

## SIS100 TUNNEL DESIGN AND STATUS

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### Abstract

As the FAIR project is proceeding, many of the building and tunnel designs in the meanwhile are frozen and documents are prepared for tendering. For the future FAIR driver accelerator, SIS100, the accelerator tunnel "T110" comprises a 1100 m long tunnel, which has a depth of 17 m under ground. In this paper, its environmental boundary conditions, design principles and the finally chosen layout are presented.

### INTRODUCTION

Large progress has been achieved in the civil construction of the FAIR project which now leads to an early construction of the northern building site of FAIR - which includes the SIS100 tunnel, too.

### ACCELERATOR

The originally proposed FAIR project comprised two main accelerators, SIS100 and SIS300 [1]. As it has been decided to build a modularized start version with the SIS100 first, only the space, but no infrastructure has been reserved for the future installation of SIS300 [2].

The SIS100 is a 1083.6 m long, superconducting heavy ion accelerator [3]. It's length was chosen to match 5 times the SIS18 booster length, which is 216.72 m. To achieve the demands for average beam intensity of the FAIR experiments, it is a fast ramped synchrotron ( $\dot{B} = 4$  T/s). Therefore, sufficient space for the necessary insertions (RF, injection, extraction and transfer SIS100/SIS300) had to be provided, which is fulfilled by a 6-fold symmetry with 51.6 m long straight sections, see Fig. 1. The SIS100 reference orbit height is 1.4 m above floor. The SIS300 later on will be placed at a reference orbit height of 2.8 m above floor on top of SIS100. Both machines, their necessary infrastructure and transport space require an accelerator tunnel cross section of (W×H) 6.5 m×4.5 m.

Both liquid helium and electric current supply for the cold arcs are bridged throughout the straight sections with an unique, integrated cryogenic bypass system.

The SIS100 accelerates all ions from 28.8 GeV Protons to 2.7 GeV/u Uranium, but is optimized for high intensity heavy ion beams with a specific beam loss pattern - which impose constraints on the radiation protection.



Figure 1: Overview of the lowest underground level of T110.

### TUNNEL DESIGN

#### Environmental Boundary Conditions

The land development plan of the GSI/FAIR site in Darmstadt, approved by the authorities, can be seen in Fig. 2. It regulates, among type and degree of building and land use:

- Building positions,
- building height,
- forest clearance and
- ecological balancing.

Hence, in the area north of the *Prinzenschneise*, only underground buildings are allowed with a minimum distance to the surface of 6 m and a maximum footprint of 10 000 m<sup>2</sup>. This fact hinders the economic placement of above ground supply buildings in the forest.

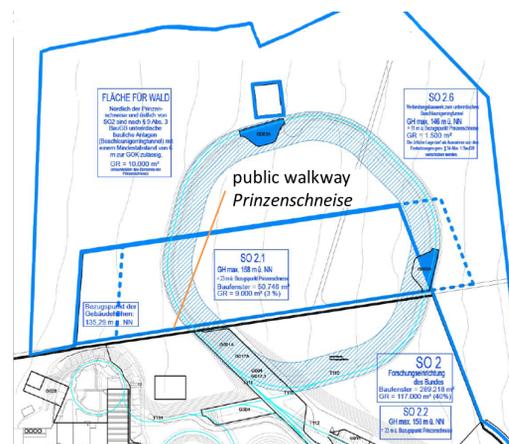


Figure 2: Land development plan of the northern FAIR site.

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### Maintenance and Availability Aspects

The experience gained with the GSI SIS18 and other accelerators shows that electronics is prone to radiation damage at dose rates which can be expected for the SIS100 supply areas without proper shielding. Furthermore, activation of components and air in the T110 supply area could be expected, too.

Assuming 6000 h operation per year, an availability of 65% (3916 h/y) is currently estimated for SIS100 [4]. If the access to supply area access during operation would be restricted due to radiation issues, the availability would drop to  $\approx 50\%$  or below (MTTF reduces, MTTR rises).

To fit all SIS100 and future SIS300 accelerator supply components like power converters, beam diagnostics, vacuum, RF, injection/extraction, controls, cryogenics, quench detection and protection devices, a total supply area floor space of 12 670 m<sup>2</sup> has been planned. This area is subdivided into:

- 15% HVAC infrastructure components,
- 45% SIS100 supply components,
- 30% SIS300 supply components and
- 10% personnel and material access labyrinths.

### Radiation Protection

Particle acceleration, beam extraction and experiments lead to planned and unplanned beam losses causing ionizing radiation, which has to be shielded.

According to the definition of radiation protection areas and radiation protection laws in Germany, only extremely low dose rate limits in public areas are allowed:

- 0.5  $\mu\text{Sv/h}$  on the GSI/FAIR premises and
- 45 nSv/h for the general population north of the *Prinzenschneise*.

Sufficient shielding and other measures have to be foreseen to fulfill the legal boundary conditions, namely

1. Direct radiation shielding for workers on site of the facility and the public areas and
2. control of the emission of radionuclides by air and water, especially for the general population.

Due to the flexible SIS100 operation, the shielding has to cope with beam losses of either  $1 \times 10^{10}$  2.7 GeV/u U<sup>28+</sup> ions/s or  $1 \times 10^{11}$  28.8 GeV protons/s. Fortunately, both impose similar constraints to the necessary shielding around the accelerator, see Figs. 3/4.

Besides the necessary accelerator tunnel shielding with 2 m, water-tight sealed concrete on all sides, additional shielding is required at the SIS100 extraction section and on top of the HEBT extraction line towards ground level, because above is public area. The height of soil required on top of SIS100 tunnel defines the vertical depth of the SIS100

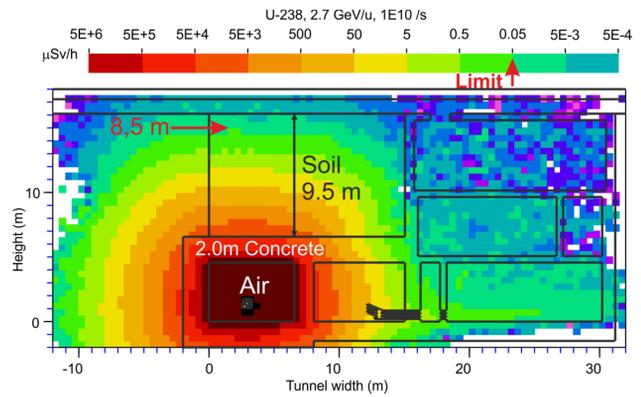


Figure 3: FLUKA calculation of  $1 \times 10^{10}$  2.7 GeV/u U<sup>28+</sup> ions/s beam loss.

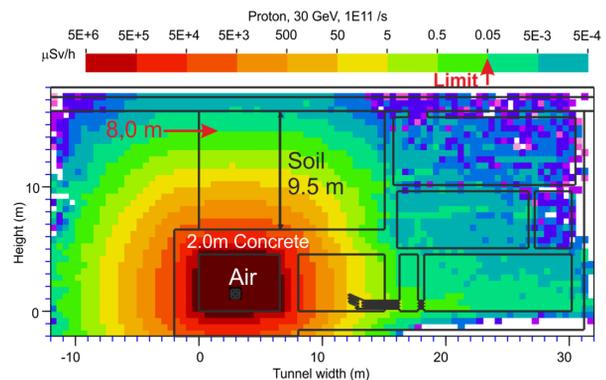


Figure 4: FLUKA calculation of  $1 \times 10^{11}$  28.8 GeV protons/s beam loss.

itself. Since the beam losses of the future SIS300 in parallel operation are a factor of 100 lower than SIS100 beam losses, no additional shielding is required.

To hinder air, activated in the accelerator tunnel, from reaching public areas, a low pressure air system in the tunnels has been foreseen. To decay shortlived nuclei, this air will travel at least 2 h through dedicated air ducts to the central chimney.

Furthermore, to provide a high availability of SIS100, a low dose rate in the supply areas has to be guaranteed to prevent electronics damage and logic errors and to assure and enable personnel access during beam operation.

### Structural Topics

Due to the small bending radius of SIS100 (50 m), it is not possible to use a tunnel boring machine (TBM). Additionally, the length of the tunnel is on the lower limit for economic use of such a machine. Further, additional supply and access buildings will be stacked on top of the tunnel - up to 5 levels high. A very high groundwater level (up to 1 m below ground) poses an additional boundary.

Before digging the open excavation pit for the tunnel, the ground water has to be lowered by use of pumps and an appropriate concrete barrier/wall. This wall is stabilized by earth anchors. After construction of the tunnel, the pit will

be filled up with earth. Finally, to allow groundwater flow to the forest's trees, the upper part of the barrier/wall will be removed.

## GENERAL TUNNEL LAYOUT

Given the above mentioned constraints, the SIS100 tunnel *T110* was chosen to be separated into an outer ring tunnel housing the accelerator itself, an inner ring tunnel for the supply installations and a 7 m wide soil shielding package in between, see Fig. 5. This is embedded into a rectangular shaped, massive concrete structure with a 4-beam layout.

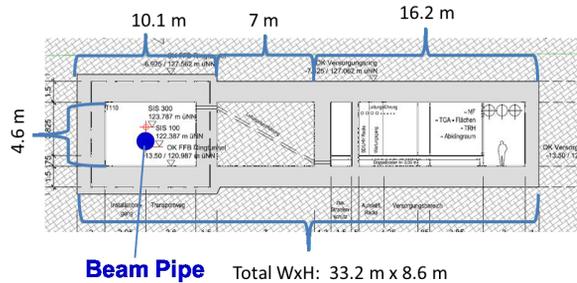


Figure 5: Typical *T110* tunnel cross section.

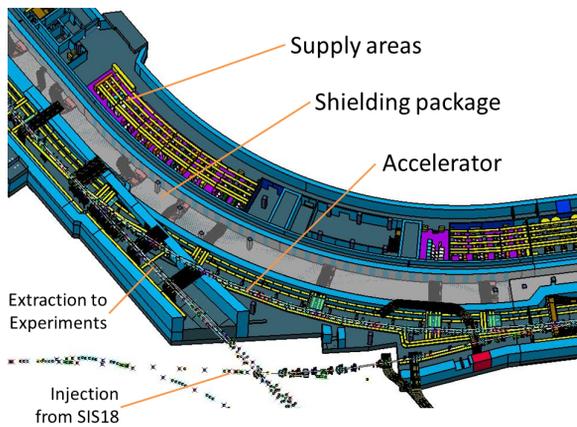


Figure 6: Detailed view of *T110* layout.

For radiation protection reasons, cables between the accelerator and the supply area are routed diagonally in ductwork which will be air-tightened at one end. The whole tunnel is separated into 6 segments with fireproof walls (see Fig. 6).

## TUNNEL WORKSHOP

To validate the design for the SIS100 tunnel, a workshop took place in 09/2015, where an international expert's review panel scrutinized all aspects of it. Its goals were to:

- seek an independent expert view on the present design of the tunnel *T110*,
- seek advice, whether the present design of tunnel *T110* is an adequate solution for the realization of SIS100 and
- discuss and identify optimizing / cost saving potentials in the area of construction works.

The conclusions of the review panel were:

Given the demanding constraints (accelerator requirements, radiation protection issues, environmental obligations), the present design is a feasible solution and can be implemented.

Potential cost savings for redesign of the tunnel as presented by the planning team as well as by the review committee indicating no significant cost savings, at this stage, do not appear to be justified considering the potential lengthy planning delays and the exclusion of future options at a later point in time.

## CURRENT STATUS

In the last year, major steps aiming for an earliest possible start of civil construction of the SIS100 tunnel and related parts have been taken. This has been done with a priority to the northern buildings of the FAIR construction site:

- SIS100 tunnel *T110*,
- HEBT tunnel from SIS18 to SIS100 *T101*,
- HEBT crossing and supply building *G004/4a*,
- HEBT tunnel from SIS100 to the CBM experiment *T112* and
- FAIR main supply building *G17.1* (main electrical distribution and cooling/heating water supply).

The infrastructure has been thoroughly checked against possible collisions, fully integrated in a 3D-CATIA model of the buildings, accelerator components, cable trays, electrical grounding, air and water cooling and helium distribution systems.

The radiation protection allowance has been received already 09/2013. All necessary tendering documents have been prepared meanwhile. Currently, European tendering processes for the northern site excavation pit took place and contracts are expected to be closed in May 2017. Tendering of the shell building has been started, they should be contracted this year. Therefore, the start of groundbreaking is scheduled for the summer 2017. The following start of concrete shell building construction of the FAIR northern site is scheduled to follow swiftly in 2018. It is planned to finish the building construction end of 2022.

## CONCLUSIONS

Parts of FAIR will be constructed in a public area and in very special environmental conditions (ground water, soil, building height, etc.). The radioprotection requirements from proton and uranium beams are similar. The wall thickness requirements from radioprotection and structural engineering are similar, too. The chosen parallel tunnel design respects the environmental boundary conditions and fulfills the German regulations and laws for radioprotection.

**REFERENCES**

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