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Title:	Closed-Loop EPICS EPID Control on CompactRIO for the IPF Water Skid at LANSCE
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Closed-Loop EPICS EPID Control on CompactRIO for the IPF Water Skid at LANSCE

EPID EPICS Module

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Current systemPID

PLC Main Program

- Mode logic and transitions
- Discrete control and sequencing
- Alarms and computed readiness
- Global permissives and interlocks

PLC PID Program

- Analog command preparation
- Analog readback housekeeping
- PID execution and mode selection
- Valve output handling

EPICS SoftIOC

- Reads/writes PLC interface arrays
- 1-second scan for most readbacks
- Autosaves setpoints and alarm limits
- Preserves PV names and EDM semantics

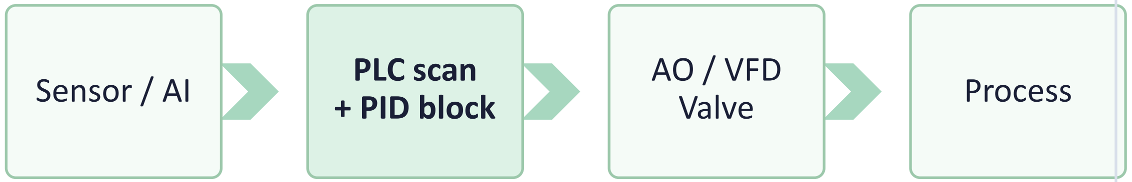
PLC PID strategy: one active owner per process objective

Mode / function	Controlling valve	Process variable	Setpoint	Why it matters
Production	**CV-212**	FIT-252 IPFD252D01	IPSP035P01 Set Point[35]	CV-221 is expected shut for readiness
Purify / Standby	**CV-221**	FIT-252 IPFD252D01	IPSP040P01 Set Point[40]	This loop owns HX flow outside production
Transfer tube level	**CV-235**	LIT-226 IPLV226D01	IPSP039P01 Set Point[39]	Independent level-control loop

Where the control loop lives

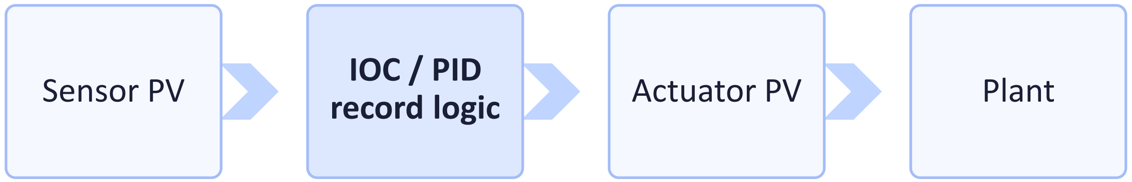
Loop location determines latency, jitter tolerance, and what happens during network or IOC disturbances.

PLC PID architecture



- Low transport latency
- Predictable scan execution
- Controller survives HMI/EPICS disruption

EPICS std module PID architecture



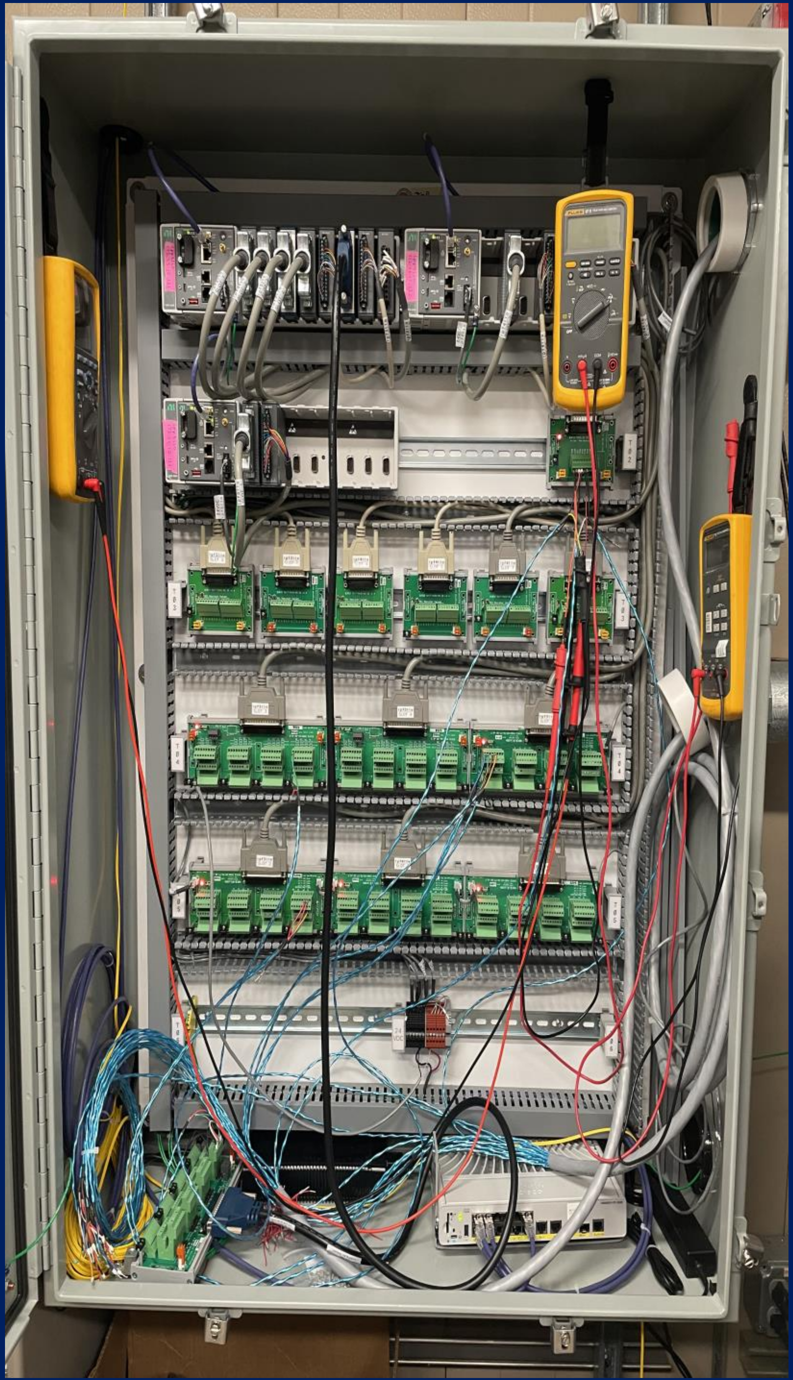
- Flexible PV wiring
- Easy scripting, archiving, displays
- More exposed to host and network jitter

Architecture implemented

Three separate EPICS IOCs:

- ipf3iio: core analog/discrete I/O, control-valve analog commands and readbacks, and EPICS PID (epid) loops.
- ipf4iio: discrete valve and pump coil outputs plus proof/timeout logic for commanded operations.
- ipf5iio: mode/state logic, sequencing/lineups, permissives, PID enable gating, setpoints, and EDM-compatibility PVs.

Hardware addressing is defined in substitutions using C# S# channel mapping; this provides traceable mapping from physical wiring to PVs.



Process and PLC Behavior

The IPF water skid is the closed-loop cooling and water-handling system for the irradiation target.

It:

- Circulates de-ionized water through the target and heat exchanger.
- Maintains the vertical transfer tube essentially full of water to avoid air slugs.
- Manages inventory between:
  - Receiver tank TK-208 (LIT-219 → `TIPLV219D01`),
  - Holding tank TK-209 (LIT-243 → `TIPLV243D01`),
  - Sump TK-210,
  - RLW load-out.
- Monitors flow, level, pressure, temperature, conductivity, radiation, chain tension.
- Provides the water-related interlocks and OK bits that feed Target Ready / Run Permit.

What the PLC Does

Today the legacy PLC:

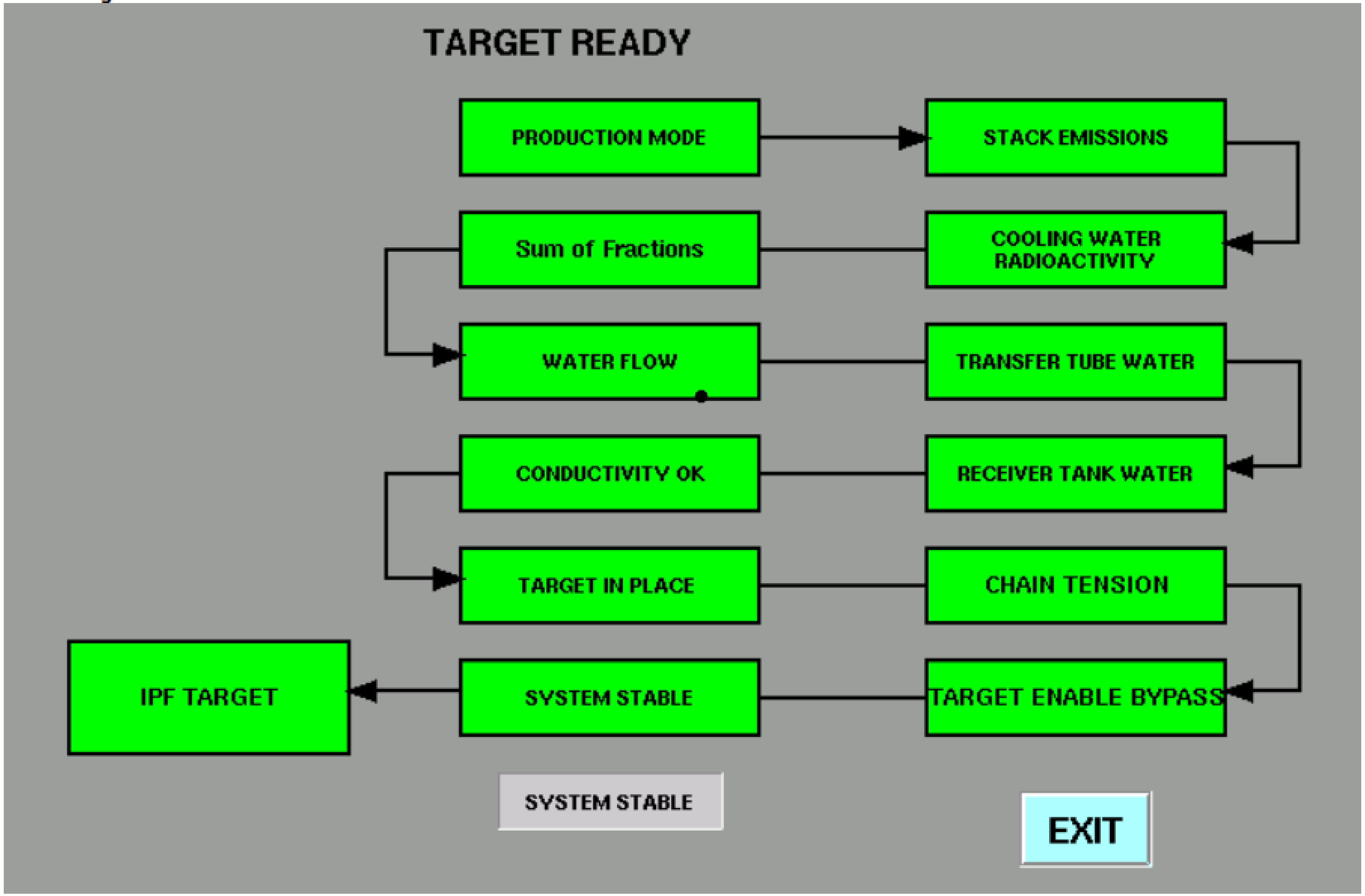
- Reads all AIs (flows, levels, pressures, temperatures, conductivity) and DIs (level switches, flow switches, valve limit switches, pump starters) every scan.
- Runs the PID blocks:
  - `CV_212_PID`: FIT-252 → CV-212, SP `Set_Point[35]` = 55 gpm.
  - `CV_221_PID`: FIT-252 → CV-221, SP `Set_Point[40]` = 35 gpm.
  - `CV_235_PID`: LIT-226 → CV-235, SP `Set_Point[39]` = 95%.
- Maintains the `Set_Point[]` array and uses those entries in PIDs and alarms.
- Evaluates each `Alarm[n]` rung to set bits such as Low Target Flow, Low Transfer Tube Level, Receiver Tank Low, etc.
- Combines Card-0 hardwired interlocks and alarms into intermediate OK bits: Flow_OK, Level_OK, Cond_OK, Chain_Tension_OK, Kanne_OK, System_Stable.
- ANDs those together to form the Target Ready / Run Permit bit (e.g. `TIPRN004L11` in the PLC, "IPF Target Ready SUM (RP)").

Target Ready Screen – PVs Behind It

In `target_ready.edl`, each green box is an `activeRectangle` whose `alarmPv` is one of the TIPMO/TIPRN bits:

- PRODUCTION MODE: `IPMO001L03`.
- WATER FLOW: `IPRN004L03` (Target Flow OK).
- TRANSFER TUBE WATER: `IPRN004L04`.
- RECEIVER TANK WATER: `IPRN004L05`.
- CONDUCTIVITY OK: `IPRN004L06`.
- CHAIN TENSION: `IPRN004L08`.
- SYSTEM STABLE: `IPRN004L09`.
- STACK EMISSIONS / COOLING WATER RADIOACTIVITY: `IPRN004L12`/`IPRN004L13`.
- IPF TARGET: `IPRN004L11` (Target Ready SUM).

Target Ready Screen – Screenshot



Run Permit Screen – Mapping

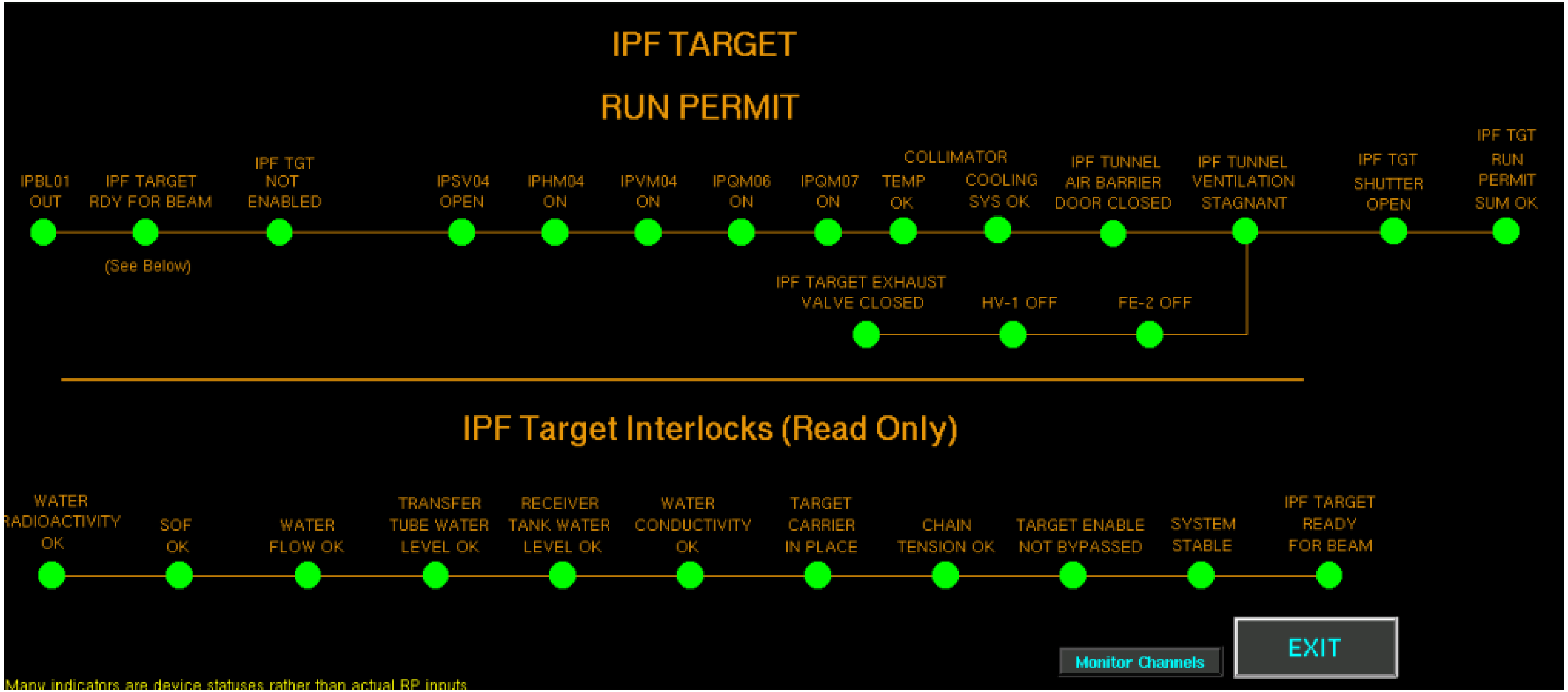
The IPF Target Run Permit screen shows:

Top row (RUN PERMIT chain): beamline valves open, monitor conditions OK, collimator cooling OK, tunnel ventilation OK, shutter open, etc.

Bottom row (IPF Target Interlocks):

- WATER RADIOACTIVITY OK (Rad/Kanne bits).
- SOF OK (Sum of Fractions).
- WATER FLOW OK → `IPF:INTLK:FLOW_OK`.
- TRANSFER TUBE WATER LEVEL OK, RECEIVER TANK WATER LEVEL OK → `IPF:INTLK:LEVEL_OK`.
- WATER CONDUCTIVITY OK → `IPF:INTLK:COND_OK`.
- TARGET CARRIER IN PLACE, CHAIN TENSION OK, TARGET ENABLE NOT BYPASSED, SYSTEM STABLE.
- IPF TARGET READY FOR BEAM → `IPF:RP:READY`.

Run Permit Screen – Screenshot



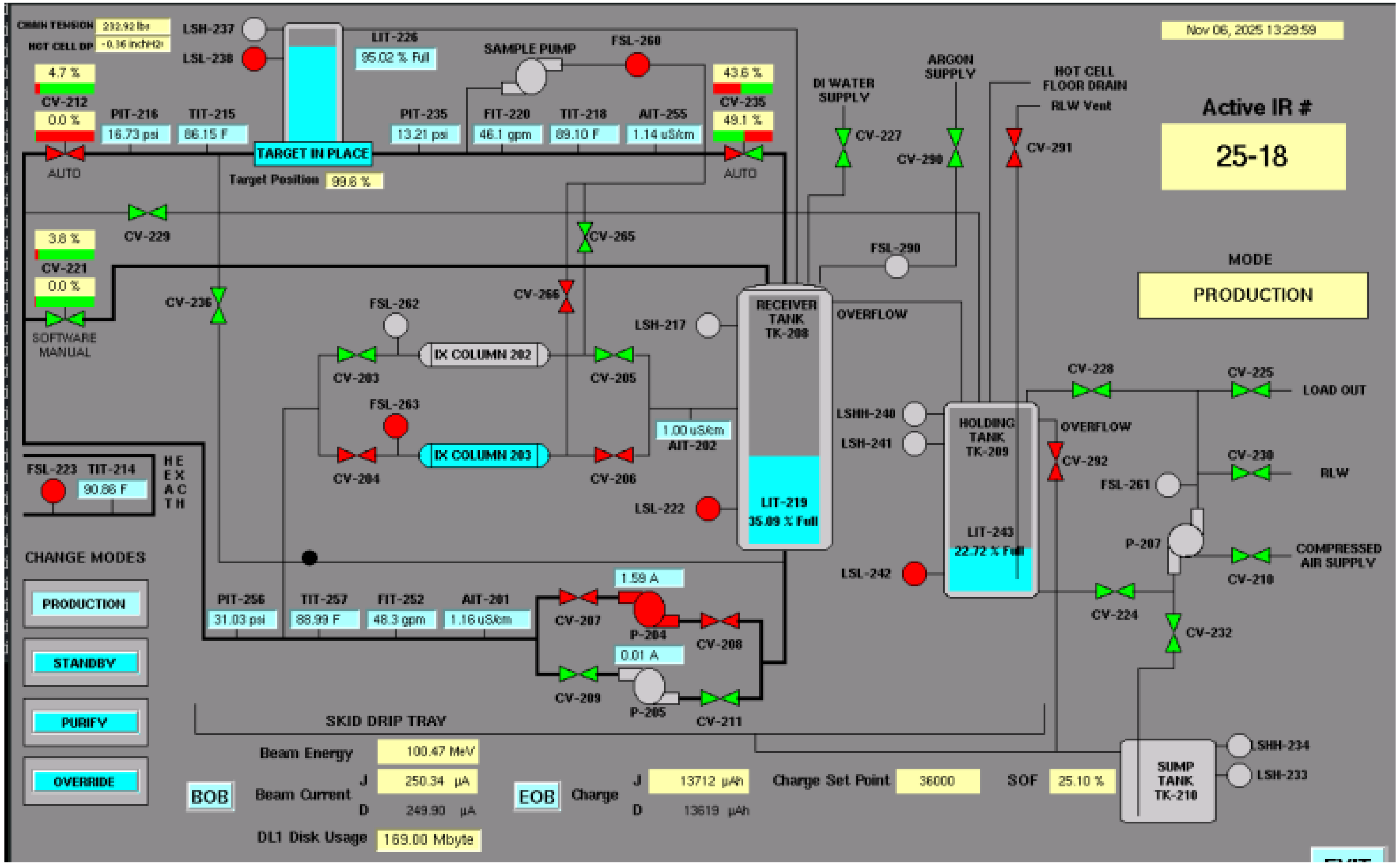
The bottom row is a visual summary of `IPF:INTLK:*_OK` bits plus `IPF:RP:READY`.

Overview Screen – PV Map

The main overview screen (overview.edl) is the P&ID mimic. It shows:

- Bars for `IPLV226D01`, `IPLV219D01`, `IPLV243D01` (transfer tube, receiver, holding tank).
- Numeric readouts for `IPFD252D01` (FIT-252), pressures, temperatures, conductivity.
- Valve symbols driven by `IPSV207L01/IPSV207L02`, `IPSV208L01/IPSV208L02`, `IPSV224L01/IPSV224L02`, `IPSV229L01/IPSV229L02`, `IPSV292L01/IPSV292L02`, etc.
- Pump symbols and currents for P-204, P-205, the sample pump.
- Mode indicator and target bits from `IPMO001Lxx`, `IPTW001Z01`, etc.

Overview Screen – Screenshot



New Architecture: FPGA + EPICS

We split the PLC's responsibilities across:

LabVIEW FPGA bitfile:

- Card-0 composite interlocks: `Tanks_Level_OK`, `Cooling_Flow_OK`, `Inert_Gas_OK`, `Transfer_Tube_Level_OK`.
- Raw NI I/O scanning and simple local protection.

Hardware IOCs (ipf3iio, ipf4iio, ipf5iio):

- ipf3iio: analog inputs (flows, levels, pressures), AOs for CV-212/221/235, PIDs.
- ipf4iio: digital I/O for valves and pumps, level/flow switches.
- ipf5iio: mode bits, TIPMO/TIPRN summary bits, Run Permit interface.

Soft IOC (ipf-soft / IPFLOGIC):

- IPAS alarms (`IPASxxxL01`), setpoints (`TIPSPxxxP01`), derived PVs, OK bits (`IPF:INTLK:*_OK`), Run Permit (`IPF:RP:READY`), and mode logic.

Main Loops and Key PVs

Flow loop (FIT-252):

- PV: `TIPFD252D01`.
- Production controller: CV-212 PID, OUT `TIPAW212P01`, SP `TIPSP035P01` (~55 gpm).
- Standby/Purify controller: CV-221 PID, OUT `TIPAW221P01`, SP `TIPSP040P01` (~35 gpm).

Transfer-tube level loop (LIT-226):

- PV: `TIPLV226D01`.
- Controller: CV-235, OUT `TIPAW235P01`, SP `TIPSP039P01` (~95%).

Tanks:

- TK-208 receiver: `TIPLV219D01`.
- TK-209 holding: `TIPLV243D01`.

Requesting Production – Mode Command

To move from Standby to Production, the operator presses "GO TO PRODUCTION."

On the PLC this asserts the mode command bit IPMO001B03. The mode logic then checks:

- Tanks_Level_OK, Cooling_Flow_OK, Inert_Gas_OK, Transfer_Tube_Level_OK from Card-0.
- IPF:INTLK:COND_OK for water quality.
- IPF:INTLK:TARGET_ENABLE_OK for target enable or bypass.
- Any alarm or condition that should prevent Production.

If any prerequisite fails, the mode change is blocked and an IPAS alarm asserts. If they all pass, the PLC latches the Production mode bit IPMO001L03 and the system prepares to hand off the flow loop from CV-221 to CV-212.

Flow Loop Handoff – Standby vs Production

The main behavioral difference between Standby and Production is *which* valve is used to satisfy the FIT-252 flow setpoint.

In Standby:

- CV-221 PID is in AUTO: PV `TIPFD252D01`, OUT `TIPAW221P01`, SP `TIPSP040P01` (∼35 gpm).
- CV-212 PID is parked.

Once Production is enabled and `IPF:RP:READY`=1:

- CV-212 PID is put into AUTO: PV `TIPFD252D01`, OUT `TIPAW212P01`, SP `TIPSP035P01` (∼55 gpm).
- CV-221 PID is placed in MAN or its output is parked/closed.

Both loops use the same PV `TIPFD252D01`. The mode logic swaps which PID is allowed to be the controller and which setpoint is used.

Production Mode – Example Snapshot

In a typical Production snapshot:

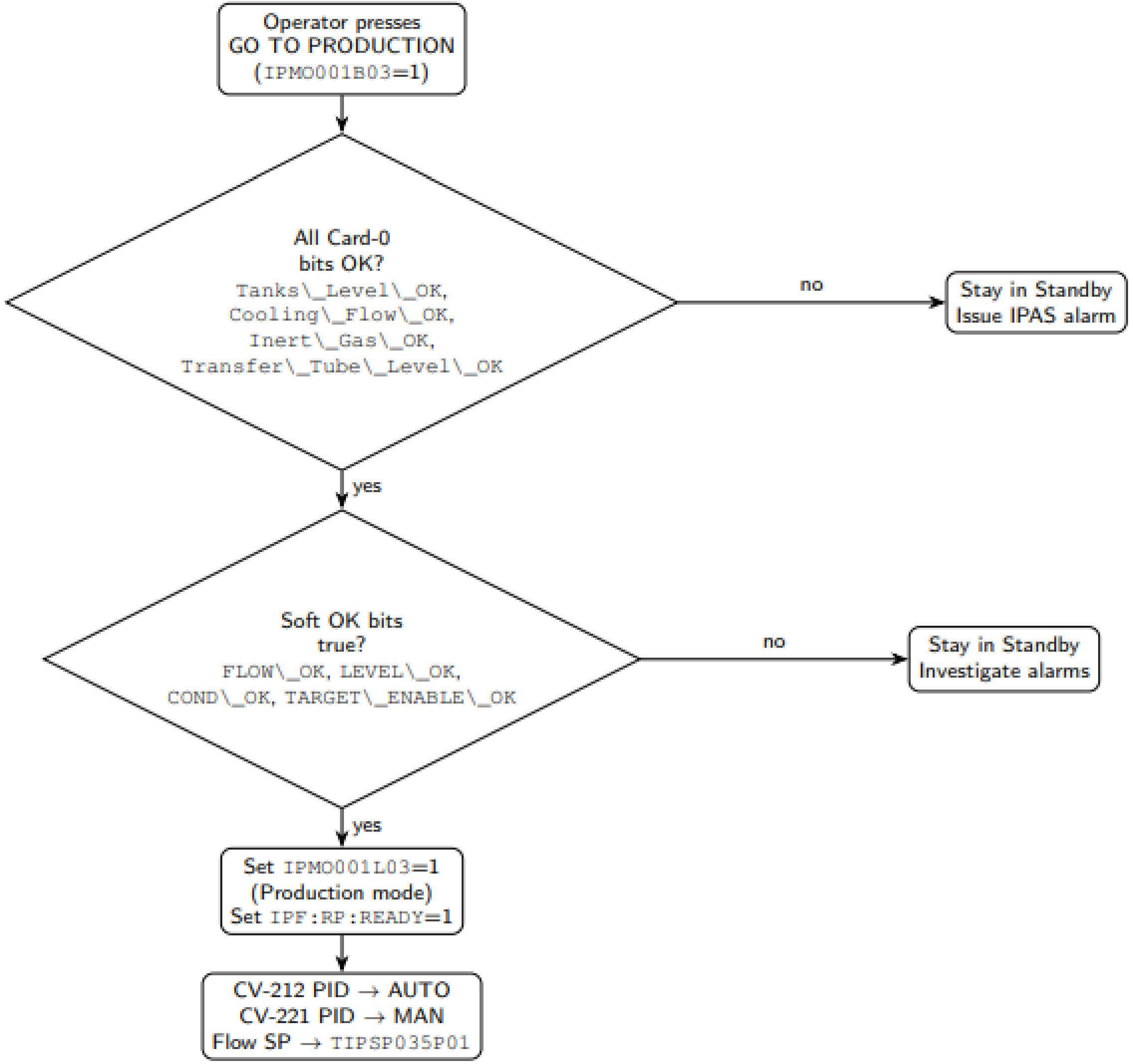
- Mode is PRODUCTION: `IPMO001L03` = 1 and `IPF:RP:READY` = 1.
- Flow: `TIPFD252D01` is held near `TIPSP035P01` (55 gpm) by the CV-212 PID (OUT `TIPAW212P01`); CV-221 PID is in MAN and parked.
- Transfer-tube level: `TIPLV226D01` is held near `TIPSP039P01` (95%) by the CV-235 PID (OUT `TIPAW235P01`).
- Receiver and holding tanks: `TIPLV219D01` and `TIPLV243D01` are inside their allowed bands.
- Routing: P-204 running (motor current and ON status true), with CV-207/CV-208 open, moving water between the skid drip tray and the tanks.
- Interlocks: Card-0 bits `Tanks_Level_OK`, `Cooling_Flow_OK`, `Transfer_Tube_Level_OK` are all 1; OK bits `FLOW_OK`, `LEVEL_OK`, `COND_OK`, `TARGET_ENABLE_OK` are all 1.

Production → Standby – What Changes

When the operator requests Standby from Production (e.g. IPMO001B04 asserted):

- The logic clears IPMO001L03 (Production) and sets IPMO001L04 (Standby) once the transition is safe.
- The CV-212 PID is taken out of AUTO and its output is ramped or clamped toward a safe parked position.
- The CV-221 PID is re-enabled in AUTO with PV TIPFD252D01, OUT TIPAW221P01, SP TIPSP040P01 (lower standby flow).
- FIT-252 flow TIPFD252D01 transitions from the production setpoint down to the standby setpoint.
- The CV-235 PID continues to hold TIPLV226D01 at TIPSP039P01; tanks and routing continue operating at the lower flow.
- Interlocks continue running; IPF:RP:READY is dropped and Production is no longer permitted, but the skid remains in a safe, controlled state.

Flowchart – Standby → Production Transition



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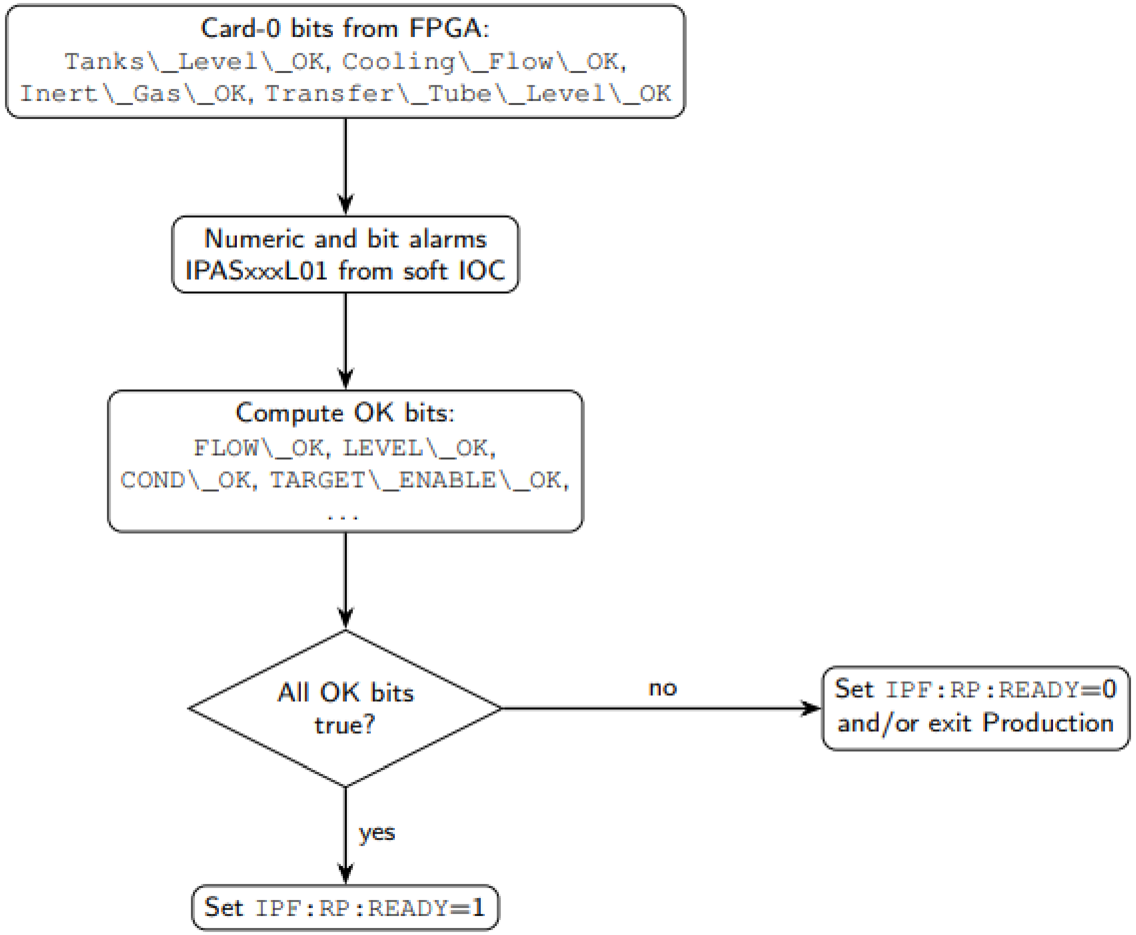
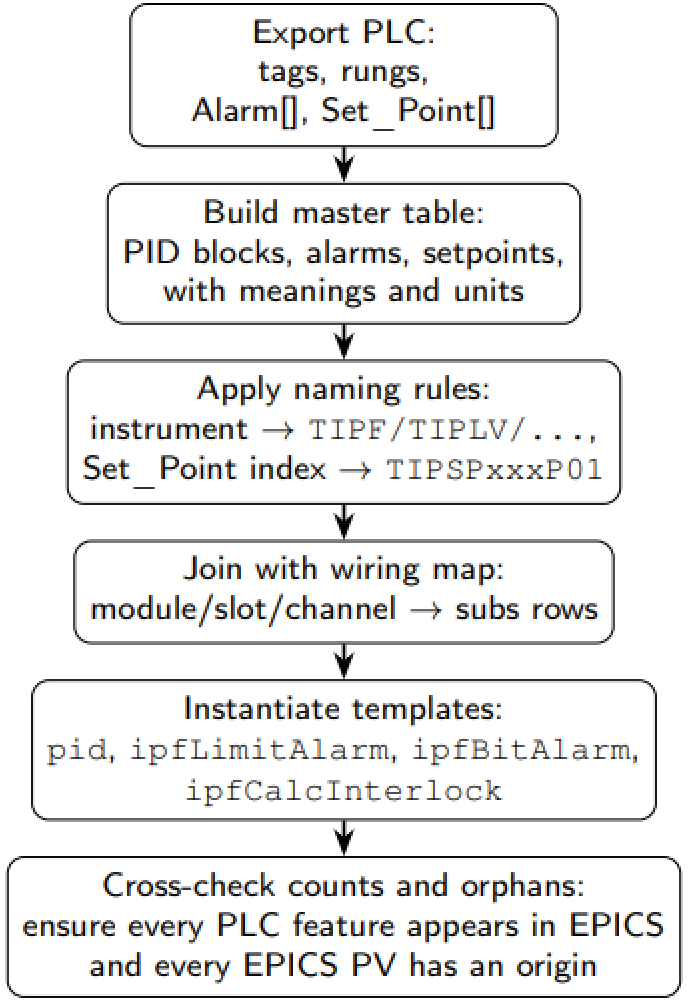
Flowchart – Run Permit Evaluation



Flowchart – PLC → EPICS Mapping Workflow



Example: CV_212_PID Mapping

beginframe[fragile]Example: CV_212_PID Mapping PLC `CV_212_PID`:

- PV: `FIT252_Heat_Exchanger_Flow` (FIT-252).
- SP: `Set_Point[35]` = 55.0 gpm.
- AO: `CV_212_analog_cmd`.
- Gains: Kp = 0.06, Ki = 0.04, Kd = 0.005.

EPICS `pid.template` row:

```
{"IPF:", "CV_212", "TIPFD252D01", "TIPAW212P01",
 "55.0","0.06","0.04","0.005","0.1","0","100"}
```

Resulting record:

```
record(pid, "IPF:CV_212:PID") {
   field(INP, "TIPFD252D01") # PV = FIT-252
   field(OUT, "TIPAW212P01") # AO to CV-212 I/P
   field(SP, "TIPSP035P01") # Set_Point[35]
   field(KP, "0.06")
   field(KI, "0.04")
   field(KD, "0.005")
}
```

PLC vs Substitution Files

- PLC:
  - Cyclic scan: read all inputs, execute all rungs/blocks, update outputs, repeat.
  - State distributed across coils, timers, PIDs, registers.
- SNL (EPICS sequencer):
  - Explicit states and transitions (when/next_state).
  - Suitable for stepwise sequences, but not required for every rung.
- EPICS design here:
  - Many small records (PIDs, calc, alarms) and FPGA bits re-evaluated continuously, mirroring the PLC's rung behavior rather than bundling it into one large SNL program.

Substitution Files

- The way the PLC's ladder logic was translated into EPICS records.
- Each row corresponds to a specific piece of PLC behavior:
  - A PID block,
  - An Alarm[n] rung,
  - An OK-bit or Run Permit rung,
  - A Card-0 composite,
  - A setpoint in the Set_Point array.
- They are not ladder syntax, but they encode the same decisions in a structured, tabular format that EPICS templates use to generate records.

Summary

- The EPICS/cRIO implementation mirrors the PLC's main control loops and interlocks: same PVs, same setpoints, same tuning, in a new control architecture.
- Standby vs Production is mainly about which PID controls FIT-252 and which setpoint is in use; the transfer-tube level loop and interlock layer remain active in both.
- Card-0 interlocks are implemented in the FPGA; alarms, OK bits, Run Permit, and mode logic live in the soft IOC.
- The overview, Target Ready, Run Permit, OPER_INIT_SEQ, and Rb-overview screens are all views of the same underlying PVs and logic.
- The substitution files and soft IOC code are a structured, traceable translation of the PLC's PIDs, Alarm[], Set_Point[], OK bits, and Run Permit rungs into EPICS.