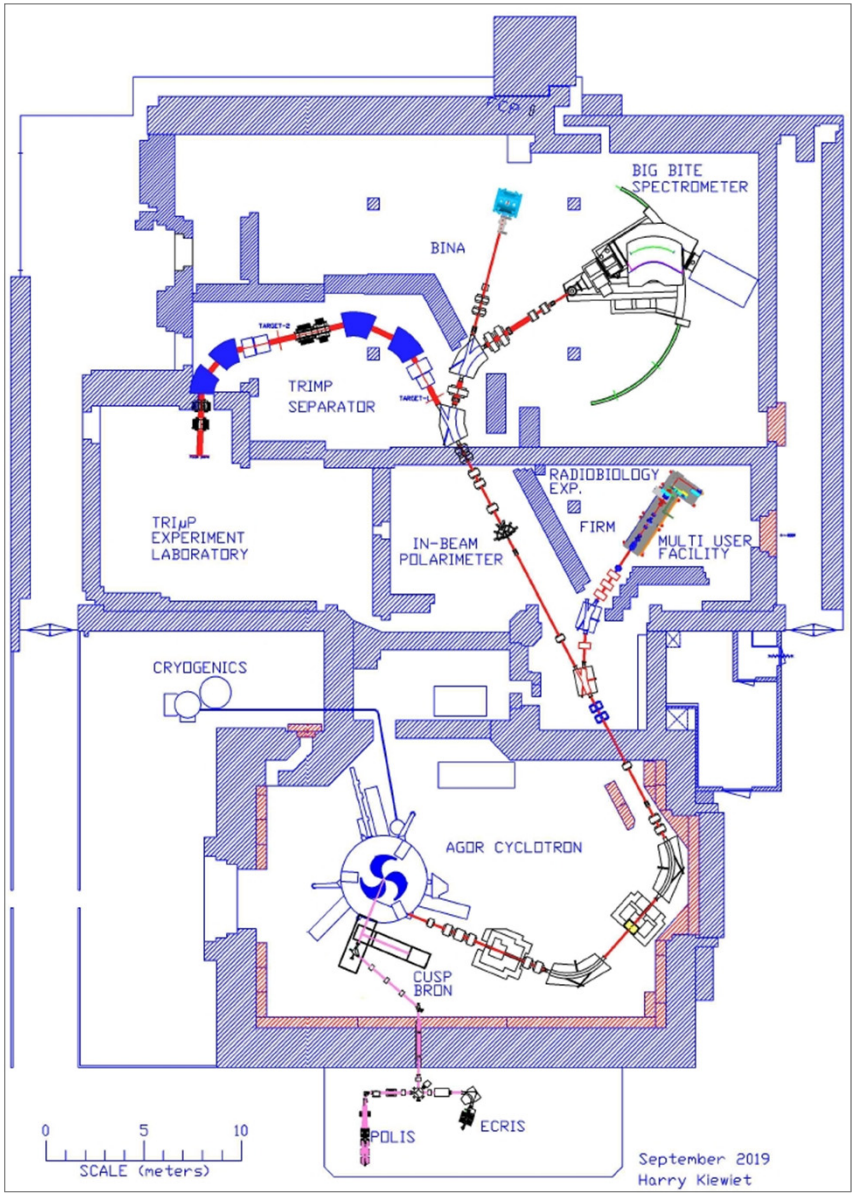

AGOR Biomedical Research

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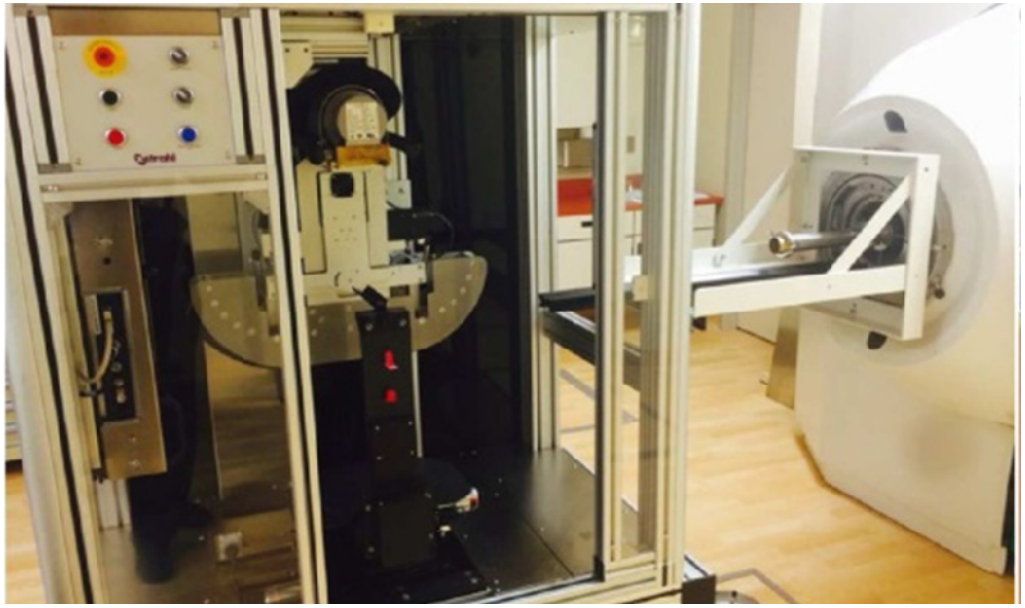
- A new beam line with 3D X-ray and bioluminescence imagining at the irradiation position (individually optimized small animal irradiations) will be built in the coming years
- Several new dose delivery modalities will be available, including pencil beam scanning, spatial fractionation and very high dose rate (>1000 Gy/s)
- Operated as an open access facility



DUTCH CANCER SOCIETY

AGOR Heavy Element Research

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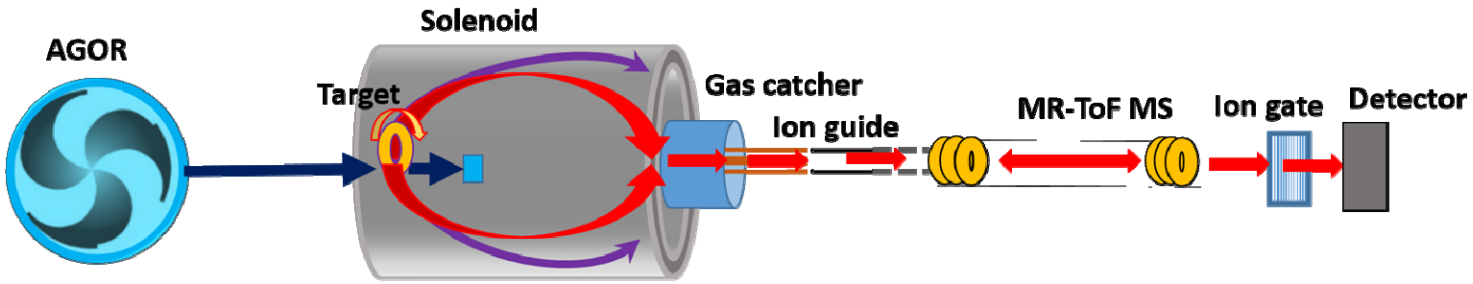
- New experimental research on the production of neutron-rich heavy nuclei using multi-nucleon transfer reactions between heavy nuclei (e.g. ^{136}Xe on ^{208}Pb) has recently been started
- AGOR will provide the heavy ion beams in the mass range A= 140 to 160 with energies around 10 MeV/A for the experiments
- This requires substantial development work to produce rare earth beams
- A new experimental station consisting of a 3 T superconducting solenoid fragment separator and MR-ToF mass spectrometer will be installed



erc Starting grant 2018

AGOR's plans for the future

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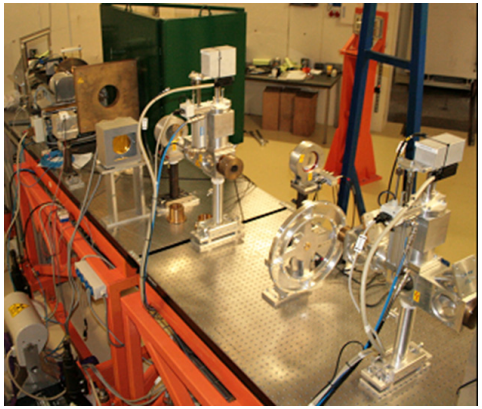
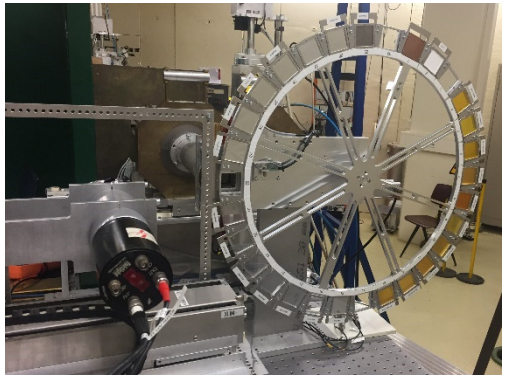
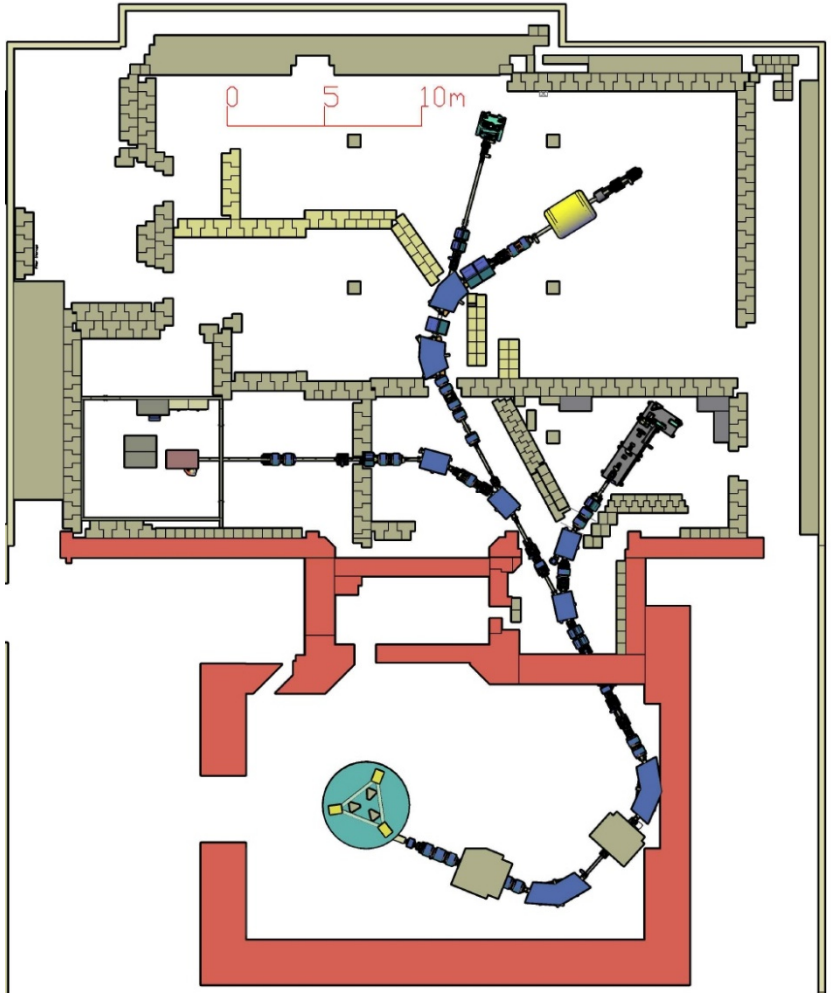
- The radiation hardness testing is expanding
- Proton and heavy ion beams (cocktail up to ^{129}Xe at 30 MeV/amu)
- A cocktail with ions up to ^{209}Bi at 15 MeV/amu (in vacuum) is under development







ACKNOWLEDGEMENTS

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- Thank you to the KVI-CART technical staff!
- The operation of the AGOR facility is supported by the European Union Horizon 2020 programme (contract nr. 654002 & 730983) and the CORA IBER program of the European Space Agency
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