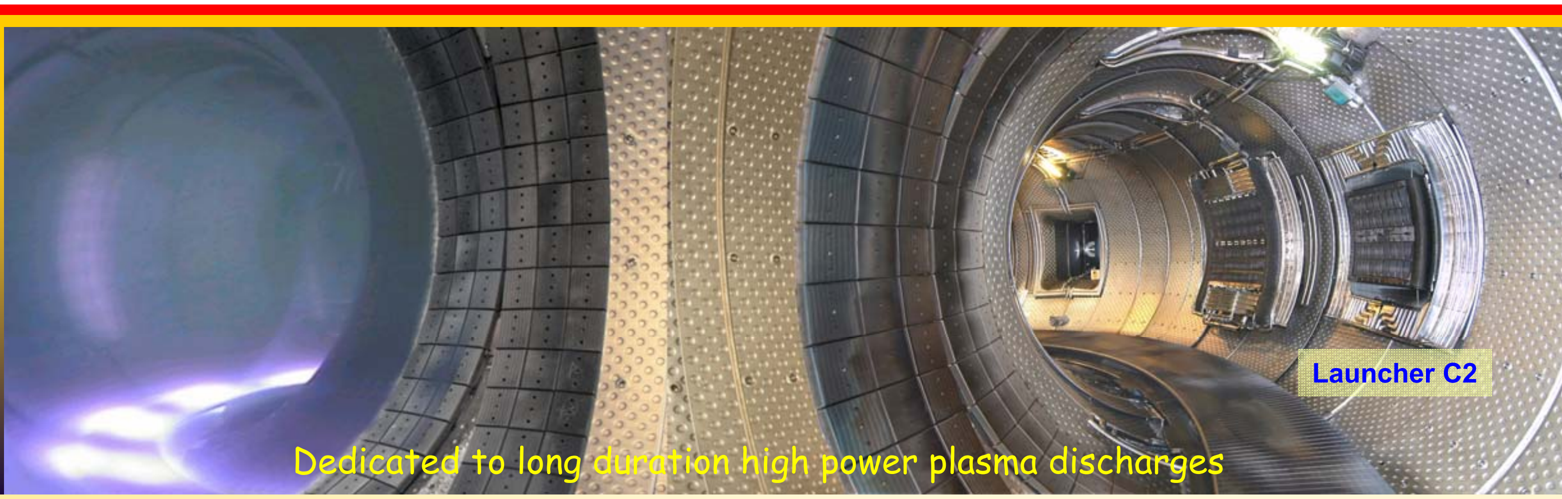
Machine Protection and Advanced Plasma Control in TORE SUPRA Tokamak

F. Saint-Laurent, Ph. Moreau, S. Bremond, J. Bucalossi, G. Martin

Association EURATOM-CEA

CEA / DSM / Département de Recherches sur la Fusion Contrôlée

CEA-Cadarache, 13108 ST PAUL-LEZ-DURANCE (France)

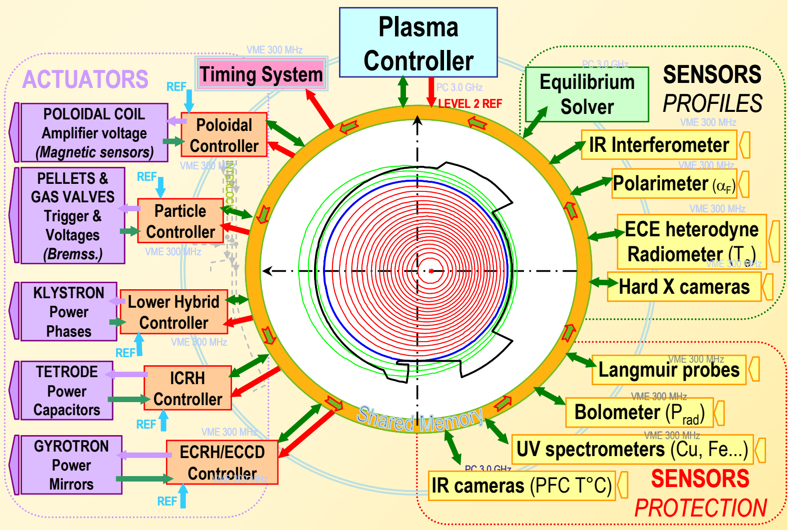


Tore Supra Tokamak

- Cryogenic plant (LHe 1.7K)
- Toroidal (4T) and Poloidal magnetic fields (power supplies)
- Main water cooling loop (30b-120°C) Plasma Facing Components
- Auxiliary water loops for additional power systems
- 3 Plasma Heating & Current drive systems (ICRF, LH, ECRF)
- Gas fuelling
- Vacuum system (10^{-5}Pa) turbomolecular pumps

Real Time Control System

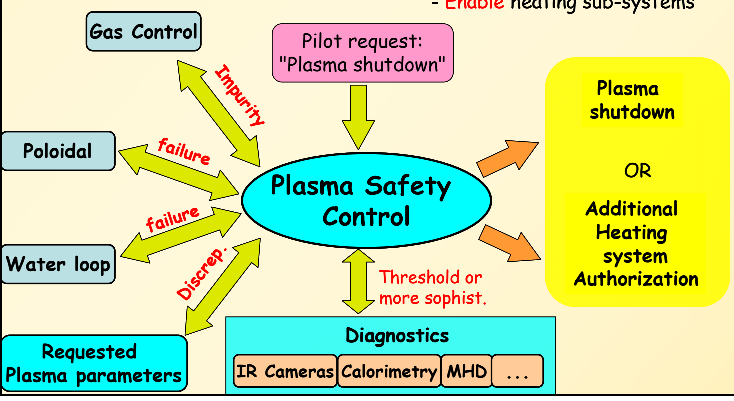
- 1 Central Plasma Supervisor
- 15 passive nodes (Diagnostics), 5 active nodes (Controllers)
- SCRAMNet® from SYSTRAN Corp. 150MHz



Plasma Safety Control System

Part of the RTC system, 4 levels of alternative strategies

- **Avoid the premature shutdown of subsystems**
  - Never reach the internal hardware limits
  - ⇒ Automatic reorganization of the subsystem loads : Control of the load margin : "intelligent" controller
- **Operate close to the technological limits**
  - Perform discharge with a high injected power…
  - ⇒ Need to react as quickly as possible
  - ⇒ Need a reliable and robust safety control
    Specific controls dedicated to the protection purpose
- **Avoid machine damages**
  - Water or air leakage, First wall melting…
  - ⇒ Robust & soft plasma shutdown procedure
    - when subsystem limits are reached
    - when a subsystem fails (Water loop cooling…)
  - ⇒ Fast "Killer" plasma procedure in case of emergency
    - Automatic (wired or soft)
    - Enable heating sub-systems



Four levels of alternative strategies

First Level

- Detect an abnormal event
- Treat the event

➥ **Recover the nominal state**

Second Level

- Modify parameters to preserve plasma discharge

➥ **Plasma in a degraded mode**

- Try to go back to nominal

Third Level

- Detect irreversible conditions
- No strategy to recover (known or implemented)

➥ **Soft plasma shutdown:**

- switch off additional powers
- switch off gas fuelling
- decrease plasma current
- plasma position under control

Fourth Level

- Uncontrollable loads
- High Disruption probability (confinement losses in few millisec.)

➥ **Fast plasma shutdown:**

- Massive gas injection
- Disruption under control
- Mitigate the disruption effects

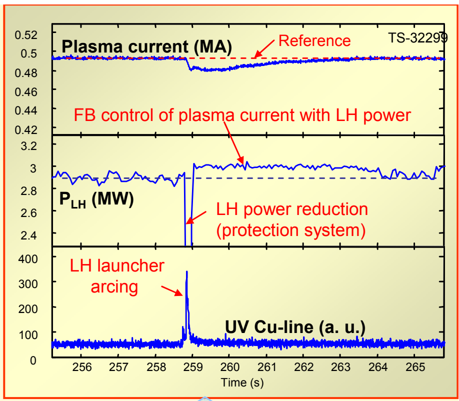
Abstract

A tokamak is a complex device combining many sub-systems. All of them must have a high reliability and robustness to operate together. Sub-systems include their own safety protections, but a more integrated level of protection is required to ensure the safety of the full device. Moreover, plasma operation with several megawatts of additional injected power requires a highly reliable advanced control system, as off-normal events may seriously damage the in-vessel components. Such an integrated control system, including protection algorithms, has been developed on Tore Supra. In the following the implementation of the Plasma Safety Control system is described as well as its real time network topology. The hierarchy of strategies applied, when more and more severe failure appears, is detailed. Finally few examples of active protections daily used in Tore Supra are given.

Impurity Spectros.

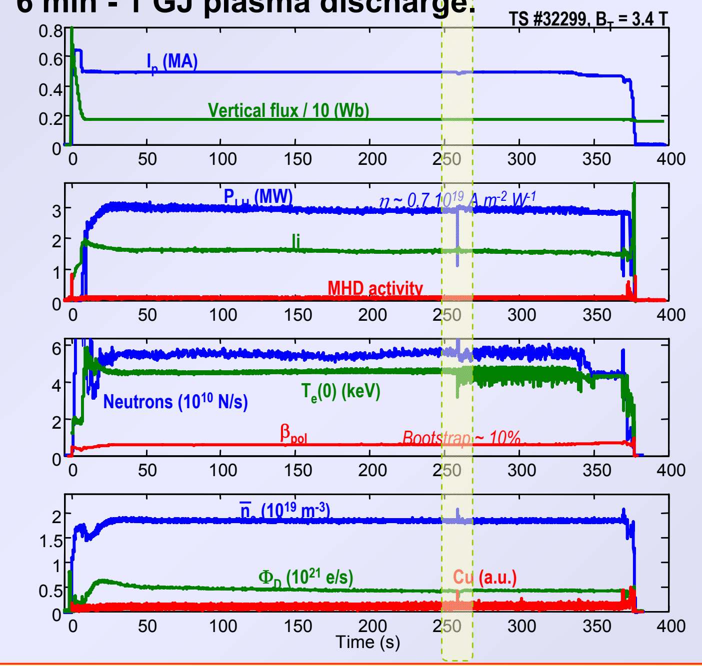
- Analyse Cu et Fe rays (UV spectroscopy)
- Take density into account
- Compare to threshold
- Provide instructions to PSC

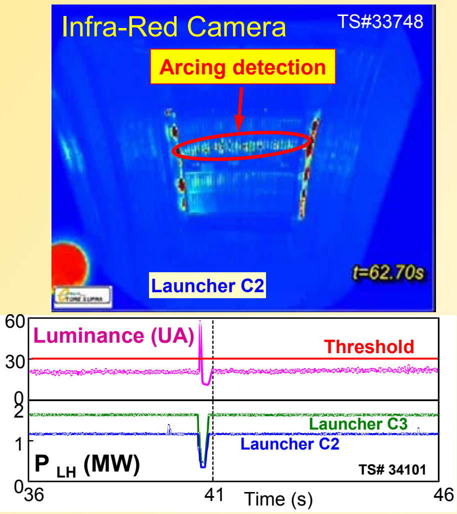
↳ Reduce rapidly Power
↳ Reapply progressively



⇒ Nominal plasma parameters are recovered
New $T_e(0)$ fluctuations ⇒ current profile has changed

6 min - 1 GJ plasma discharge.





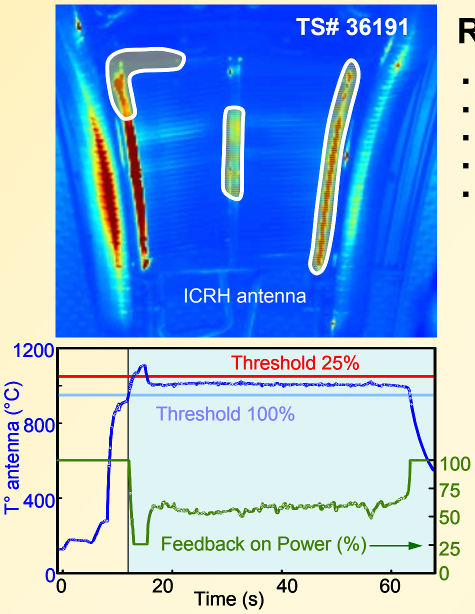
IR Thermography Dedicated to Safety

- 8 IR cameras
- 7 endoscopes
- RT controller

Arcing Detection

- Survey of the launcher,
- Specific IR signature (spatial & temporal)

↳ **PSC reduces the LH power down to 25%.**



Real Time IR Controller

- Record IR frames,
- Apply masks (zones of interest),
- Compute surface temperature,
- Compare to technological limits,
- Provide instructions to PSC.

Between 100% and 25% thresholds the Real Time IR controller provides information to modulate the additional power.

↳ **PSC modulates the ICRF power (100%-25% range)**

⇒ Nominal plasma power is not recovered.

Fast Plasma Shutdown

- When disruption probability becomes too large
- loads closed to be uncontrollable

PSC initiates a controlled disruption by Massive Gas Injection ⇒ Kill the plasma

Benefits :

- Disruption effects are mitigated
- MGI characteristics adjusted to deal with the disruption effects
- **With Helium gas, no formation of decoupled electron beam**

Disruption:

Loss of the plasma confinement in few milliseconds.

↳ Mechanical stresses induced on structures
↳ Plasma stored energy released on the first wall
↳ Decoupled electron beam (E=10-20 MeV, several hundred kA)

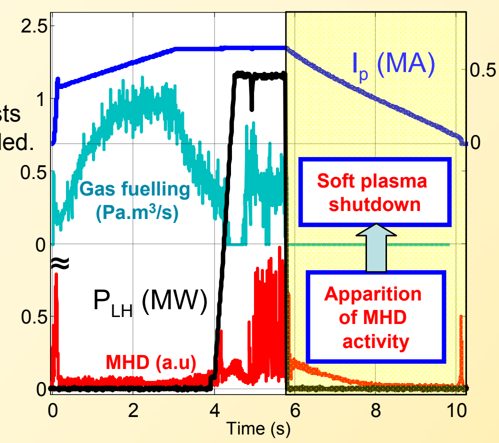
Soft Plasma Shutdown

- When no recovery strategy exists
- or parameters too much degraded.

PSC initiates a Soft stop

- Plasma position still controlled,
- Stop gas fuelling,
- Stop additional heating,
- Decreases plasma current.

Need several seconds to stop the plasma.



Future Plans

- Create a separate PSC unit,
- Expert system approach for implementation
- The PSC will address the individual sub-system controllers
- Develop advanced recovery strategy for MHD activity (use ECRH current drive capability to modify current profile)
- With the help of integrated tokamak modeling, develop advanced scenarios to recover nominal plasma after events.
- Take advantage of modeling to develop control strategies.