Report

from the Committee for

First-Science and Staging Review of the FAIR Project

Submitted to FAIR Council, October 2022

Executive Summary

As a consequence of cost increases for the FAIR project due to several different reasons, the FAIR Council requested a review of the FAIR status to determine how to proceed toward the Intermediate Objective (IO), as defined in 2020. The review committee was then formed in April 2022.

The committee had as a starting point a project that was unable to provide capabilities for FAIR science with the original budget defined by the FAIR Council. In addition, the fact that both the construction of the buildings required for the IO, and the corresponding interior Technical Building Infrastructure (TBI) were already fully contracted, presented strong constraints for the review as a reduction in already-let civil construction scope will not yield significant cost savings due to liquidated damages.

The committee investigated the science case of FAIR in light of international competition, the progress of the construction, the requested budget and suggested options to proceed to a world-class facility given the present circumstances.

Each of the four science pillars has a compelling, often world-leading, science case. There is no other facility now being planned or under construction that can carry out the full program of science planned for FAIR. There will be competition for parts of the program from other facilities in Asia and the US, as has been noted in the discussion of the four pillars, although a delay of a few years will still enable FAIR to begin attacking many of the outstanding questions in nuclear physics. However, with the delays and uncertainties in the FAIR schedule, it is crucial that FAIR management in cooperation with the FAIR Council put forward a realistic plan for starting first science for each of the pillars. Without this, researchers, especially young researchers, will not be able to plan for their future. This could lead to a serious loss of a talented workforce that is being counted on to carry out the FAIR science program.

The committee expresses the opinion that all member states represented on the FAIR Council should own the budget problem that now faces FAIR. Together they should contribute either funds or in-kind contributions to move the project forward.

The committee came unanimously to the following recommendations in order to advance FAIR to science beyond Phase-0:

- First priority should be the completion of the S-FRS into the HEB cave for NUSTAR to carry out the Early Science program.
- Completion of SIS100 needs to have the next highest priority.
- If resources are tightly constrained, completing SIS100 with beams into the S-FRS and HEB cave, plus setting up and commissioning the CBM experiment offers an intermediate solution for developing world-class science at FAIR.
- Completing the infrastructure and instrumenting the APPA cave should have priority over instrumenting the additional area in LEB for NUSTAR.
- Tendering for civil construction of the West lot should be postponed, but a plan is needed for the time frame to implement PANDA.
- The orderly set of steps towards the IO, presented in this document, represents the most cost-effective plan for moving FAIR forward. In order to accomplish this, a yearly budget

needs to be defined for the project, as well as an overall budget cap. The budget should provide funds to complete milestones that are agreed upon by FAIR management and FAIR Council. Costs will need to be managed during the year to achieve those milestones.

- It is imperative that the GSI and FAIR management coordinate resources to optimize the workforce for success as construction, commissioning, and operations are intertwined.

The committee also outlined recommendations specific for the FAIR Council:

- The committee recommends a budget cap of an additional 500 million euro beyond the already approved 2.151 billion euro to complete the phase of the project that includes SIS100, S-FRS into HEB and CBM. This budget cap includes the funds needed to replace the missing Russian (hardware) components.
- Setting up a cost scrutiny group, consisting of external technical experts, is essential now to provide the appropriate advice to the FAIR Management and to the FAIR Council for the oversight needed to achieve their goals. If successful for delivering the phase defined in the previous bullet with the proposed budget cap, this approach should be expanded to achieve the IO in additional steps, and then continue on to the MSV or the next phase for FAIR as defined by the FAIR Council.
- The committee recommends that an external panel be commissioned by FAIR Council to help inform how the interactions between two separate efforts—GSI and FAIR—can be managed, or preferably combined into a single effort for construction, commissioning and operation. This transition must be done in the near future to optimize the overall program.
- The committee recommends that a new external panel be set up to review plans for operations and provide recommendations for how to set up efficient and cost-effective operations planning.

Introduction

Nuclear physics research programs, and the facilities supporting them, have undergone a major transformation in the past few decades. Small accelerator facilities, which were the norm through the 1980's, began to be replaced by larger, more powerful, facilities. By the beginning of the new millennium the transition to large regional facilities was well underway, with user groups carrying out experimental programs replacing small investigator groups. The research emphasis was shifting in nuclear structure from detailed nuclear spectroscopy to the study of nuclei far from stability with the goals of establishing the limits of particle stability and understanding how nuclei evolve when the neutron to proton ratio undergoes significant change. Furthermore, the realization that quantum chromodynamics (QCD) is the underlying theory of the strong interaction opened new research directions for nuclear physics, which led to the need for much higher energy facilities.

With this changing landscape, the Organization for Economic Co-operation and Development commissioned a MEGA Science report on the future directions in nuclear science. The report was published in 2008 and can be found at (https://science.osti.gov/-/media/Isotope-Research-Development-and-Production/pdf/program/docs/oecm_npwg_report_051908.pdf). At that time, key regional facilities were identified and the possible need for even larger international facilities was identified. FAIR was prominent in the report as one of the two major nuclear physics facility for Europe, together with GANIL-SPIRAL2. With its broad capabilities, FAIR would provide European researchers with unique opportunities for programs in nuclear structure, nuclear astrophysics, high density nuclear matter, the extremes of atomic physics, and QCD. It was further recognized as a center for applied research, including nuclear medicine. While this potential has been slow to materialize, FAIR today remains as the center piece of European nuclear physics. This recognition was clear in the most recent Nuclear Physics European Collaboration Committee (NuPECC) long range plan, which was published in 2017.

From its inception, FAIR has been developed as an international facility with partners from Europe and India. It is governed by the FAIR Council, which was set up after the FAIR GmbH was established in October 2010. Germany is the major partner in the Council and is responsible for the civil construction now underway at the facility. The Modularized Start Version (MSV) proposed by the FAIR Council as the initial stage for FAIR science was to be achieved through direct and in-kind contributions by the governments associated with the FAIR Council.

The FAIR project got off to a slow start, which led to a review initiated by BMBF in 2015 to assess its status. One of the main recommendations from this review led to a change in the FAIR leadership team. But the delays in the start of civil construction, which did not commence on site until 2018, had already led to significant cost increases for the project. Four years after the 2015 review, a project review was commissioned by the FAIR Council as it became clear that the cost of civil construction was continuing to escalate. This review set priorities for the project and it pointed out the need to complete the MSV. With growing concerns over the escalating cost, the Council modified its goals in 2020 to build the Intermediate Objective (IO), which did not include several buildings needed for completing the MSV. The budget approved for the IO was 2.1 billion euro in 2020. Recognizing the interconnections needed between GSI and FAIR, today they are jointly managed by the same management team, while they remain legally separated.

By the time that civil construction actually began for FAIR, the construction market had become quite competitive, which drove up costs. Furthermore, about two years into the construction, major world-wide disruptions began occurring. The first of these was the outbreak of the COVID-19 pandemic early in 2020. This was a huge disruption to daily life all around the globe that still continues today. As the world shut down, delays occurred in civil construction, and supply-chain interruptions made it difficult to obtain many materials and supplies needed for construction. An immediate effect was to further increase the cost of civil construction. Unfortunately, many of these issues persist today.

Because Russia, a major FAIR partner invaded Ukraine early in 2022, other FAIR partners severed ties with Russia. In developing the budget in 2020 for the IO, significant parts of the FAIR infrastructure were contracted for construction in Russia, which was also committed to provide funds directly in support of the FAIR project. Now the status of the Russian contributions is uncertain, but they were not assumed to materialize in developing this report. The status of the funding promised by Russia is not clear either. Driven by the issues due to COVID, and then exacerbated by the war, significant world-wide inflation is now occurring. This is also adding to the cost for completing the IO, which today is estimated to be about 30% over the budget set in 2020.

With this developing situation, the FAIR Council requested this review of the FAIR status to determine how to proceed toward the IO. The full document setting up the review is attached as Appendix A to this report. The principal points that the review is asked to address are:

- Are there scientifically sound start configurations (below the scope of the IO) possible, which make optimum use of the investments already made in FAIR and at the same time trigger a minimum of additional costs? Are there possible scenarios which will allow for a) a substantial and b) a modest reduction of the scope below the IO?
- Regarding the situation of the Russian shareholder: Are there alternatives, especially for the components and personnel to be provided by Russia? What are the financial implications of the proposed alternatives?
- Would further staging of the project (i.e. - introducing steps before the IO) still produce a program of world class science (meaning a facility which makes it possible to achieve cutting edge science in comparison to other competing facilities), in proportion to the coherent with the costs investments incurred so far? What are the financial requirements for each module?
    - Which components of the facility are indispensable to reach the goal of world class science?
    - What would be a realistic timeline for realizing this staging until the IO?
    - Is there a point in time when the scientific competiveness of a certain module would expire, especially in comparison with competing facilities?
- Are there alternative scenarios, which should be considered?

    For further decisions on the future of the FAIR project, there is the need for a firm estimation of the additional cost risks for each of the developed scenarios. Recommendations with respect to the organizational structure will also be welcome.

The Review Process

The review committee was formed in April, 2022; a list of the members is attached as Appendix B to the report. The committee had as a starting point a project that was unable to provide capabilities for FAIR science with the original budget defined by the FAIR Council. In addition, the review was strongly constrained by the fact that both the construction of the buildings required for the IO and the corresponding interior Technical Building Infrastructure (TBI) were already fully contracted. A reduction in scope of the already-let civil construction will not yield significant cost savings due to liquidated damages.

The committee has had multiple remote meetings and an in-person meeting at GSI/FAIR on June 23-25, 2022. During the in-person meeting, the committee toured the FAIR construction site, heard presentations from scientists representing the four science pillars, discussed different construction options with FAIR management and heard a brief presentation on the proposed costs associated with commissioning and operations of the IO. Following the in-person meeting, the review committee has iterated with FAIR management on additional options for proceeding with the project.

Early in the review process, the committee leaders met with a representative from ECONUM, a German company tasked by BMBF to provide an independent assessment of the FAIR project status. The presentation provided by ECONUM gave their assessment of the project, the continued risks in moving the project forward, and an assessed range of funds needed to complete the IO. This information was shared with the full committee prior to the in-person meeting. The group from ECONUM has continued to provide support for the review committee with their own cost estimates for the different scenarios that the committee has considered. These estimates form the basis for the cost evaluation that the review committee has used in formulating options and providing recommendations.

The principal goal of the FAIR project is to produce world-class science over a wide range of topics in nuclear and atomic physics. These topics cover much of the science that is recognized by the international nuclear physics community as defining the field of nuclear science today and into the future [see the facility report from Working Group 9 of the International Union of Pure and Applied Physics for a summary of the science questions that drive the field: https://iupap.triumf.ca/icnp/IUPAP%20Report%2041-finalOct23-18.pdf]. The committee's report provides an up-to-date look at the science projected for FAIR and the status of the collaborations working toward that science. The science sections covering the four pillars of the MSV discuss the international competitiveness of their science, both near term and long term. Following the science discussion is a brief status report of the civil construction, accelerator systems, beam transport systems and experimental areas that make up the GSI/FAIR complex. Potential resources needed for facility operations are briefly discussed. The report then concludes with recommendations on how to proceed.

The review committee thanks FAIR management and future scientific users for their help in setting up the in-person meeting and for all of the work done in response to questions from committee members.

The Science of FAIR

The FAIR science program enabled by a completed MSV will be world-leading and address many of the open questions in nuclear physics and closely related fields as noted above. The science has been divided into four pillars, each of which has a large collaboration of scientific users working to develop the instruments needed to carry out their science. FAIR management routinely tracks the progress of the pillars separately towards meeting their instrumentation and funding goals. The broad areas of physics covered by the pillars are: atomic and applied physics—APPA; high energy-density nuclear matter—CBM; nuclear structure and astrophysics—NUSTAR; and the structure of exotic states of QCD—PANDA. The charge to the review committee requested information about the importance and uniqueness of FAIR science to the international nuclear physics community. Below are short reports for each of the pillars that address these questions.

Beginning in 2018, a science program was reinstated at GSI as FAIR Phase-0. The program uses the existing facilities at GSI, in particular SIS18 and the fragment recoil spectrometer. This program has been crucial for providing research opportunities for the workforce that will carry out the FAIR science. The extension of this program to Early Science at FAIR can be done with SIS18 and the FAIR superconducting fragment recoil spectrometer (S-FRS), as noted below. Beginning the early science program will be an important step, but it is only a temporary solution. Realizing the full potential of FAIR will require the completion of SIS100, including commissioning and use in delivering new science. Later in this report a step-wise plan is proposed to bring new science opportunities into existence at FAIR.

APPA

The APPA pillar of the FAIR facility represents more than 700 scientific users from 30 countries who conduct both basic and applied research in a diverse range of disciplines, including atomic physics (SPARC collaboration), biomedical research (BIO), material science (MAT), and plasma physics (HED). FAIR is unique in its ability to deliver to these experiments high-quality ion beams of a wide range of energies, high intensities, and high charge states. In addition, each collaboration has developed a unique set of instruments and apparatus that are difficult to reproduce elsewhere. In FAIR Phase-0, the collaborations are conducting world-leading research in their respective fields. They are also likely to produce Day-1 results in the future when SIS100 is operational and then again when the APPA cave becomes available.

The SPARC collaboration studies atomic physics on highly-charged ions stored in either ion traps or storage rings. The highly-charged ions provide a unique environment to test Quantum Electrodynamics theory (QED) in a strong field where non-linear effects could be expected. In the HITRAP ion trap, researchers are measuring the magnetic moment of the bound-state electron, from which the fine-structure constant α is determined. In the combination of ESR and CRYRING storage rings, both laser cooling and electron cooling are applied to generate cold ions well-prepared for precision measurements, on which atomic structure, transition, and collision properties are studied. The results have astrophysical significance since highly-charged ions are prevalent in the space environment. In the next phase, the collaboration plans to apply laser cooling to relativistic ions of even higher energy stored in SIS100.

The BIO collaboration has two missions: space radiation protection and cancer therapy. For the first mission, ion beams from FAIR are used to simulate galactic cosmic rays with energies of up to 1 GeV per nucleon at present, and 10 GeV per nucleon in the future when SIS100 becomes operational. The wide range of ion species as well as the high energy available at FAIR makes it a world-leading, for some topics unique, facility in this area of research. It serves the critical needs of the European Space Agency (ESA) as the ESA reference facility for ground-based space radiation protection studies. On the second mission, members of the BIO collaboration have pioneered cancer therapy with ion beams. The collaboration is conducting extensive research in particle therapy ranging from studying biological mechanisms to developing effective treatment procedures. The studies so far have used ion beams of stable isotopes. FAIR's ability to deliver ion beams of radioactive isotopes for cancer therapy will open up a new frontier. SIS100 and the APPA cave will provide beams of higher intensities, thus enabling faster experiments and treatments.

The MAT collaboration studies radiation effects on materials. As in the BIO case, the ion beams at FAIR are used to simulate cosmic rays in studies of radiation damage of space materials and space electronics. The ion beams are also used in astrochemistry research, in particular, to induce chemical reactions in a simulated space environment. Moreover, ion irradiation is combined with high pressure to study phase transitions of condensed matter materials. The large variety of ion species and the wide range of energies available at FAIR are important to this area of research. SIS100 and the APPA cave will further expand both the energy and intensity ranges for MAT studies.

The HED collaboration uses the ion beams to heat and compress samples to study high-energy-density matter that simulates the interior material of planets and stars. While the world-wide HED community has built multiple facilities with a variety of compression drivers, the ion beams of FAIR are uniquely situated to produce the so-called "warm dense matter (WDM)" with temperatures reaching hundreds of thousands of degrees and pressures of mega-bars. The collaboration has developed unique lasers to be used with the ion beams in pump-probe studies. In addition, a state-of-the-art proton beam microscope (PRIOR) has been developed for diagnostics. Ion beams of higher energy and intensity will bring qualitative advantages in WDM research, thus successful construction of SIS100 and the APPA cave is critical to the HED collaboration.

The HED collaboration has suffered a major loss of membership – about 30% of the members were from Russian institutes whose contributions include theoretical research and a superconducting focusing magnet system. The theory capability has to be recreated by recruiting new members. Re-procuring of the magnet system based on the existing design is estimated to cost 4-5 million euro and take three years to complete. Facilities elsewhere, in particular, the HIAF facility under construction in China, are likely to develop competing programs and may attract away part of the HED collaboration, including the newly departed Russian teams. This situation could cause a loss of scientific leadership and opportunities. However, the review committee feels optimistic that the European community can retake the initiatives to FAIR once the facility is back on track.

For the APPA pillar [and parts of NUSTAR], it is important for the near term that support for FAIR Phase-0 research continues at the current level. In addition to producing scientific discoveries and developing important applications, the on-going collaborations will also grow the next-generation workforce for the future of FAIR science. For the longer term, it is important that SIS100 and the APPA cave be completed in a timely manner.

If the FAIR schedule is delayed by five years, SPARC, BIO and MAT collaborations within the APPA pillar will remain productive and competitive provided that Phase-0 research, and the facilities used presently by the collaborations, continue to be supported. On the other hand, the HED collaboration may lose some valuable research opportunities to competing facilities.

CBM

The Compressed Baryonic Matter (CBM) and HADES experiments represent 400 scientific users from 11 countries who work together to investigate the phases of strongly interacting matter in the non-perturbative QCD regime, especially to understand the role of the strong interaction in the evolution of the universe. The questions being addressed by the CBM experiment include: how does the strong force produce the confinement phase leading to nucleons and other particles; how are the fundamental symmetries in QCD, in particular chiral symmetry, broken in nature; how does the complex spectra of hadrons emerge from QCD; how do the quarks and gluons of QCD behave in extreme conditions, e.g. high density and high temperature. The CBM and HADES experiments have complementary polar-angle coverage and their measurements can help uncover the nature of QCD phases through event-by-event fluctuations (criticality), the production of dileptons (emissivity) and strangeness (vorticity) in the unexplored regions of density and temperature for QCD matter.

The CBM experiment will complement the low-energy run, measured by the STAR experiment at the Relativistic Heavy Ion Collider (RHIC), to search for the QCD critical point. An important aspect of the CBM experiment is the greater amount of data that can be obtained compared to other efforts. This will greatly enhance the ability of CBM to find and confirm new physics.

Dileptons are the message carrier of the evolution of hot and dense QCD matter. An excess of dileptons is expected due to the evolution of the fireball produced in high-energy heavy-ion interactions crossing a phase boundary. Thermal dilepton spectra will be measured by the CBM experiment at SIS100, while the thermal excess radiation has been established by the HADES experiment at lower center-of-mass energies. The measurements will be further extended to di-muon channels, which are expected to further solidify the picture of radiation from the hot and dense QCD matter.

Collective flow and polarization of strange baryons and anti-baryons are expected to probe the spin degree of freedom in the matter produced in high-energy heavy-ion collisions. STAR measurements of hyperon polarization have already indicated an increasing tendency towards lower center-of-mass energy of heavy-ion collisions. The study can be extended to even lower energies by the CBM experiment.

The measurements noted above are highly competitive and potentially superb, even during the first three-year program, mainly due to the high statistics that can be obtained with CBM. For example, CBM will have 100 times more statistics at the same central energy than the Beam Energy Scan program by STAR at RHIC (STAR-BES).

Under the present schedule, the CBM experiment is preparing to be ready for commissioning in 2027, one year prior to SIS100 commissioning. While HADES can execute physics with SIS18 at its present location, it will be moved to the CBM platform to receive SIS100 beam. These staging and step-by-step approaches are expected to provide uninterrupted physics production, which will maintain the impact of the experiment and therefore the competitiveness in the field.

Therefore, it is proposed that the momentum of the CBM and HADES collaborations be kept high for early realization of the proposed measurements, especially to shed a light on the behavior of the QCD matter near the phase boundary.

It should be emphasized that timely completion of SIS100 is critical because it will provide a truly unique opportunity in the world for CBM to carry out its heavy-ion science program.

While a potential further delay would not diminish the competitiveness of the CBM and HADES experiments, it should be stressed that the momentum of the collaboration should be preserved by minimizing the delay and by clarifying the new timeline for the project.

NUSTAR

The Nuclear Structure, Astrophysics and Reactions (NUSTAR) collaboration at GSI/FAIR comprises 663 registered members from 124 institutions in 32 countries across the world. 19 countries support or have expressed interest in supporting NUSTAR experiments financially. An additional 350 scientists are interested in joining NUSTAR at FAIR.

NUSTAR explores fundamental science questions, including the following:

- The development and tests of a predictive model of atomic nuclei and their internal degrees of freedom close to stability and at the limits of nuclear existence;
- The origin of the elements and the role of atomic nuclei in astrophysical events; and
- The origin of elements heavier than iron on earth.

NUSTAR already supports a rich experimental program at the GSI SIS18/FRS and UNILAC/SHIP facilities with dedicated instruments and corresponding theoretical studies. The discovery potential of the NUSTAR experimental program at FAIR depends on the ability of the accelerator facility to create, separate, and identify radioactive ion beams of interest at sufficient intensities to measure observables in the available instruments.

International Context and FAIR competitiveness

NUSTAR is in scientific competition with scientists at radioactive ion beam facilities in Asia, America, and Europe. The two major competitors, with similar aspirations of making the most radioactive beams accessible based on in-flight fragmentation of primary ion beams, are RIKEN in Japan and FRIB in the USA. More than 20 additional radioactive beam facilities around the world have features and instruments offering various advantages. Generally these facilities focus on producing low-energy radioactive beams that can be used to carry out secondary reaction and decay studies for nuclear structure and nuclear astrophysics. The secondary beams are typically only a few neutrons away from their stable parent isotope, which dictates a very different experimental program than that planned for NUSTAR.

Relative to its international competitors, FAIR offers the highest primary beam energy for all ion species (up to 1.5 GeV/nucleon, compared to 0.35 GeV/nucleon at RIKEN and 0.2 GeV/nucleon at FRIB). This advantage translates into superior discovery potential at FAIR. The high primary beam energy at FAIR offers:

- Higher production rates of radioactive beams at the same primary beam current As thicker production targets increase the production luminosity and better kinematic focusing at FAIR energies affords higher transmission, FAIR can *produce* more usable rare isotopes;
- Superior isotopically pure radioactive beams. As fully-stripped radioactive ion beams can be produced for all elements (up to uranium), this allows cleaner *separation and identification* of isotopically pure radioactive ion beams than at facilities with lower primary beam energies;
- *Unique* discovery potential for heavy radioactive beams (Z>70) at rates and purities not achievable elsewhere.

The existing scientific instruments and those currently under development at FAIR are competitive with those available or under development at other international facilities. To maintain the competitive edge at FAIR, construction and commissioning of these instruments will need to be completed. Central to the NUSTAR program is the Superconducting Fragment Recoil Spectrometer (S-FRS). Indeed the S-FRS and associated experimental halls are critical for the scientific program at FAIR, including the Early Science program. The re-procurement program of the components previously thought to be provided by Russia needs to be commenced immediately to avoid further delay in completion of the S-FRS for Early Science.

For high-mass systems, the main competitor for this program is the HIAF facility in China. Discovery potential of NUSTAR at FAIR will be lost if the program is delayed substantially beyond the present schedule.

PANDA

A collaboration of 450 scientists from 19 countries has designed the PANDA experiment at FAIR to produce a program of physics accessible through anti-proton collisions with protons as well as through anti-proton collisions with heavier nuclei. PANDA's main focus is to produce measurements that probe the strong interaction with unprecedented precisions at lower energy scales. In this energy regime, QCD, the theory of the strong interaction in the Standard Model (SM), has historically faced challenges to provide testable predictions at precision levels comparable to QCD predictions at higher energy scales, where perturbative field theory methods can be applied. Consequently, the strong interaction theory has not been tested as thoroughly as the electroweak theory in the SM. In this lower-energy 'non-perturbative' regime, Lattice QCD (LQCD) and other theoretical approaches that have been developing over the past number of years and are beginning to yield more precise predictions. The program at PANDA will yield unique measurements that will provide the most stringent experimental observables against which the improving LQCD calculations can be tested and could lead to new insights on theoretical approaches beyond LQCD.

The very small spread in the anti-proton beam energy expected at FAIR yields high-precision energy measurements in the 'formation' channel program of PANDA. This makes it considerably more precise than other experiments, giving it the most stringent experimental observables against which the improving LQCD calculations can be tested. These could lead to new insights on the need to consider theoretical approaches beyond LQCD. Two components of the PANDA physics program are particularly impactful because of their importance to understanding the physics of the strong interaction and because PANDA is the only experiment able to make the measurements:

1. Discoveries of electrically neutral particles comprised solely of massless gluons, the spin-one particle responsible for mediating the strong force. These so-called 'glueballs' are predicted in the QCD sector of the SM but have not been definitively established in any experiment, though there are 'glueball candidates' reported in the literature. Glueballs are particularly interesting because they are the only particles predicted in the SM with mass generated entirely through the strong interaction. Consequently QCD predictions of their mass spectra are relatively insensitive to the values of light quark masses. QCD predicts that PANDA will not only produce many different types of glueballs with different masses and quantum numbers for the first time, but will also produce them in abundance, which will allow for measuring their mass spectra with high precision. In so doing, LQCD and future improved approaches for calculating QCD in this non-perturbative regime, will be stringently constrained and tested.
2. Definitively establishing the existence of 'exotic' hadronic particles. With the antiproton energies precisely known, PANDA will be able to measure the decay properties of 'exotic' particles containing charm quarks at a precision level that is substantially beyond the existing capabilities of LHCb (which uses pp collisions at the LHC), Belle II and BES II (which use e^+e^- collisions at ~ 10 GeV and 2-5 GeV, respectively), and GlueX (which uses polarized tagged-photon collisions). PANDA's unique energy resolution is of great importance because it allows experiments to determine whether a particular particle is 'compact' or 'molecular' – i.e. like conventional hadrons (mesons or baryons) or exotic (e.g. molecules).

In addition, PANDA has a broad program including studies of baryons containing more than one strange quark (strange hyperons). These studies incorporate tests of CP violation that conceivably might explain the matter-antimatter asymmetry in the Universe, one of the most fundamental questions in physics today. The program also includes studies of lepton universality in $\bar{p}p \rightarrow e^+e^-$ and $\bar{p}p \rightarrow \mu^+\mu^-$ decays. Delays should be minimized in starting this program in order to ensure that PANDA remains as competitive as possible in its science program.

In summary, there is great interest in the field to understand the nature of the strong interaction in the 'non-perturbative' lower-energy regime with notable experimental efforts at CERN (LHCb), Japan (Belle II), China (BESIII) and the U.S. (Gluex) focused on this problem using different experimental approaches. With its use of a stored anti-proton beam, PANDA is unique and is the only experiment in the world that can definitely answer the question as to whether or not the states under study are new, ‘exotic’, forms of hadronic matter. PANDA’s unique glueball-discovery program will provide the critical tests of strong interaction theory that predict masses of the only particles with mass generated entirely through the strong interaction.

The compelling case of PANDA’s high-precision science program justifies the execution of the full MSV, even if delayed by five years. In particular, it is recognized that many of the accelerator components for the full MSV are available and currently in storage. The team is encouraged to complete designs of the system using CERN’s Antiproton Accumulator (AA, currently in storage in Japan), for parts of the Collector Ring (CR) and recycling the COSY ring for the RESR Accumulator Ring. This would alleviate the problems caused by reduction of contributions from Russia.

PANDA’s high precision measurement program is unique. With no other competing experiments of comparable precision on the horizon, PANDA can afford to be delayed by five years. However, a clear schedule from the Council is necessary. It is important that the steps in a staged and well-developed plan, including the required civil construction and installation of accelerator components towards its completion, be carefully monitored and any updates are clearly communicated to the PANDA collaboration.

Summary of FAIR Science

Each of the four science pillars has a compelling, often world-leading, science case. There is not another facility now being planned or under construction that can carry out the full program of science planned for FAIR. There will be competition for parts of the program from other facilities in Asia and the US, as has been noted in the discussion of the four pillars. With the start of its science program, FAIR will be able to begin attacking many of the outstanding questions in nuclear physics.

With the delays and uncertainties in the FAIR schedule, it is crucial that FAIR management in cooperation with the FAIR Council puts forward a realistic plan for starting first science for each of the pillars. Otherwise, researchers, especially young scientists, will not be able to plan for their future. This could lead to a serious loss of a talented workforce that is being counted on to carry out the FAIR science program.

Facility Status

To date there has been significant investment in FAIR civil construction, accelerator and beam line components and experimental programs. The following sections describe the status of the facility at the time of this review.

Site construction is divided into three lots,

- “North” including SIS100 tunnel and technical buildings, CBM hall and junction tunnel from SIS18,

- “South” including tunnels and technical buildings for Super-FRS, APPA cave, halls for NUSTAR—HEB and LEB, as well as the pbar target area,
- “West” including tunnels and transfer lines for CR and HESR.

Civil Construction

The North and South lots, which need to be available for the Intermediate Objective (IO), have been contracted and are under execution. The tendering process for the West lot that will complete the Modularized Start Version (MSV) has not been initiated yet.

The civil construction of the North lot is close to completion, with most of the external building structures done and the contractor starting to dismantle its worksite. The South lot, adjudicated to a different company, is still under major construction. Civil construction of the North and South lots is estimated to be complete by end 2024.

Postponing the civil construction of the West lot would impact the schedule of the MSV, but allows the project to concentrate resources on completion of the IO and achieving significant science. It would have limited effect on worksite installation as it is possible that a different contractor would be selected for this lot in the future.

Technical building equipment

An order for the installation of technical equipment and all other internal finishing has been placed encompassing all buildings needed for the IO, but the work has just started. This offers the possibility to carry out the technical building infrastructure work in steps that are adjusted to the scientific steps, and to the budget available. The consequence may be penalties to be paid to the contractor for modifying the order of execution within an established contract or stretching it, resulting in a delay in schedule.

The review committee has explored the possibility that work on completion of technical infrastructure for buildings that will not be used in the first stage of science operations be postponed. This option will be part of the consideration in the recommendations put forward.

Budget situation

Following the decision in 2020 to concentrate on the IO for the facility, FAIR Council had approved a budget for the completion of the IO of 2.151 billion euro. With new information, the project, as of February 2022, estimates a budget need of 3.025 billion euro, including both an amount of 0.818 billion euro as risk, but most likely needed, and 0.1 billion for re-procurement of missing Russian components. If this additional funding were made available as needed by the project, the completion date of the IO is estimated by the management to be 2029.

It is important to note that 1.810 billion euro are already spent or committed by the project.

Accelerator systems

Acquisition and acceptance testing of accelerator components is making good progress. In particular, all completed superconducting magnets have been cold-tested in the FAIR test facility for the SIS100 dipoles and at CERN for the S-FRS magnets. The facility at Salerno for the cold-testing of the SIS100 quadrupoles is now operational.

For the Early Science objective, the manufacturing of the components of S-FRS is showing good progress. The components for the High Energy Beam Transport (HEBT) are missing some Russian deliveries that will have to be replaced. To meet the deadlines of finishing the installation in Q1 2026 and starting science by the end of 2026, the re-procurement of the missing components is time critical—it must be launched during 2022.

The Early Science program (SIS18 to S-FRS) is a significant step towards starting of commissioning and starting up of the FAIR facility, but it does not in itself offer scientifically a world-leading discovery opportunity for FAIR.

For SIS100 completion a large part of the superconducting quadrupoles needs to be re-procured (only 13 modules out of 85 have been delivered from Russia). The final assembly of the SIS100 quadrupole modules is being done at BILFINGER NOELL GMBH. This company could also deliver the missing subassemblies that should have come from Russia. FAIR has ownership of design and it should be no problems to transfer it from Dubna to NOELL. Re-procurement of the steel and superconductors is also needed with a decision to be made as soon as possible. The completion of the production of the SIS100 SC quadrupoles represents the main technical and schedule risk for the SIS100 completion.

Concerning the existing accelerator facilities at GSI:

- Linac—The demonstrated beam performance is adequate for Early Science. Planned refurbishments and an upgrade program are under way.
- SIS18—Operation at high repetition rate was demonstrated. The beam performance at SIS18 is also adequate for Early Science, but the beam intensity needs to be drastically increased for full FAIR performance goals.

Super-FRS

The S-FRS is indispensable for the scientific program at FAIR, including Early Science. Delays in construction of S-FRS result mainly from missing Russian contributions, which cannot be delivered due to the on-going conflict. The re-procurement of these components has to be launched as soon as possible in order to mitigate further slippage of the schedule towards Early Science.

In summary, the cost and timing impact of non-delivery of Russian in-kind components are:

- 17 million euro of time-critical components to be re-procured in September 2022;
- 83 million euro of others to be re-procured preferably by December 2022.

Storage rings

The storage rings CR and HESR are needed for the full Modularized Start Version (MSV). They will be used to expand the science programs of APPA and NUSTAR, and they are critical for the PANDA science program. For the CR, 28 % of the components are available and 72 % have to be reordered. Most of the components of HESR (90%) have already been delivered.

Since much of the CR has to be re-procured the project explored alternative solutions. One possibility is to reuse the components of the COSY storage ring. COSY at the Jülich Forschungszentrum will be decommissioned soon. The Committee commends the project for considering alternative and creative solutions and encourages further efforts in this direction.

Operation cost

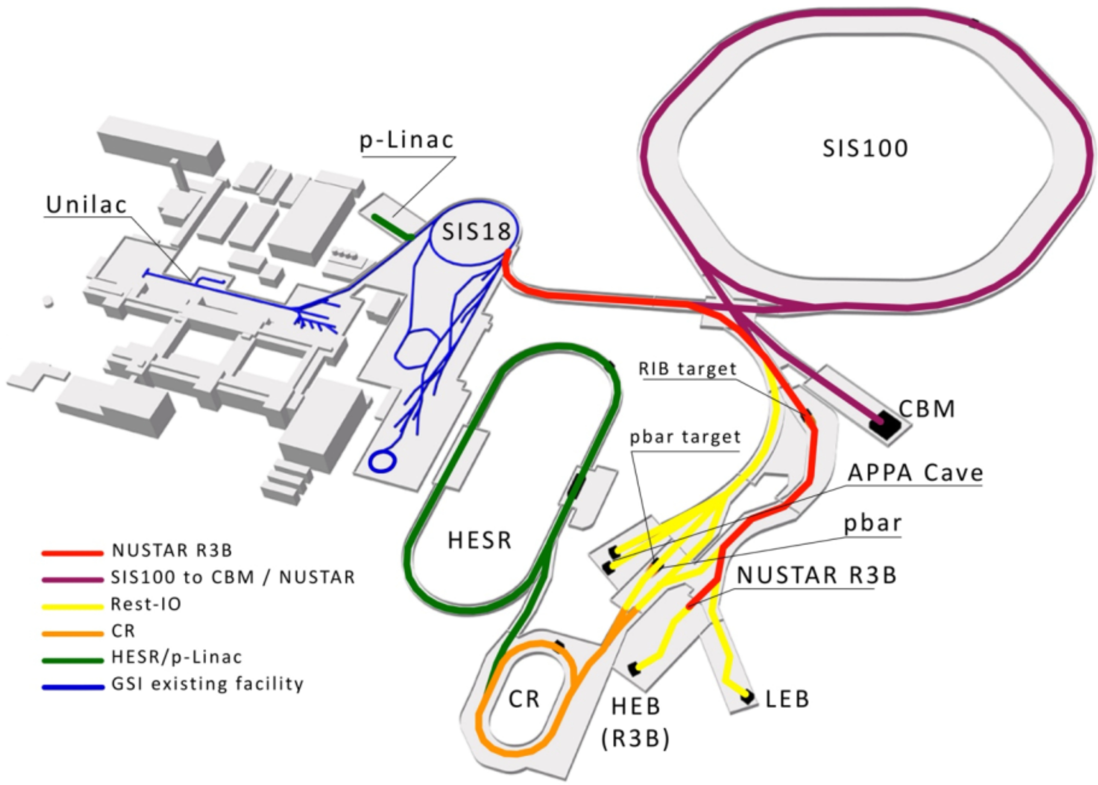
FAIR management reported that the estimated yearly operation cost for the full MSV facility amounts to 350 million euro. Out of this total cost 83 million euro is for the electric power consumption of about 70 MW at present electricity rates. Personnel for the accelerator complex are estimated at about 570 FTE. Although a detailed analysis of resources for accelerator operation is outside the scope of this review meeting, a rough comparison with other accelerator facilities indicates that the FTE number for FAIR is rather high, and not credible. Moving forward, FAIR management should perform benchmark comparisons with other comparable accelerator facilities (CERN LHC injectors, RHIC injectors, J-PARC, etc.) and have the operations cost estimating methodology reviewed by experts experienced in the operation of accelerator facilities of similar scale. Also FAIR management should explore options to reduce the electric power bill through either lower electricity rates and/or improved energy efficiency.

Summary and Recommendations

To date there has been significant investment in FAIR civil construction, accelerator and beam line components and experimental programs. But due to cost overruns, the approved budget of 2.151 billion euro will not provide the funding needed to complete the civil construction and the infrastructure required to carry out science with the IO. The committee affirms that it is important to capitalize on this investment and to move FAIR toward its first science, but additional funds, and a careful approach, will be needed.

With civil construction coming to completion, the project organization should be adapted to one where decisions on scope and management of cost risks are optimized for scientific discovery. This approach reduces the likelihood of additional cost overruns and enhances the likelihood of scientific success.

The newly estimated cost by FAIR management for the *immediate* realization of the IO of 3.025 billion euro calls for a stepwise course of action driven by scientific considerations and practical aspects. The latter ones are determined by the design and consequently by the existing layout of the facility, displayed below:



The panel considers the following steps as a possible path toward the IO:

(1) Early Science with SIS18, NUSTAR and parts of APPA
(2) First Science with SIS100 replacing SIS18
(3) First Science with CBM in addition
(4) First Science in the APPA Cave in addition

Completing these steps will provide opportunities for world-class science for three of the four science pillars. NUSTAR will be the first pillar to benefit from FAIR. This is fortuitous since the international competition is highest for the physics being pursued by NUSTAR. The combination of SIS100 and the S-FRS will provide NUSTAR with a world-wide unique science program. The CBM program is unique to FAIR. The delay bringing it on-line may impact the availability of the workforce, but it does not impact the science potential. The APPA program, as noted earlier, can continue carrying out important science with its present facilities. Moving the program into the APPA Cave will open new avenues of discovery by using the SIS100 beams with new instrumentation. Today, the PANDA science program is compelling. Since PANDA is not part of the IO planning, it will be delayed further than the other pillars as a schedule that provides resources for the MSV is determined. If the delay pushes PANDA implementation beyond 2032, the committee would urge FAIR management and Council to carry out a new review of the PANDA program to determine if changes are warranted in the scope based on the results from other experimental programs.

Priorities toward the IO

As the top priority, present civil construction efforts should focus on completing the external parts of buildings whose construction is now underway, in order to preserve their integrity. Work on internal finishing is recommended as buildings are being readied for science operations. This means that internal finishing should be done in steps in synchronization with the scientific requirements.

The committee recommends that the next set of priorities follow the four steps toward first science for the different pillars given above. This approach presents the possibility of defining milestones and could allow breakpoints if financially required. For each step, the cost saving with respect to the present estimate of FAIR management for the completion of the IO (3.025 billion euro) is given from estimates by ECONUM, assuming the respective step as the point where construction ends, or temporarily ends. Note that these numbers include the cost to re-procure Russian components. Different weighting of risk probabilities determine the ranges presented.

Early Science

Completing the S-FRS is the first priority toward FAIR science. The Early Science with FAIR program requires a completed S-FRS, SIS18 beam transport be in place to deliver beams to the S-FRS target, and the experimental area HEB be completed for the use with experimental apparatus. The initial program will provide improved secondary beams compared to the present FAIR phase 0 operation.

Estimated cost saving if used as breakpoint: 600-700 million euro.

The committee believes that stopping FAIR construction at this point should not be considered a viable alternative, as SIS100 is existential to FAIR. This should only be done as an intermediate step and any extra costs associated with carrying out an Early Science program with SIS18 and the S-FRS should be minimized.

First Science with SIS100

For FAIR to continue, SIS100 is essential – without it very little of the FAIR program is possible. Obtaining the parts that are needed to complete the SIS100 accelerator should be the next priority once the S-FRS issues are resolved. The first science with SIS100 will utilize the S-FRS into HEB as is done in Early Science. Completing this step will greatly expand the capabilities for NUSTAR, allowing it to produce world-class science soon after commissioning. This step requires procuring the magnets to complete SIS100, installation of components, commissioning, and then delivering beams to the S-FRS target.

Estimated cost saving: 350-550 million euro.

First Science + with CBM in addition

The experimental area for CBM is being readied as part of the on-going civil construction. Procuring and then installing the CBM magnet and detectors, moving the HADES detector system, and providing beam transport magnets to the CBM detector set up should suffice to begin the CBM program. Enabling this science pillar will be a major extension of the FAIR science program at a minimal cost.

Estimated cost saving: 320-500 million euro.

First Science ++ in the APPA Cave in addition
The APPA cave construction is on-going now as part of the overall civil construction. Completing the beam transport into and setting it up for experiments would significantly expand the APPA program.

Estimated cost saving: 0-250 million euro.

Completing all steps would move three of the four science pillars forward and would allow FAIR to produce world-leading science in all three pillars. During construction, it is important to maintain the science program that was started as FAIR Phase 0 until new science opportunities, such as beams into the S-FRS, begin to come on-line. The FAIR Phase 0 program will continue to keep young scientists engaged in the field while the first major components of the FAIR IO are brought on-line.

The steps outlined above are considered by the committee as the best path to follow in order to move toward the IO. But implementation of the steps requires a substantial increase in funds over that presently available. If the interior TBI is included now, these steps represent the most cost-effective way to proceed uninterrupted toward the IO. Stopping the TBI on buildings that are not a part of the early stages, and resuming this work later will incur penalties and a higher cost.

In addition to the steps outlined above toward the IO, the committee considered other options for the future of the FAIR facility. These are given in the two bullets below.

- If funding constraints do not allow for the addition of the APPA cave, which was the last step above, three options were considered after completing the step for First Science + with CBM in addition. (1) Stop FAIR construction and carry out science for NUSTAR, APPA and CBM with limited facilities. This would likely require negotiations about the status of the buildings that were constructed but would not be implemented for FAIR use. (2) Continue to move toward the IO with an extended schedule. (3) Develop the antiproton facility with higher priority than completing the IO.
- Stop all FAIR construction now and proceed to demolition of buildings already completed or under construction.

The action of stopping the FAIR project now, the second bullet, would be hugely disruptive to the global nuclear science community. As already noted, FAIR is considered the centerpiece of nuclear science in Europe. Cancelling FAIR would result in the nuclear science community in Europe either shrinking in size, or moving to other major facilities around the world. The most logical place for many scientists now active in FAIR to go would be HIAF, which is a facility currently under construction in China and scheduled to provide first beams in 2026. FAIR would provide more science opportunities than HIAF and would clearly be the science leader into the future. If FAIR were cancelled, HIAF does represent an alternative that would cede leadership to China in the science slated for FAIR.

Combining Operations and Construction

The scientific success and viability of GSI and FAIR are closely intertwined and the two entities are being jointly managed by the same management team. Early science experiments, beam commissioning and future operation of FAIR rely on operation of GSI. Decisions and resource allocations for GSI and FAIR need to be optimized across the whole GSI and FAIR complex, so that the imperatives of scientific discovery, FAIR beam commissioning, and affordable facility operation can be achieved. Prior to beam commissioning, the management team needs to define how decisions are made and how conflicts will be resolved so that all three imperatives are successfully achieved. Delivering on fewer than all three imperatives will not meet scientific, public, and political expectations. To make this happen, the committee, in the section below, strongly recommends that FAIR Council commission an external panel to help inform how the interactions between two separate efforts—GSI and FAIR—can be managed, or preferably combined into a single effort so that decisions are optimized for science. This transition must be done in the near future in order to optimize the overall program.

While the present review did not focus on the workforce and other support needed to operate the new FAIR facility as it transitions from a project to a science laboratory, some information on operations support was provided to the committee. The focus in the report to the committee was on commissioning and operations toward the IO. The plan that was presented started with the present support for GSI operations as the base and requested an additional 60 million euro to be added to this base in 2024, followed by additional increments of 60 million euro to provide totals of 120 million euro added in 2025 and 180 million euro added in 2026. This would correspond to a total operations and commissioning budget of approximately 300 million euro by 2026. From that brief overview, it appeared that costs had been derived primarily from a bottom-up approach. Often this leads to duplication of personnel as each operations unit will request enough personnel to deal with unexpected problems. Consequently the numbers appeared to be high compared to operations costs at comparable facilities around the world. Below, the committee recommends that an external panel be set up to review plans for operations and provide recommendations for how to set up efficient and cost-effective operations planning. This would require that the step of managing GSI and FAIR together was completed. Performance milestones can help monitor progress. But it is important to develop a top-down approach to staff the facility for efficient operations. The FAIR Council should set funding expectations for the cost of operations as a guide for managing the top-down approach.

Recommendations

The following recommendations are endorsed by the review committee. They are divided into two categories. The first set of recommendations is for the continued development of FAIR. The second group is specifically to the FAIR Council.

The following recommendations are aimed at advancing FAIR to science.

- Complete the S-FRS into the HEB cave for NUSTAR to carry out the Early Science program.

- Completion of SIS100 needs to have the next highest priority.
- If resources are tightly constrained, completing SIS100 with beams into the S-FRS and HEB cave, plus setting up and commissioning the CBM experiment offers an intermediate solution for developing world-class science at FAIR.
- Completing the infrastructure and instrumenting the APPA cave should have priority over instrumenting the additional area in LEB for NUSTAR.
- Tendering for civil construction of the West lot should be postponed, but a plan is needed for the time frame to implement PANDA.
- The orderly set of steps towards the IO, which was presented above, represents the most cost-effective plan for moving FAIR forward. In order to accomplish this, a yearly budget needs to be defined for the project, as well as an overall budget cap. The budget should provide funds to complete milestones that are agreed upon by FAIR management and FAIR Council. Costs will need to be managed during the year to achieve those milestones.
- It is imperative that the GSI and FAIR management coordinate resources to optimize the workforce for success as construction, commissioning, and operations are intertwined.

The following recommendations are specific for the FAIR Council.

- The committee recommends a budget cap of an additional 500 million euro beyond the already approved 2.151 billion euro to complete the phase of the project that includes SIS100, S-FRS into HEB and CBM. This budget cap includes the funds needed to replace the missing Russian (hardware) components.
- Setting up a cost scrutiny group, consisting of external technical experts, is essential now to provide the appropriate advice to the FAIR Management and to the FAIR Council for the oversight needed to achieve their goals. If successful for delivering the phase defined in the previous bullet with the proposed budget cap, this approach should be expanded to achieve the IO in additional steps, and then continue on to the MSV or the next phase for FAIR as defined by the FAIR Council.
- The committee recommends that an external panel be commissioned by FAIR Council to help inform how the interactions between two separate efforts—GSI and FAIR—can be managed, or preferably combined into a single effort for construction, commissioning and operation so that decisions are optimized for science. This transition must be done in the near future to optimize the overall program.
- The committee recommends that a new external panel be set up to review plans for operations and provide recommendations for how to set up efficient and cost-effective operations planning.

In addition, the committee expresses the opinion that all member states represented on the FAIR Council should own the budget problem that now faces FAIR. Together they should contribute either funds or in-kind contributions to move the project forward.

Appendix A

“First-Science” and staging review of the FAIR project in Q2 2022

Mission

The “First-Science” and staging review team for the FAIR project is asked to assess options for realising the FAIR project, given the current financial and political situations.

Background

The FAIR project has undergone several scientific reviews since it was conceived, which all have confirmed the outstanding scientific opportunities FAIR will offer. The latest review was established in 2018 by the FAIR Council and was concluded in 2019. It highlighted that the scientific programme of FAIR will lead to world leading science, it recommended to construct the FAIR Modularized Start Version (MSV) asap and identified the the Super FRS as the part with the highest priority to be operational.

Following these recommendations and the commitment of several, but not all, of the shareholders to provide the additional funds, a subset of the FAIR MSV (named Intermediate Objective (IO)) was prioritized for completion until further funding has been granted. The IO includes the procurement and delivery of all accelerators and all experiments for the MSV but not the civil construction of the buildings HESR, p-LINAC and CR.

With the update of the baseline (overall time schedule) in March 2021 the internal cost estimation of the FAIR GmbH has been revised in the light of the defined goals of the updated baseline and due to the severe economic implications of the COVID Pandemic. The FAIR GmbH has informed the BMBF in March 2021 about additional cost risks for the IO of up to 593 Mio. €. To confirm the substantial additional cost risks for the IO the BMBF has requested an external company for an additional audit. The results show a range of 708.8 (min) to 1237.5 Mio. € (max) of additional cost risks to realize the IO. These findings include the 593 Mio. € stated by the Fair GmbH and are presented in the extra ordinary meeting of the FAIR Council of the 22. March 2022.

Russia as the second largest shareholder is responsible for the development and production of a large number of key elements for the accelerator and the experiments. Due to the invasion of the Ukraine by the Russian Government starting in February 2022, the delivery of accelerator and experiment components from Russia is impacted as the collaboration has been suspended for the time being.

The serious financial issues, which severely threaten the feasibility of the project as a whole, have to be addressed.

FAIR project realization - status March 2022

All IO buildings are very much advanced or already completed in regards to the realization of the concrete buildings. All IO Technical buildings installation (heating, ventilation, building automation, electrical etc.) contracts have been placed at the beginning of 2021 and the installation process is in progress since beginning of 2022. Approximately 80 % of all components for accelerators and experiments have been contracted. Numerous components for IO and MSV are already delivered and are stored on site. However, the invasion of Ukraine by Russia resulted into a suspension of the items to be provided from Russia for the time being.

Tasks of the "First-Science" and staging review team

Given the recent financial audit, and the current restrictions on transactions of funds and resources between the EU and the Russian Federation, the review panel is asked to assess the following:

The review panel is asked to assess:

- Are there scientifically sound start configurations (below the scope of the IO) possible, which make optimum use of the investments already made in FAIR and at the same time trigger a minimum of additional costs? Are there possible scenarios which will allow for a) a substantial and b) a modest reduction of the scope below the IO?
- Regarding the situation of the Russian shareholder: Are there alternatives, especially for the components and personnel to be provided by Russia? What are the financial implications of the proposed alternatives?
- Would further staging of the project (i.e. - introducing steps before the IO) still produce a program of world class science (meaning a facility which makes it possible to achieve cutting edge science in comparison to other competing facilities), in proportion to the coherent with the costs investments incurred so far? What are the financial requirements for each module?
    - Which components of the facility are indispensable to reach the goal of world class science?
    - What would be a realistic timeline for realizing this staging until the IO?
    - Is there a point in time when the scientific competiveness of a certain module would expire, especially in comparison with competing facilities?
- Are there alternative scenarios, which should be considered?

For further decisions on the future of the FAIR project, there is the need for a firm estimation of the additional cost risks for each of the developed scenarios. Recommendations with respect to the organisational structure will also be welcome.

Charge to the FAIR Management

The FAIR Management is requested by the FAIR-Council to assist the review panel and provide all requested information, assessments and documents as soon as possible.

Membership

tba

Planned procedure of the review

The primary focus of the report is to obtain qualified answers to the Charge Questions listed above and to give recommendations to the FAIR Council. These recommendations will be part of the base for the decisions on how to reach initially the first science and then how to proceed with the scientific buildout.

The board should seek input at least from the following entities:

- the FAIR experimental collaborations
- the JSC
- the chair of the G-PAC

To support the review team in this regard the BMBF will give access to their project-consulting agency ECONUM and their project management agency (PT-DESY[1]).

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[1] PT-DESY is a independent organization affiliated to Deutsches Elektronen-Synchrotron (DESY)

The report should comment on each of the charge questions, initially as a bullet points to the questions. The format of the report should be in writing to the Council and should be internal.

The members of the review panel will be appointed by FAIR Council. The chairperson of the review panel will be Prof. xxxxxxxxxx, who will also be the rapporteur of the panel to FAIR Council. The panel should consist of at least one specialist for each major experimental pillar at FAIR.

Presentation of results

The results and their rationale should be presented in the course of a meeting of the FAIR-Council.

Schedule

The review shall be conducted during the second quarter of 2022. The report should be presented to the FAIR Council, if possible at the Summer Council 2022 but at the latest in September 2022.

Appendix B

The Review Committee Members

Nicolas Alamanos	CEA, France
Reinhard Brinkman	DESY, Germany
Thomas Glasmacher	Michigan State University, USA
Marco Grumler, ex-officio	ECONUM
Rolf Heuer – co-chair	CERN
Magdalena Kowalska	CERN
Philippe Lebrun	CERN
Zheng-Tian Lu	University of Science and Technology of China
Michael Roney	University of Victoria, Canada
Thomas Roser	Brookhaven National Lab emeritus, USA
Naohito Saito	KEK, Japan
Robert Tribble – co-chair	Brookhaven National Lab and Texas A&M University, USA