Machine Protection Systems:

**Local Hardware Trip:** This describes any special systems which perform very fast (<100usec) trips on interlocks. Reverse power detection for klystrons is an example.

**Local MPS:** This is protection for self-contained sub systems. An example is the system to shut down a modulator when a klystron arc is detected. These systems report a summary status to the global MPS.

Local MPS will use a micro controller that looks at analog and digital inputs. In general, redundancy is not required as local shutdowns will not prevent machine operation.

**Global MPS:** This system looks at global interlocks, and summaries from local MPS systems. It contains logic to shut down large parts of the accelerator if faults are detected.

Global MPS will use a pair of central processors. Each processor has its own data network to the input and output devices. It is assumed that if a processor fails, it will not produce well formed messages and so voting is not required. The inputs to the networks will be from 2/3 redundant sensors.

**MAID:** This is the system which looks at the beam parameters on a pulse and, if they are within specifications, allows the next pulse to be delivered normally. If the beam is disabled, this system requires a standard ramp of emittance and current over the next set of pulses. The MAID system controls the beam through the global MPS system.

**Fast Beam Abort:** This system takes a summary of a limited set of fast interlocks to abort a beam pulse just before beam time. The abort delay is dominated by speed of light delays from the inter-locked device to the nearest dumper.

Fast beam abort contains two sub-systems: fast trip, and diagnostics. The fast trip is essentially a long heliax cable which can receive a trip pulse from any of a number of devices along its length. The diagnostic section will indicate which device has tripped, and verify that a trip pulse was received.

Note that proper system design may be able to eliminate the need for this system.

**LEM:** Linac energy management. This system activates spare 8-packs, or structure triplets within 8-packs to maintain beam energy throughout the linac. It adjusts lattices (if possible) to compensate for failed devices.

**VETO:** This system collects information on all Machine protection trips to allow filtering of data acquisition and display.
**High power RF:**

**Klystron arcs:** This system protects against high voltage arcs in the klystrons or modulators.
- **Detection:** overcurrent.
- **Local MPS:**
  1. Trip Modulator.
  2. Wait 1 second for vacuum burst.
  3. Re-apply power on standby.
  4. If a second trip occurs within 1 minute, Reduce HV, try again.
- **Global MPS:** Add to count of inactive 8-packs for this pulse
- **MAID:** N/A
- **Fast Beam Abort:** N/A
- **LEM:** Notify LEM that this 8-pack will be offline next pulse. 8-pack will be spare after local MPS recovery (with energy gain determined by maximum operating voltage).
- **VETO:** Mark pulse as “minor energy error”

**RF Arches:** This system protects against high power RF arcs in the DLDS or structures.
- **Detection:** Reflected power, power detector imbalance
- **Local Hardware Trip:** Immediate disable of RF drive.
- **Local MPS:**
  1. Disable RF drive.
  2. Move Modulator to standby.
  3. Wait 1 second for vacuum burst.
  4. Re-apply power on standby.
  5. If a second trip occurs within 1 minute, Drive single triplets, look for fault.
- **Global MPS:** Add to count of inactive 8-packs for this pulse.
- **MAID:** N/A
- **Fast Beam Abort:** N/A
- **LEM:** Notify LEM that this 8-pack will be offline next pulse. 8-pack will be spare after local MPS recovery (Possibly with one or more triplets disabled).
- **VETO:** Mark pulse as “minor energy error”

**Vacuum:** This protects against vacuum bursts in the DLDS.
- **Detection:** Vacuum gauge
- **Local MPS:**
  1. Disable RF drive.
  2. Move Modulator to standby.
  3. Wait 10 seconds for burst to recover. If not, mark 8-pack offline.
  4. Re-apply power on standby.
  5. If a second trip occurs within 1 hour, disable 8-pack.
- **Global MPS:**
  1. If pressure passes second trip point, Trip full global MPS, close fast valves.
  2. Otherwise, Add to count of inactive 8-packs
- **MAID:** None, unless Global MPS trip point is passed.
- **Fast Beam Abort:** N/A
LEM: Notify LEM that this 8-pack will be offline next pulse. 8-pack will be spare after local MPS recovery
VETO: N/A

**DLDS Sequencing Errors:** This protects against hardware or software errors causing excessive average power to be delivered to a triplet of structures.
- **Detection:** Mode amplitude detectors at the launch of the DLDS detect excessive power directed to a triplet of structures.
- **Local Hardware Trip:** Immediate (100ns) trip of RF drive.
- **Local MPS:**
  1. Disable RF drive.
  2. Move Modulator to standby.
  3. Operator intervention required to restore unit
- **Global MPS:** Add to count of inactive 8-packs
- **MAID:** N/A
- **Fast Beam Abort:** N/A

LEM: Notify LEM that this 8-pack will be offline next pulse.
VETO: Mark pulse as “minor energy error”

**Minor Phase / Amplitude Errors:** This protects against minor failures in the RF drive system which could result in beam energy errors.
- **Detection:** The output phase and amplitude of each waveguide mode is measured and digitized. The LLRF control system checks to see that the waveforms are within specifications.
- **Local MPS:**
  1. Move Modulator to standby.
  2. Wait 1 minute to check for additional failures
  3. If no additional failures, return to active spares. Otherwise mark offline.
- **Global MPS:** Add to count of inactive 8-packs
- **MAID:** N/A
- **Fast Beam Abort:** N/A

LEM: Notify LEM that this 8-pack will be offline next pulse.
VETO: Mark pulse as “minor energy error”

**Over Temperature:** This protects against over temperature, on waveguide, and water systems. Sensors on RF components, water systems, structures.
- **Detection:** Thermocouple
- **Local MPS:**
  1. Disable RF drive.
  2. Move Modulator to standby.
  3. Wait 1 minute for recovery
  4. Restore power
  5. Wait 10 minutes with unit on standby
  6. If good, return to service, otherwise set offline.
- **Global MPS:** Add to count of inactive 8-packs
- **MAID:** N/A
- **Fast Beam Abort:** N/A
LEM: Notify LEM that this 8-pack will be offline next pulse.
VETO: N/A

Water Interlock: This checks water pressure and flow.
Local MPS:
1. Wait 1 second for interlock to clear (water bubble, etc.).
2. If not clear, disable 8-Pack (or other subsystem).
Global MPS: Add to count of inactive 8-packs
MAID: N/A
Fast Beam Abort: N/A
LEM: Notify LEM that this 8-pack will be offline next pulse.
VETO: N/A

Water Leak: This checks for water leaks.
Detection: Level sensor, Flow balance (dual flow meters). Total flow in / out of an 8-pack system is measured.
Local MPS:
1. Wait 10 seconds for interlock to clear (water bubble, etc.).
2. If not clear, disable 8-Pack (or other subsystem).
3. Shut down water system.
Global MPS: Add to count of inactive 8-packs
MAID: N/A
Fast Beam Abort: N/A
LEM: Notify LEM that this 8-pack will be offline next pulse.
VETO: N/A

Critical High Power RF Systems: These include the bunch compressors, first structures of each linac, and the crab cavity. This system is in addition to the normal RF machine protection system.
Detection: Each system will have a very long DLDS pipe. Phase and amplitude detectors at the start of the pipe will be compared with AFG pulse shapes. Note that the pipe must be long enough to allow a fast beam abort.
Local MPS:
1. Move Modulator to standby.
2. Wait 1 minute to check for additional failures
3. If no additional failures, return online.
Global MPS: Mark unit as down, and offline.
MAID: Beam off, start ramp after interlocks clear.
Fast Beam Abort: Trip first upstream abort kicker. In some cases, also trip downstream kicker.
LEM: Bring spare (if any) online.
VETO: Mark pulse as “BAD”

Additional notes on critical RF systems: Where possible, critical systems should be designed out of the accelerator. Examples:
Bunch Compressor: Use multiple klystrons driving separate sets of structures, rather than an 8-pack. This will reduce the effect of the failure of a single system. In addition, energy collimation in the chicane will reduce the risk of downstream damage.

Early Structures: For the low energy part of each linac, use separate klystrons rather than 8-packs to reduce the effect of a single failure.

**Magnets:**

**Fast Field Changes:** Due to power supply, cable, or magnet failures.
- **Detection:** AC coupled voltage and current trip points on power supply.
- **Local MPS:** N/A
- **Global MPS:**
  - MAID: Beam off, Start ramp after 1 second.
  - **Fast Beam Abort:** Trip first upstream abort kicker.
- **LEM:** N/A
- **VETO:** Mark pulse as “BAD”

**Current / Voltage out of tolerance:** Due to power supply, cable, or magnet problems
- **Detection:** Current and voltage measurement with independent ADCs.
- **Local MPS:** N/A
- **Global MPS:** Stop beam.
  - MAID: Beam off, Start ramp after 1 second if problem clears.
- **Fast Beam Abort:** Trip first upstream abort kicker.
- **LEM:** If problem does not reset, look for alternate lattice with magnet disabled.
- **VETO:** Mark pulse as “BAD”.

Note: It may be possible to replace the fast beam abort system with the maid system if the magnets can be designed to prevent their fields from changing significantly in an interpulse period.

**Water Flow, Water leak, Temperature:** The actions for these failures are the same as for the equivalent failure in an 8-pack, except the beam is disabled while the magnets are off.

**Other Beamline Devices:**

**Catastrophic Vacuum Leak:** These interlocks are used to detect a vacuum leak which results in pressures sufficient to disrupt the accelerator beam. A catastrophic leak to atmosphere will result in beam loss over ~ 1 radiation length. This will produce a single shot dose on the order of tens of kilorads. This should not cause catastrophic radiation damage. It is possible that the “blow torch” damage from the beam will be significant, but the affected structures will already be vented, and probably destroyed.
- **Detection:** Fast vacuum gauge. Possibly a corona breakdown gauge. 2/3 Voting system.
- **Local Hardware Trip:** Close fast valves.
- **Local MPS:** N/A
- **Global MPS:** Stop beam and RF. Operator intervention required to restart.
MAID: N/A
Fast Beam Abort: Trip first upstream abort kicker.
LEM: N/A
VETO: N/A

Small Vacuum Leak: From various causes.
Detection: Standard Vacuum gauges (cold cathode?). 2/3 redundant.
Local MPS: N/A
Global MPS:
1. Stop beam and RF.
2. Wait 10 seconds for leak to clear / degrade
3. If OK, restart RF.
4. If OK after 10 seconds, restart Beam.
MAID: Beam off. Ramp beam after 10 seconds.
Fast Beam Abort: N/A
LEM: N/A
VETO: N/A

Radiation Detection: This detects radiation due to beam loss. Due to the high beam power, this is probably the most sensitive beam loss detection.
Detection: PLIC cable, with peak detect, Discrete Ion chamber.
Local MPS: N/A
Global MPS:
1. Stop beam.
2. On repeat trips, operator intervention required.
MAID: Beam off. Begin to ramp beam.
Fast Beam Abort: N/A
LEM: N/A
VETO: Mark pulse as “BAD”

Runaway Mover: This detects uncommanded motion of the magnet or structure movers.
Detection: BPM / Maid system
Local MPS: N/A
Global MPS:
1. Stop beam.
2. Allow diagnostic pulse
MAID: Beam off. Begin to ramp beam.
Fast Beam Abort: N/A
LEM: N/A
VETO: Mark pulse as “BAD”.

Note: Movers should be designed so that they cannot move out of limits in an interpulse period.

Valve and Stopper status: This checks for any beam obstructing devices.
Detection: Direct interlocks to global MPS
Local MPS: N/A
Global MPS:
1. Stop beam.
2. Operator intervention required.

MAID: N/A
Fast Beam Abort: N/A
LEM: N/A
VETO: N/A

Global Systems:

AC power: This protects against problems caused by glitches in the AC power distribution system.

Detection: AC power spike detectors in each sector (2/3 redundant)
Local MPS: N/A
Global MPS:
1. Stop beam.
2. Allow diagnostic pulse
MAID: Beam off. Begin to ramp beam.
Fast Beam Abort: Abort beam.
LEM: N/A
VETO: Mark pulse as “BAD”.

Timing System: This protects against loss of timing signals.

Local MPS: N/A
Global MPS:
1. Stop beam.
2. Allow diagnostic pulse
MAID: Beam off. Begin to ramp beam.
Fast Beam Abort: Abort beam.
LEM: N/A
VETO: Mark pulse as “BAD”.

Control System: Checks for a global failure of the control system or network.

Detection: Look for missing “OK” signal on control networks. Trip if both failed.
Local MPS: N/A
Global MPS: Stop beam. Operator intervention required.
MAID: N/A
Fast Beam Abort: N/A
LEM: N/A
VETO: Mark pulse as “OFF”.
Machine Protection Systems Overview

- BPMs
- Control System
- Local Hardware Trip
- Local MPS
- Local Interlocks
- Global MPS A
- Global MPS B
- Dual MPS nets
- Fast Detectors
- MAID
- Local Shutoff Device
- Network
- 2/3 Vote
- Fast Beam Abort A
- Fast Beam Abort B
- Fast Beam Abort C
- Fast interlock
- Trip
- Control network (dual?)
- X3

Local MPS Network
Global MPS (Radiation detector example)

Ion Chamber → Comparator → DAC → Network → MPS Controller → Net A

Ion Chamber → Comparator → DAC → Network → MPS Controller → Net B

Control system Network

DAC

Network

MPS Controller

Net A

Net B

Dumper 1

Dumper 2
Fast Beam Abort 1 of 3 channels shown

100MHz Source

End of Linac

FBA module

Switch

MPS interface

Detector

Setpoint from control system

Detector

3/2 Vote

To Abort Device

MPS interface

From other channels

To other abort device