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Operational Machine States and Modes

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INTRODUCTION

The life cycle of the ESS facility can be described by using four main states:

- Pre-construction,
- Construction,
- Operation,
- Decommissioning.

The scope of this document is to give an overview of "operational states", to be applied during the Construction and Operation of the ESS facility. These "operational states" (or operational machine states) refer to nominal situations of the machine (the off normal situations, such as incidents, accidents and beyond design basis accident scenarios are not considered yet).

DEFINITIONS

Definition of the ESS machine:

In this document, the ESS machine consists of the ESS Accelerator, Target Station, Integrated Control System, Energy platform, and Conventional Facility suite layout.

Definition of an "operational state[1] ":

An "operational ***state***" consists of a ***set*** of "operational ***modes***[2]".
The transition between "operational states" a) and b) implies the correct completion of state a) and the validation of 'readiness' of related ESS sub-systems for state b).

Definition of an "operational mode":

An "operational mode" consists of
- 1 "machine mode" **AND**
- 1 "beam mode".

The functions of machine and beam modes will be described in the next 2 sections.

[1] In general: The state refers to the conditions that characterize the behavior of a function or element of the system at a particular point in time.
[2] In general: A mode is a designated condition for performing a task or responding to a problem.

MACHINE MODES

Definition of the machine mode:

The machine mode provides an overview of the ***machine activity***.
Examples of such machine activity are given below:

- The machine or parts of it are powered/unpowered
- The machine or parts of it can be 'open':
  - Accessible for specific personnel for specific time intervals
- The machine or parts of it can be 'activated' (radiol.) and therefore not accessible by personnel
- The machine or parts of it can cool-down or warm-up
- The machine or parts of it can be under repair, maintenance work, installation work
- There can be beam(s) in the machine or not and if there is beam, the machine parts affected are not accessible by personnel

The machine mode refers to a ***specific machine configuration***.
This mode defines the ***source and intended destination of the p^+ beam*** within the Accelerator and Target suite layout.

Before starting any beam-based operation, all transport systems must be ready and validated to transport the p^+ beam from the source to the intended destination, as it is defined by the machine mode.

The same holds for non-beam based operation: before loading any machine mode configuration settings, the machine (or part of the machine) must be ready and validated for the setting.

The Beam Permit System as part of the Machine Protection System will perform this validation.

The source of the p^+ beam will always be the Ion source, however the destinations of the p^+ beam within the accelerator can vary. The accelerator extends from the Ion source up to the Target Station (TS) including the tuning dump (close to the Target Station).

Different intended destinations of the p^+ beam are:

- Interceptive stop (like Faraday cup in the DTL, LEBT stop, MEBT stop, etc.),
- Dump at the end of a spur,
- Tuning dump,
- Target Station.

The facility will be constructed and commissioned stepwise and it is planned to set up the machine modes according to the different construction and commissioning-steps (i.e. it should be possible to set the destination for each machine mode according to the accelerator and target station segments that have to be installed, integrated and commissioned).

The following 2 tables summarize the different machine modes.

The table refers mainly to accelerator specific machine modes and should be extended by more detailed target specific machine modes, defining the beam destination inside the TS system.

Machine Mode	Description	
ACCESS*	Access to machine or parts of it. Example: if ACCESS.DTL is *ON* then it is allowed to access the DTL section of the accelerator according to pre-defined and validated conditions.	No Beam
SHUTDOWN*	Longer period of maintenance or break. Machine is not powered or only powered on a minimum level. Example: SHUTDOWN.ACCELERATOR, SHUTDOWN.TARGET	No Beam
COOLDOWN*	Prepare specific elements in specific parts of the machine for operation (i.e. cool down).	No Beam
RECOVERY and ABORT	Typically after p^+ beam trip (RECOVERY) or abort ABORT): p^+ beam is switched 'off' AND the Target Safety System and the Personnel Protection System did not request the abort. Only the Machine Protection System (MPS) did trigger the abort. No beam is allowed and the beam extraction must be interrupted for a certain time. Currently two mitigation techniques can be applied by MPS: next pulse inhibit or fast beam abort.	No Beam
WARMUP*	Warming up of specific elements in specific parts of the machine for repair-work.	No Beam
CALIBRATION*	Could be power converter calibration in specific parts of the machine.	No Beam
NAHZ*	Non Accessible Hazardous Zones: Activated parts of the machine are cooling down. No beam is allowed and no access is allowed.	No Beam
STANDBY*	Machine or part of it is commissioned, validated and fully operational, e.g. ready for access, or ready for beams. Could be a transition (state) between operational states.	No Beam
SETUP*	Setup the machine for beam-based "tuning measurements" of different parts of the machine (diagnostics, measurements, validations) in order to prepare the machine or parts of it for (full power) beam-based operation. The beam will be sent from the source to the destination indicated by the *. Examples: • *SETUP.LEBT*: p^+ beam will be stopped in the LEBT • *SETUP.DTL.FC.4:* p^+ beam will be stopped in the DTL in a Faraday Cup, nr. 4 counted	Beam

	downstream • *SETUP.LINAC* indicates that the p^+ beam will be stopped in the tuning dump • *SETUP.ACC**: p^+ beam will be stopped in the TS systems. • This mode can have sub-modes: o *SETUP.ACC.A2T*: "performance/tuning" measurements of the A2T line as part of the accelerator (specific configuration settings are needed for the TS in this case) o *SETUP.ACC.SHIELDING*: "performance/tuning" measurements of the Shielding as part of the accelerator (specific configuration settings are needed for the TS in this case) • *SETUP.TARGET:* p^+ beam will be stopped in the TS systems. Setup of the machine for testing power on target.	
PREPARE-TARGET	Prepare machine for testing power on target. p^+ beam will be stopped in the TS systems. Neutron beams available (low power).	Beam
PRODUCTION**	Machine setting for Neutron production. p^+ beam will be stopped in the TS systems. Neutron beams available. The ** indicate different target station settings concerning the power, e.g. low power and full power (PRODUCTION.FULL-POWER or PRODUCTION.LOW-POWER).	Beam
STUDIES	Beam based studies, development and measurements.	Beam

Modes marked with a * indicate that this machine mode can be different for different parts of the machine. As an example: Access can be different for the LEBT and the MEBT, i.e. ACCESS.LEBT can be OK and ACCESS.MEBT can be NOK, etc. (see table below).

Machine Mode	**Related sub modes (examples only, list is not complete)**
ACCESS*	SOURCE, LEBT, RFQ, MEBT, DTL, SPOKES, MEDIUM-B, HIGH-B, HEBT, TARGET and its sub-systems, DUMP(s)
SHUTDOWN*	ACCELERATOR, TARGET, CONVENTIONAL FACILITIES, ENERGY, ICS
COOLDOWN*	tbd
WARMUP*	tbd
CALIBRATION*	tbd
STANDBY*	LINAC, A2T, TARGET
SETUP*	LEBT, MEBT, DUMP, FC, LINAC, ACC.A2T, ACC.SHIELDING, TARGET

BEAM MODES

Definition of beam mode:

The beam mode is defined through pre-defined beam properties, like peak current, pulse structure, beam energy, pulse repetition rate, etc.

At least four main p^+ beam modes are required in order to commission and to operate the accelerator and the Target Station: 1-2 probe beam modes, 1-2 production modes and 2-3 setup beam modes:

1. Probe Beam Mode:
    a. Beam parameters are set up such that the beam is considered to be "safe", i.e. the p^+ beam can go to any destination without causing damage. A reasonable damage level and its margin must be defined.
    b. All interceptive devices/stops are allowed to go *IN*.
2. Power Production Mode:
    a. Full power (full pulse charge allowed)
    b. Reduced power
3. Setup Mode(s)

The following table summarizes the different p^+ beam modes and their sub modes (not complete!).

p+ Beam Modes	Description
No-Beam	No beam is allowed in the machine
Probe-Beam.LINAC Probe-Beam.A2T	Defined to be a safe beam, which can't damage any element along the beam pipes concerned (from source up to the pre-defined destination, i.e. in case of Probe-Beam.LINAC, the beam must be 'safe' from the source up to the tuning dump and in case of Probe-Beam.A2T the beam must be 'safe' up to the target, including safety for the TS systems)
Setup-Beam.LINAC Setup-Beam.A2T Setup-Beam.Target	Parameters of such beams allow for several diagnostics measurements in order to prepare either the LINAC or the A2T line to be ready for operation. Setup-Beam.Target indicates beam settings, which allow the beam-based preparation of the target for ramping up in power.
Prepare-Physics-Beam	Beam settings which allow to validate that the target is ready for full power (or low power)
Stable-Beam.Low-Power Stable-Beam.Full-Power	Beam settings needed for constant and 'long-term' full (low) power production
Beam-Trip	The p^+ beam is switched 'off' AND the Target Safety System and the Personnel Protection System did not request the abort. Only the Machine Protection System did trigger the abort. The beam production is interrupted for a short time only (Next Pulse Inhibit).

	Beam Trip is not referred to a parameter set! but as: Beam is "outside" a pre-defined parameter set.
Beam-Abort	The p^+ beam is switched 'off' AND the Target Safety System and the Personnel Protection System did not request the abort. Only the Machine Protection System did trigger the abort, however the origin of the failure needs a longer interruption of the beam production (Fast Beam Abort). Beam Abort is not referred to a parameter set! but as: Beam is "outside" a pre-defined beam parameter set.

The number of p^+ beam modes might change later on during ESS construction and operation.

Examples of possible p^+ beam parameters for some p^+ beam modes are listed in the table below.
Please note that the table gives only examples and NOT final beam parameters! Margins need to be applied, criticalities, abort thresholds.

p^+ Beam Mode	**Pulse Length [µs]**	**Peak Current [mA]**	**Repetition Rate [Hz]**	**Power @ 2.5GeV [kW]**	**Destination**
Probe-Beam.A2T	10±x	50±x	(1 or 14) ±x	17.5 (@14 Hz)	Target, all tuning dumps, interceptive devices
Setup-Beam.LINAC	100±x	50±x	1±x	13.1	Target, all tuning dumps, interceptive devices
Stable-Beam.Full-Power	2860±x	50±x	14±x	5005	all

The matrix below provides an overview on the operational modes, i.e. the different machine and beam mode combinations. Modes marked with a * have different settings for different parts of the machine.
Modes marked with ** indicate that the part of the machine has been commissioned and is fully operational, i.e. ready for beam (like STANDBY.LINAC means that the LINAC is ready for beam injection). Such modes refer to transitions between operational states (see introduction of this document).
Modes marked with *** indicate differences concerning the power, e.g. low power and full power (PRODUCTION.FULL-POWER or PRODUCTION.LOW-POWER). A probe beam refers to safe beam settings, i.e. this beam is considered to be safe throughout the part of the machine concerned and no damage can occur. Probe beam settings can be different for the LINAC (ending

in the tuning dump line) and the A2T line (ending in the Target Station). The setup beam refers to settings, which allow measurements for diagnostic and tuning purposes, i.e. preparation for full power operation.

BEAM MODE	MACHINE MODE	SHUTDOWN*	COOLDOWN*	ACCESS*	WARMUP*	CALIBRATION*	RECOVERY	ABORT	NAHZ*	STANDBY**	SETUP*	PREPARE-TARGET	PRODUCTION***	STUDIES
	NO-BEAM	X	X	X	X	X	X	X	X	X				X
	PROBE-BEAM*										X			X
	SETUP-BEAM*										X			X
	PREPARE-PHYSICS-BEAM											X		X
	STABLE-BEAM***												X	X
	BEAM-TRIP												X	X
	BEAM-ABORT						X			X	X	X	X	X