2018 Recommissioning & Dry-Run Strategy and Planning

Ralph J. Steinhagen, S. Reimann, D. Severin for the FC²WG

* based on 2015/16 FC²WG presentations & meeting minutes
An attempt on defining a ...

FAIR Figure of Merit

- Integrated Luminosity per experiment

\[
\frac{\int \mathcal{L}(t) \, dt}{\int \mathcal{L}(t) \, dt}_{\text{ref}} \sim \int \mathcal{L} \, dt_{\text{OP year}} \cdot \epsilon_{\text{FAIR}} \cdot \frac{dN_{\text{ions}}/dt}{\epsilon_{x,y,s}}
\]

Experiment constraints:
- \(dN_{\text{ions}}/dt\) constant (spill-structure)
- \(dN_{\text{ions}}/dt|_{\text{max}}\) constraints
- ...

beam brightness: \(N_{\text{ions}} \times \epsilon_{x,y,s}\)
- x 10-100 higher intensities \(N_{\text{ions}}\)
- x 10 beam energies
  → new:
  - machine protection
  - activation/loss minimisation (ALARA)

FAIR efficiency (simplified):
\[
\epsilon_{\text{FAIR}} \approx \frac{\langle t_{\text{physics}} \rangle}{\langle t_{\text{physics}} \rangle + \langle t_{\text{operation}} \rangle + \langle t_{\text{down-time}} \rangle}
\]

Primary FC²WG goals:
1. efficient operation
2. better & safe beam control
   ... across the whole accelerator facility
• simple\(^1,2\) estimate, but relates to qualitative control room experience:
  
  – presently: ‘\(~ 1 \) shift UNILAC’ + ‘1 shift SIS18+TL setup’ ↔ \( 1-2 \) weeks of experiments
  – potential target after 2-3 years of FAIR operation:
    
    • simple experiments (e.g. attached to SIS18/SIS100): \( 1-2 \) shift setup ↔ \( 1-2 \) weeks beam-on-target
    • more complex experiments (e.g. at HESR): \(~ \)week setup ↔ months of operation (HESR),

• Need to factor in efficiency evolution: early beam commissioning
  \(\rightarrow\) reaching final beam parameter

\(^1\)possibly strong assumption that new machines can be operated with the same routine, ease and efficiency as the present GSI infrastructure, ...
\(^2\)complex beam chains (e.g. HESR) with long beam setup times are typically run longer/more static than shorter (SIS18 experiments)
Therapy Operation (different accounting)

constant ~ 75 ± 5 %

long-running “static” experiments

Many || experiments re-configuration ~ 1-2 weeks → FAIR base-line

https://www.gsi.de/en/work/research/library_documentation/gsi_scientific_reports.htm
N.B. ion source exchanges are factored out from UNILAC & SIS18 data (~ constant overhead)
Availability: experiments + detector tests + machine development + beam to down-stream accelerators;
Down-time: unscheduled down-time + standby; Operation: accelerator setup + re-tuning

* 2018 operation limitations:
● only ½ UNILAC (w/o A3 & A4)
● only 1 element in SIS18
**FAIR Challenges & Constraints**

... SIS18 Operation Experience & Efficiency

- Beam-on-Target figure of merit (FoM) of ~75% → FAIR-BoT (efficiency $\varepsilon_{\text{FAIR}}$):

$$\varepsilon_{\text{FAIR}} := \prod_{i}^{n_{\text{machines}}} \varepsilon_i = \varepsilon_{\text{UNILAC}} \cdot \varepsilon_{\text{SIS18}} \cdot \varepsilon_{\text{SIS100}} \cdot \varepsilon_{\text{SuperFRS}} \cdot \varepsilon_{\text{CR}} \cdot \varepsilon_{\text{HESR}} \cdot \ldots$$

- New operational challenges:
  
  operating beyond present beam parameter envelope, x10-100 higher intensities, x10 higher energies → machine protection & losses/activation become an issue

“... have to improve!”
Need to be more explicit w.r.t. 'item 4' for commissioning and operation of FAIR.
FAIR Commissioning & Control WG
http://fair-wiki.gsi.de/FC2WG/

An accelerator is more than the sum of its parts:

- Commissioning Procedures & Facility Exploitation
- Personnel development & training
- FAIR-MCR & human-machine interfaces
- LSA, Archiving/Logging, Performance Monitoring
- Beam-Based Systems/BI Integration (alignment, feedbacks, ...)

FAIR Commissioning & Control Working Group
- platform to discuss, coordinate and work-out FAIR commissioning and operation
- open to all who can participate and contribute to this subject!
FC²WG Control Topics
– more than “Control System” & Data Supply

• Facility & Interface Analysis
  – Procedures: HWC, HWC-'Machine Check Out', BeamCommissioning, BC-Stage A (pilot beams), BC-Stage B (intensity ramp-up), BC-Stage C (nominal/production operation) Beam parameters, FAIR performance model, optimisation, Accelerator & Beam Modes

• Beam Instrumentation & Diagnostics – System Integration
  – Intensity (DCCTs) & beam loss (BLMs) → Beam Transmission Monitoring System (BTM), trajectory & orbit (BPMs), Q/Q', optics (LOCO & phase-advance), longitudinal & transverse emittance (FCTs. WCM, screens, IPM, etc.), Δp/p, long. bunch shape (FCTs, Tomography), abort gap monitoring, ... 

• Accelerator Hardware – System Integration
  – Power converter, magnets, magnet model, RF, injection/extraction kicker, tune kicker/AC-dipole, beam dump, collimation/absorbers, cryogenics, vacuum, radiation monitoring, k-modulation, machine-experiment interfaces 

• Control System
  – Archiving system, analog signal acquisition, test-beds, timing, bunch-to-bucket transfer, cyber security, role-based-access, middleware, RT & Feedbacks, daemons

• Components
  – post-mortem, management of critical settings (safe-beam settings), machine protection, interlocks, beam quality checks, daemons, 'Page One', aperture model, ...

• Applications
  – Sequencer (semi-automated procedures), fixed-displays, ...
  – Beam-Based Applications, Cycle-to-Cycle Feedbacks & GUIs → second talk
Some important OP boundary conditions:

A) Compared to GSI, FAIR facility size and complexity increases roughly by a factor 4
B) Expect some improvement but 'Operator' & 'System Expert' will likely remain a scarce resource

One strategy item: 'One Operator per Accelerator Domain' vs. 'One Operator per Experiment':

Operator #1

Q1 → UNILAC → SIS18 → SIS100 → SuperFRS → CR

Operator #2

Q2 → pLinac → SIS18 → SIS100 → p-Target → CR → HESR

Operator #3

Q3 → UNILAC → SIS18 → SIS100 → CBM

Operator #4

Q4 → UNILAC → SIS18 → SIS100 → APPA

Qn → UNILAC → SIS18 → ESR etc.
Poka-Yoke (ポカヨケ) – 'Mistake-Proofing'

- **Origin:**
  - to avoid (yokeru) inadvertent errors (poka)
  - industrial processes designed to prevent human errors
    - Concept by Shigeo Shingo: 'Toyota Production System' (TPS, aka. 'lean' systems)
  - minimise common mistakes, procedural errors, etc. affecting machine performance and protection

- **Real-World Examples:**
  - Polarity protection of electrical plugs (e.g. phone, Ethernet cable)
    - SIS18 profile grid connectors
  - Procedures: e.g. ATM machine: need to retrieve card before money is released (↔ prevents missing card)
Fix problems early, when and where they occur

- Minimises procrastination of errors: “Safety starts with safe habits”!
  - big losses with big intensities → bad (activation)
  - large losses with small intensities → probably OK? ... No!
    - requires paradigm change!
  - Interdependence between beam parameter & systems

- Early indication of developing/not-yet-critical faults:
  - Post-Mortem analysis (‘as good as new' SIL assurance)
  - Preventative maintenance
  - fix “domino effect” problems at the source not its symptoms
    - e.g. fix problems with low-intensity beam rather than with high-intensity beam
      (avoids revalidation of loss patterns, MPS setup, ...)
    - e.g. fix basic accelerator parameters before moving on to higher-order effect
      (e.g. extraction/injection energy/trajectory → orbit → tune → chromaticity → optic → ... → driving term s
FAIR one-of-a-kind prototype, pushing the ion intensity & other limits

Should maintain realistic goals & strategy how-to reach them
• Develop a (initial/re-)commissioning and operation strategy:
  - MoU between various stake-holders (AP, BI, CO, RF, ...)
    • define when, where and how the individual accelerator systems should fit in
  - Identify and define missing procedures, equipment and tools, e.g.:
    • define, check the need or priority of applications vs. 'use cases'
    • define, check integration and interface between specific equipment and CO/OP environment
  - Focus first on commonalities across then specifics within individual accelerators
    • MPLs/MCs define pace & resources of how fast to achieve the above
  - Dissemination/knowledge transfer from groups that constructed and performed the initial HW commissioning to the long-term operation
    • training of operational crews (physics, operation, tools, ...)
  - Scheduling tool for technical stops to follow-up possible issues found

*Procedure aims not only at the initial first but also subsequent re-commissioning e.g. after (long) shut-downs, mode of operation changes and/or regular operation
• Distinguish two forms of 'commissioning':

A) Hardware Commissioning (HWC → SAT A)
   • conformity checks of the physical with contractual design targets,
   • commissioning of individual systems & tasks ↔ MPLs/equipment group responsibility

B) Commissioning with Beam (BC → “SAT B” … )
   • Commissioning of beam-dependent equipment
   • Focus on tracking beam progress through the along the beam production chain (BPC)
     - threading, injection, capture, acceleration and extraction
   • + 'Dry-Runs': pre-checks at the end of HWC in view of beam operation:
     - Checks conformity of system’s controls integration and readiness for Commissioning with Beam
     - check as much control/system functionality without beam as possible
     - Machine ist put into a state assuming that beam could be injected into the ring/segment
     - unavailable devices/systems are at first ignored, noted down, and followed-up at a defined later stage

Terminology:
• **Dry-runs**: a rehearsal of the accelerator performance/function, starting typically six month before the targeted real BC
  • needs to (partially) repeated after shut-down or longer technical stop with substantial modifications
  • initial frequency: 1-2 days every month
  • frequency increased depending on the outcome of the initial dry-run tests
• **Machine-Checkout**: intense accelerator performance tests (e.g. machine patrols, magnet/PC heat runs, etc.), typically two weeks before BC
  • needs to repeated after every shut-down or longer technical stop
  • repeated also on the long-term during routine operation of existing accelerators (already existing procedures/usus for existing machines)
Dry-Runs for Accelerator
= equivalent of Pre-flight Checks in Aviation
Split Beam Commissioning into three stages:

A) Pilot beams/"easily available" ions (e.g. U28+, Ar)
   - basic checks: threading, injection, capture, cool, convert, acceleration/decelerate, stripping & extraction
   - always done with 'safe' ie. low-intensity/brightness beam
     - Ions: simpler optics, beam dynamics → Protons: transition crossing

B) Intensity ramp-up & special systems
   - achieving and maintaining of nominal transmission and beam losses
   - commissioning of e.g. e-cooler, slow extraction, transverse fast feedbacks
   - commissioning and validation of machine protection & interlock systems
   - Possibly unsafe operations always preceded by checks with safe beam

C) Production operation with nominal intensities
   (N.B. first time counted as 'commissioning' or 'assisted operation' → later: 'regular operation')
   - push physics and beam parameter performance (emittance, momentum spread, ...)
   - identify and improve upon bottlenecks impacting FAIR's 'figure-of-merit
   - make fast setup and switch-over between different beam production chains routine
Example: FAIR Commissioning Procedures

https://fair-wiki.gsi.de/FC2WG/BeamCommissioning

Main focus for 2018 (re-commissioning, new CO)

Stage A - Pilot Beams
- main aim:
  - drive the beam expeditiously through the BeamProductionChain (BPC), from the sources, through the synchrotrons, beam transfer, up to the experimental targets/upgrade legs
  - check basic accelerator mechanics (threading, injection, capture, cool, convert, accelerate/deaccelerate, stripping & extraction)
  - identify beam-related limitations: polarities, RF, beam instrumentation, machine alignment, effective physical machine aperture, …
  - always done with “safe” resp. low-intensity/brightness beam
  - initially with handy available lines (e.g., U238, Ar, > simpler optics, beam dynamics, etc.), then protons (beta transition crossing, etc.)

Stage B - Intensity Ramp-up & Special Systems
- main aim:
  - achieving and maintaining nominal machine performance for a limited number of reference beams
  - check that the accelerator design and systems can achieve (near) nominal beam parameters, e.g., beam intensities, nominal transmission and beam losses for e.g., U238+ & proton beams, etc.
  - commissioning of e.g., e-cooler (if not needed earlier), slow extraction, transverse fast feedbacks
  - commissioning and validation of machine protection & interlock systems
  - possibly unsafe operations always preceded by checks with safe beam

Stage C - Production Operation with nominal Intensities
- main aim:
  - make fast setup and switch-over between different BeamProductionChain routines
  - push physics and beam parameter performance (intensity, brightness/beamline, momentum spread, …)
  - identify and improve upon bottlenecks impacting FAIR’s figure-of-merit
  - improve the overall machine beam brightness

Commissioning & Control Working Group (FC2WG)
Example: FAIR Commissioning Procedures
https://fair-wiki.gsi.de/FC2WG/BeamCommissioning

FAIR Commissioning Phase A.1) - Injection and First Turn

---

**Description**
- Commissioning of the last section of the preceding transfer line (matching section + few meters before) and the injection region
- First commissioning of key beam elements
- Commissioning of the trajectory acquisition and correction
- Threading the ring (first turn)
- Closing the orbit to be ready for phase A.2 Circulating Pilot Beam

**Entry Conditions**
- Show:
  - Machine Setup
  - Show...

**Procedure**

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
<th>Who</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td>Commission injection section (A Pilot Run)</td>
<td>1</td>
</tr>
<tr>
<td>A.2</td>
<td>Threading beam around the ring</td>
<td>1</td>
</tr>
</tbody>
</table>

- Initial test in 2018

Ralph J. Steinhagen, r.steinhagen@gsi.de, 2016-07-27
Recommissioning & Operation in 2018 I/II
https://fair-wiki.gsi.de/FC2WG/HardwareCommissioning/

- Hardware Commissioning → coordinated by Sub-Project-Leaders & Machine Coordinators
  - link-existing facilities (GAF), upgrades, machine re-alignment, “SATs”, HW systems (equip. groups),
- Dry-Runs – for all machines post (possibly also UNILAC), each two days, fixed dates (↔ experts availability), starting:
  - Dry-Run #2 – 14.11.2017: as before + tbd.
  - Dry-Run #4 – 09.01.2018: as before + BI + related applications
  - Dry-Run #5 – 06.02.2018: as before + Experiments (proposal) + Machine-Experiment Interfaces
  - Dry-Run #6 – 20.02.2018: as before + AEG + “last-minute” checks
  - Dry-Run #7 – 06.03.2018: buffer
- Machine-Checkout – intensive “last minute checks” (N.B closed tunnel/machine):
  - UNILAC: -1 month → BC- ’day 0’
    - patrols, heat runs: RF & power supply conditioning, …
  - SIS, ESR, CRY: -3 weeks → BC- ’day 0’
    - patrols, heat runs: RF & power supply/AEG conditioning, safety systems: personnel safety, access system, legal ZKS & RP checks (§66 Abs. 2 StrlSchV), “very last-minute” checks/bug fixes: vacuum, power, BI, CO, …

* in 2018: light-version w.r.t. commissioning of new machines
** "guaranteed" start physics operation (Plan A), no hick-ups, sacrificial buffer being activities related to 'Stage B'
Stage-A: Initial Beam Commissioning (BC): 2 dedicated 3 week@24h/7 BC blocks, main aim:
- drive beam expeditiously through the Beam Production Chain: sources → synchrotrons & beam transfers → exp. targets & storage rings
- check basic 'accelerator mechanics': threading, injection, capture, cool, convert, acceleration/decelerate, stripping & extraction
- identify beam-related limitations: polarities, RF, beam instrumentation, machine alignment, effective physical machine aperture, ...

Immediately followed by dedicated, scheduled Technical Stop (TS)
- needed for follow-up of HW (tunnel) and SW issues (CO, ...)

- N.B. “old machine” but completely new CO, substantial modifications

Physics operation: as promised/targeted nett 3 months (to be confirmed), grouped into 2-3 blocks interleaved with
- TS: routine maintenance → increases overall availability, follow-up of OP/CO/equipment issues + major ion species/source changes
- MDs: follow-up of beam physics issues, CO improvements (e.g. beam-based FBs), improve facility to reach nominal FAIR parameters
- N.B. also better for guaranteeing smooth restart/picking-up of physics operation after technical stops (experts availability)
Upcoming FC²WG Topics

- **2018 Controls Retrofitting**
  - 'what changes' vs. 'what will remain the same'

- **Digitisation of analog signals – mandatory pre-requisite for major MCR upgrade and move to new FCC (!!!)**
  - Clarification of which signals remain to be digitised after the CO Retrofitting for 2018
  - Choice of technology for remaining signals (CO, BI, HV, RF, …) → should aim at limited number of platforms
    - Probably open items: fast (10-100 MHz) level time- and frequency domain signals

- **RBAC & Management-of-Critical Settings (MCS) kick-off**
  - Initially concepts and required roles (ie. Operator, MP-Expert, BI-Expert, RF-Expert, …)

- **Beam Transformer Integration & Beam Transmission System (in-kind) → review by FC²WG before SPLs' sign-off**
  - Specification dead-line: soonish < Q3-2017

- **BPM integration into CO/OP concepts → part of in-kind requirements → review by FC²WG before SPLs' sign-off**

- **Detailed Dry-Run Planning – starting from November (contacted already CO, RF, EPS, HV, BI)**

- **BLM/BTM Specification + Integration, dead-line: end-2016**

- **Kicker/Septa Integration → Q2-2018**

- **Java Application & FESA Training (~ 2016/2017)**

- **New LSA-based Control Systems → OP Training?!?**
FAIR, can we do it?

Yes, we can!