Status of the MINERVA cryomodules and associated cryogenic system (MYRRHA Phase 1)

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MYRRHA (fully implemented)

MYRRHA, a Multipurpose hYbrid Research Reactor for High-tech Applications

- MYRRHA is an Accelerator Driven System (ADS)
  - A full ADS demo facility at pre-industrial scale, where a "subcritical" reactor core is coupled to a proton accelerator.
  - The particle beam is needed to sustain the nuclear reaction.

Why MYRRHA?

- Nuclear waste treatment
  - Allow for Partitioning & Transmutation of nuclear waste in order to reduce its radio-toxicity.
  - Reduction of 100x in volume and 1000x in duration.
MINERVA, the 1st phase of MYRRHA

MYRRHA (fully implemented)

MYRRHA Reactor

Accelerator (600 MeV)

MINERVA (MYRRHA Phase 1)

Application Centers

Accelerator (100 MeV)
MINERVA, reliability is a core requirement

• **Beam trips**...
  • ... cause severe thermal stress on the reactor materials/components limiting its lifetime.
  • ... lead to a time-consuming restart of the reactor limiting its availability.

• Reliability requirement
  • Beam trips shall be resolved within 3 seconds to be transparent to the reactor
  • Max 10 beam trips > 3s within 90 day operational run (MTBF > 250 h)
### Specifications of the SRF LINAC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam-energy range (low-beta)</td>
<td>$E_{\text{beam}}$</td>
<td>16.6 MeV to 100 MeV</td>
</tr>
<tr>
<td>SRF cavities (single spoke, niobium)</td>
<td></td>
<td>60 units (2 per cryomodule)</td>
</tr>
<tr>
<td>Duty factor, and frequency</td>
<td></td>
<td>CW; 352.2 MHz</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>$T_{\text{cav}}$</td>
<td>2 K</td>
</tr>
<tr>
<td>Acceleration gradient (max. nominal</td>
<td>peak)</td>
<td>$E_{\text{acc}}$</td>
</tr>
<tr>
<td>Cavity unloaded quality factor (2 K)</td>
<td>$Q_0$</td>
<td>&gt; 5.2 x10^9 at 9.1 MV/m</td>
</tr>
<tr>
<td>Dissipated power in cavity walls (2 K)</td>
<td>$P_{\text{cav}}$</td>
<td>4.25 W at $E_{\text{acc}}$ = 7 MV/m</td>
</tr>
</tbody>
</table>

All QCELLs are identical, and are the only cryogenic “users”
Building layout

Storage & Warm Compressor Station

Cold-Box

CCB Building

RF Gallery

SRF LINAC

Injector

Application Centers
## Cooling circuits and heat loads

Simplified cooling circuits of one QCELL as seen by the cryogenic distribution

![Diagram of cooling circuits](image)

### Required cooling capacity (static | dynamic | total), excluding contingency margins.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>2 K Circuit [W]</th>
<th>TS Circuit [W]</th>
<th>Coupler Circuit [g/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single QCELL</td>
<td>13.9</td>
<td>9.1</td>
<td>23.0</td>
</tr>
<tr>
<td>- QM only</td>
<td>9.3</td>
<td>9.1</td>
<td>18.4</td>
</tr>
</tbody>
</table>

**Margins for cryoplant sizing**

- No margin
- Full margin +50%
- Limited margin +20%

### Required cooling capacity

- **SRF linac**
  - Min turndown $^b$ | 334 | - | 334 | 4423 | - | 4423 | 0.96 | - | 0.96 |
  - Nominal operation | 418 | 187 | 605 | 5529 | - | 5529 | 1.20 | 0.36 | 1.56 |
  - Max. operation   | 418 | 242 | 660 | 5529 | - | 5529 | 1.20 | 0.16 | 1.49 |

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*4.25 W of RF losses per cavity at 7 MV/m.  
$^b$ hypothetical staged installation of 24 QCELLs.*
The preliminary design of the MINERVA Cryoplant has been developed.

- Input from two industrial pre-studies were used to consolidate the study.
- Updated heat load values have been implemented in the ongoing conceptual design.

~ 3.5 kW @ 4.5 K, of which
~ 900 W @ 2 K (70% of total heat loads)
~ 700 kg of Helium inventory

For more details, see presentation C1Or3B-04: Michel et al. „Preliminary studies of the MINERVA cryogenic supply system“
Prototype assembly and testing

Prototype cryomodule for MINERVA

Cryomodule fully assembled in 2022
- Valuable return of experience (assembly sequence, etc...)

Test campaign at IJCLab

Test campaign 2023
- Without RF: Done. Data under analysis
- With RF: Ongoing
Design consolidation towards series production

- Design consolidation is ongoing for the remaining cryomodule components
  - RF power coupler
  - Cold tuning system
  - Cryostat
- The mechanical design of the valve box is ongoing

Example of current activities
- Implementation of latest return of experience
- Cross-checking design and performance requirements
- Update of 3D models and integration check
- Preparation of tender documentation

- All components will be tendered based on detailed 3D models. The manufacturing drawings are to be prepared by the supplier.
Ongoing series production

**Spoke cavities**

- SC spoke cavities adjudicated to Research Instruments (GER)
- **First pre-series cavity completed!**
  - 2nd and 3rd cavities are ongoing
- Post-processing steps achieved successfully
  - BCP (rotary plant)
  - High-pressure rinsing
  - High-temperature heat treatment

**Magnetic shield**

- Magnetic shields adjudicated to MECA Magnetic (FR)
- Series production started (kick-off Jan-2023)
Conclusion

MINERVA Cryogenic System
We have revised and updated the overall cryogenic system
✓ Cryogenic architecture has been defined
✓ System layout is now mature
✓ Building arrangement is consolidated
✓ Cooling requirements (SRF linac) are provided

Ongoing prototyping tests campaigns
• Plenty of insights on assemblability, operability, and opportunity for design iterations
• Return of experience already feeding the design consolidation of the series cryomodule

Design changes
• Various changes implemented, with a few still underway.
• Goal is to optimize heat loads, performance, and serialization efforts. Focus is on reliability!
• Continuously balancing between performance, cost, and schedule

Cryoplant requirements
• Total heat loads ~ 3.5 kW @ 4.5 K, of which ~ 900 W @ 2 K (70% of total heat loads)
• Helium inventory ~ 700 kg of Helium

Main cryo activities in the short term
• Finalize prototype tests for cryogenics and RF systems
• Design consolidation in view of call for tender for the remaining components
• Continue series production of cavities and magnetic shields
• Tender out for Cryoplant + Distribution
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