# Bus bar joints stability and protection

- **joint stability**
- **what was wrong with the 'old' bus-bar *protection*?**
- **the incident**
- **required threshold for QPS upgrade**

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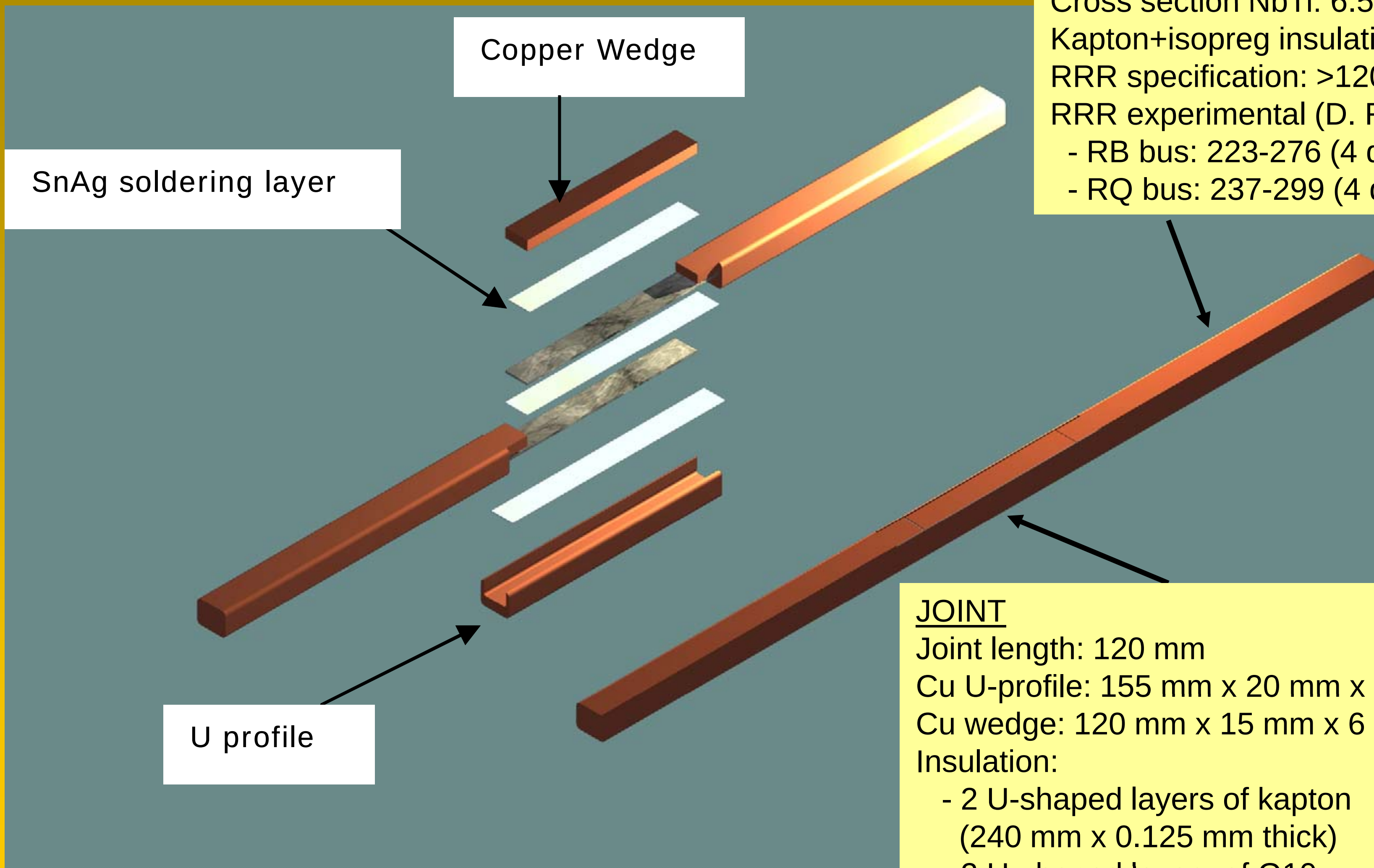
**TE-MPE**

# RB bus and joint




BUS

Cross-section Cu: 282 mm$^2$

Cross section NbTi: 6.5 mm$^2$

Kapton+isopreg insulation

RRR specification: >120

RRR experimental (D. Richter)

- RB bus: 223-276 (4 data)
- RQ bus: 237-299 (4 data)

JOINT

Joint length: 120 mm

Cu U-profile: 155 mm x 20 mm x 16 mm

Cu wedge: 120 mm x 15 mm x 6 mm

Insulation:

- 2 U-shaped layers of kapton (240 mm x 0.125 mm thick)
- 2 U-shaped layers of G10 (190 mm x 1 mm)

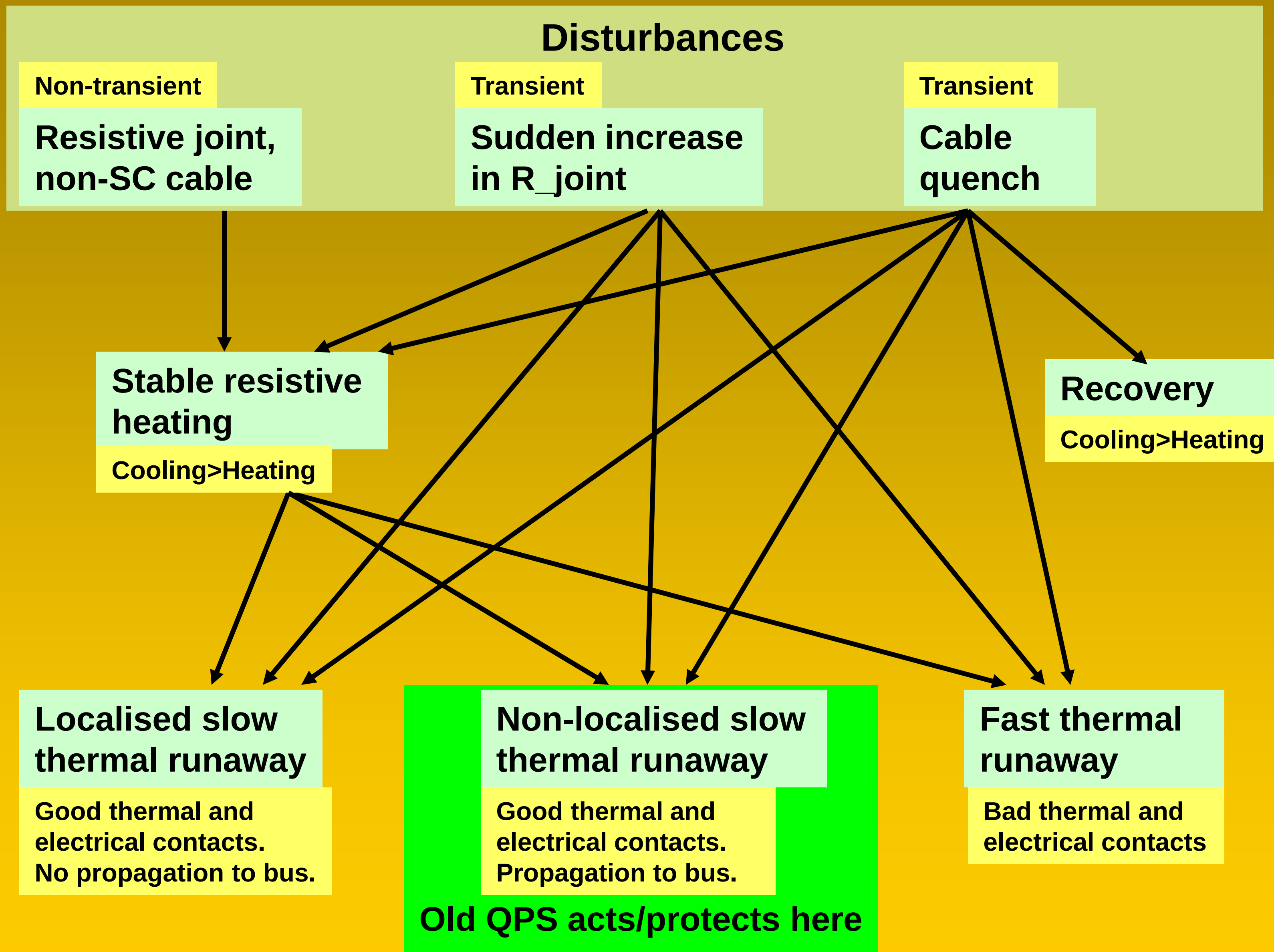
# A good joint

**Characteristics of a good joint**

- Both cables are superconducting
- Good electrical contact between both cables (R<0.6 nOhm)
- Good transverse thermal (and electrical) contact between cables and stabilising copper (U-profile and wedge)
- Good longitudinal electrical (and thermal) contact between bus and stabilising copper
- Good mechanical properties
- No possibility of mechanical opening

As long as the cables remain superconducting, the role of the stabilising copper is purely mechanic.

However, as soon as a SC-to-normal transition occurs, bad electrical and/or thermal contacts between cable and stabilising copper can (under certain conditions) lead to stability problems and possibly thermal runaway.


Disturbances
Non-transient
Resistive joint, non-SC cable
Transient
Sudden increase in R_joint
Transient
Cable quench
Stable resistive heating
Cooling>Heating
Recovery
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Localised slow thermal runaway
Good thermal and electrical contacts. No propagation to bus.
Non-localised slow thermal runaway
Good thermal and electrical contacts. Propagation to bus.
Old QPS acts/protects here
Fast thermal runaway
Bad thermal and electrical contacts

# Slow vs. Fast

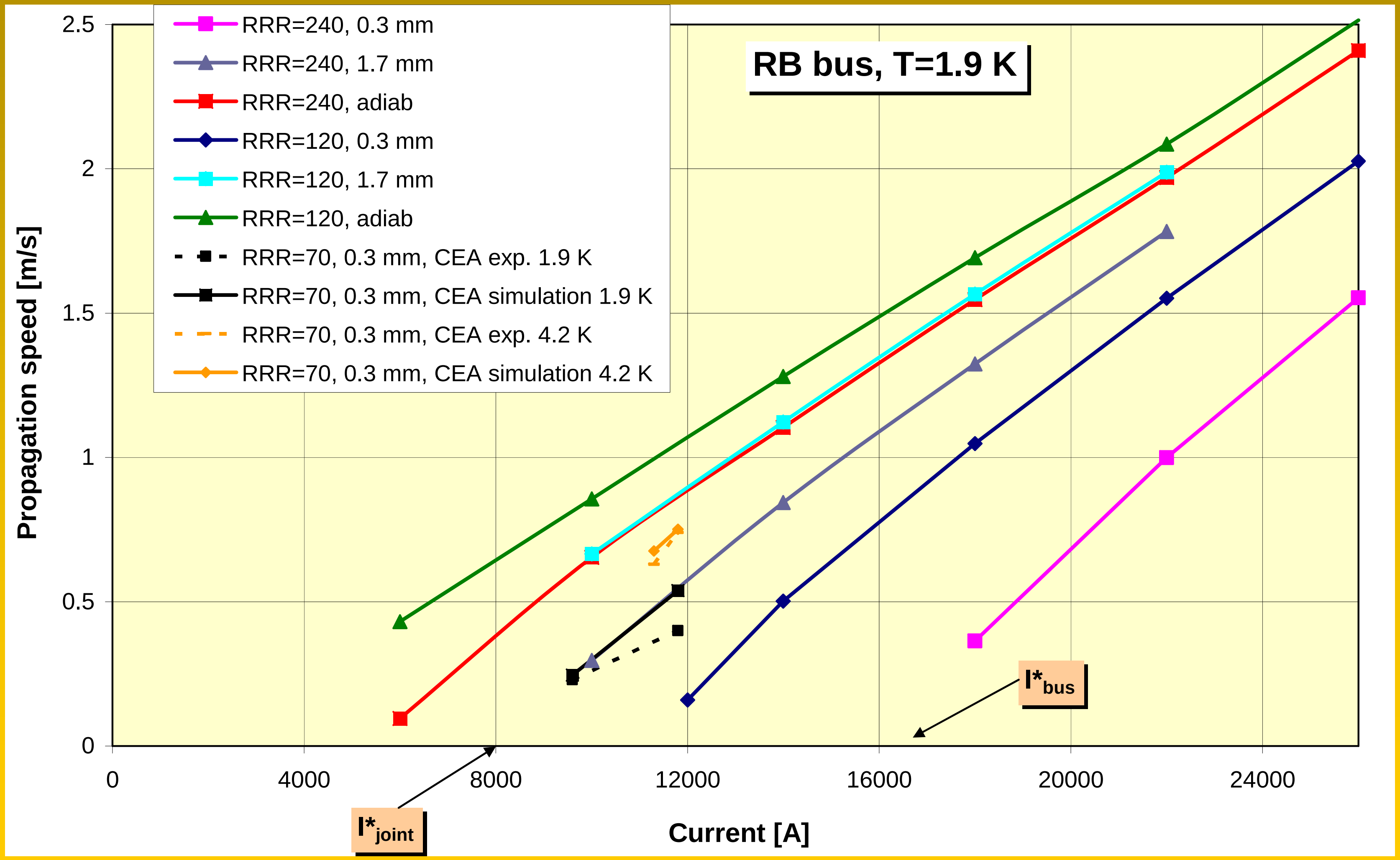
**Slow: time to go from 2 K to 600 K is much longer than the discharge time constant of the circuit ($\tau$=100 s)**

**If the SC cable is in good electrical and thermal contact with the copper stabiliser, then a thermal runaway will <u>always</u> be slow.**

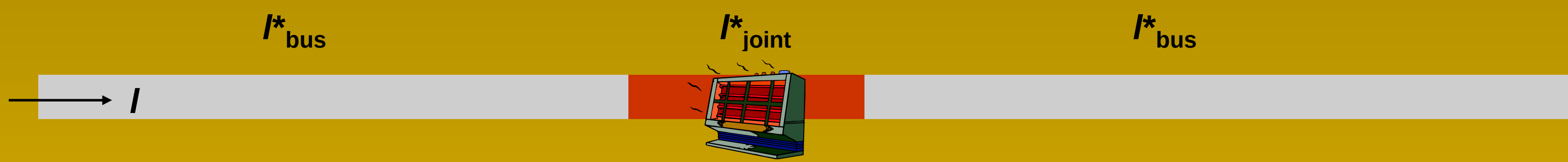
**Fastest runaway (0.1-1 s at high currents) happens if the cable is not cooled by Helium and has no thermal/electrical contact with the stabiliser.**

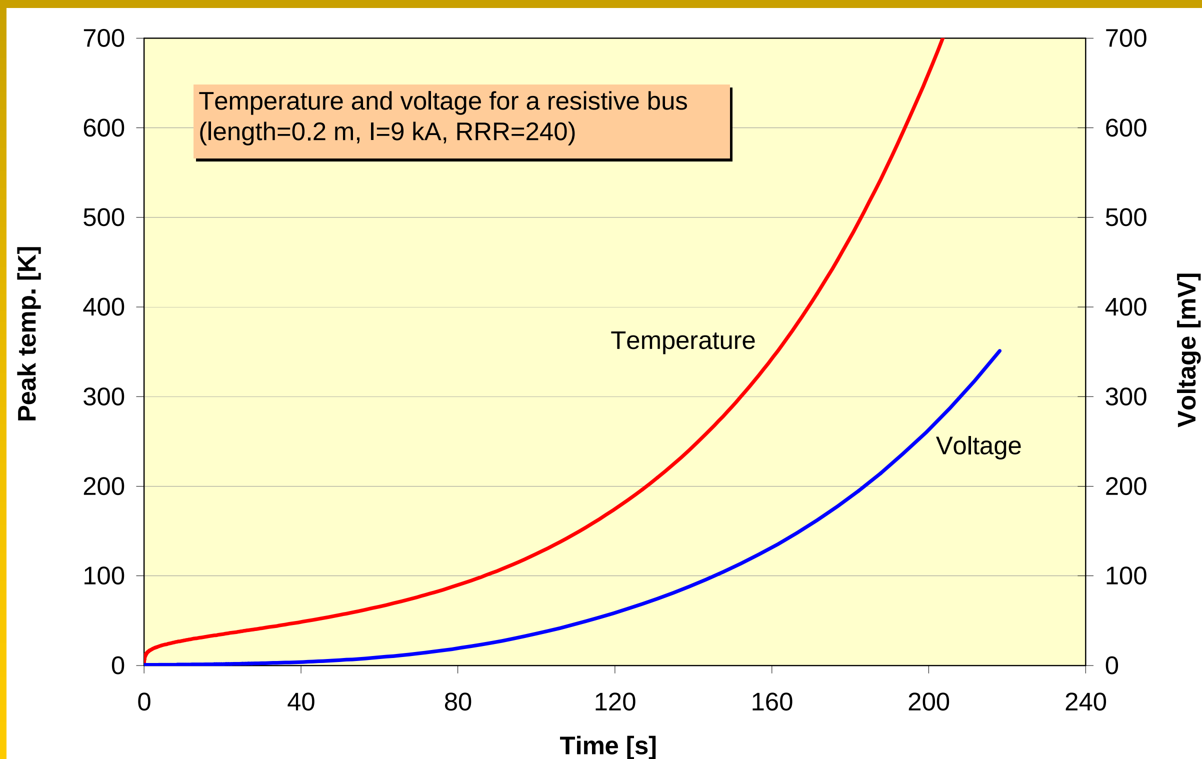
# The old bus 'protection'

The old bus protection (threshold at 1 V) could only handle **non-localised slow thermal run-aways**. However, **localised run-aways** are very likely to occur, due to variations in quench propagation speed!



Assume a highly insulated resistive joint, so $I^*_{joint} < I^*_{bus}$.
Thermal run-away will occur when the Joule heating exceeds the cooling ($I > I^*_{joint}$).
The run-away will be **localised** (and hence the voltage relatively small) when the adjacent bus acts as a “quench stopper”, i.e. when $I < I^*_{bus}$.




**Conclusion:**

The solder of the joint is already melting even before the voltage reaches the 1 V threshold!!

# The incident

**Facts:**

1.
Estimated power of 10.7±2.1 W at 7 kA (so 175-260 nΩ).

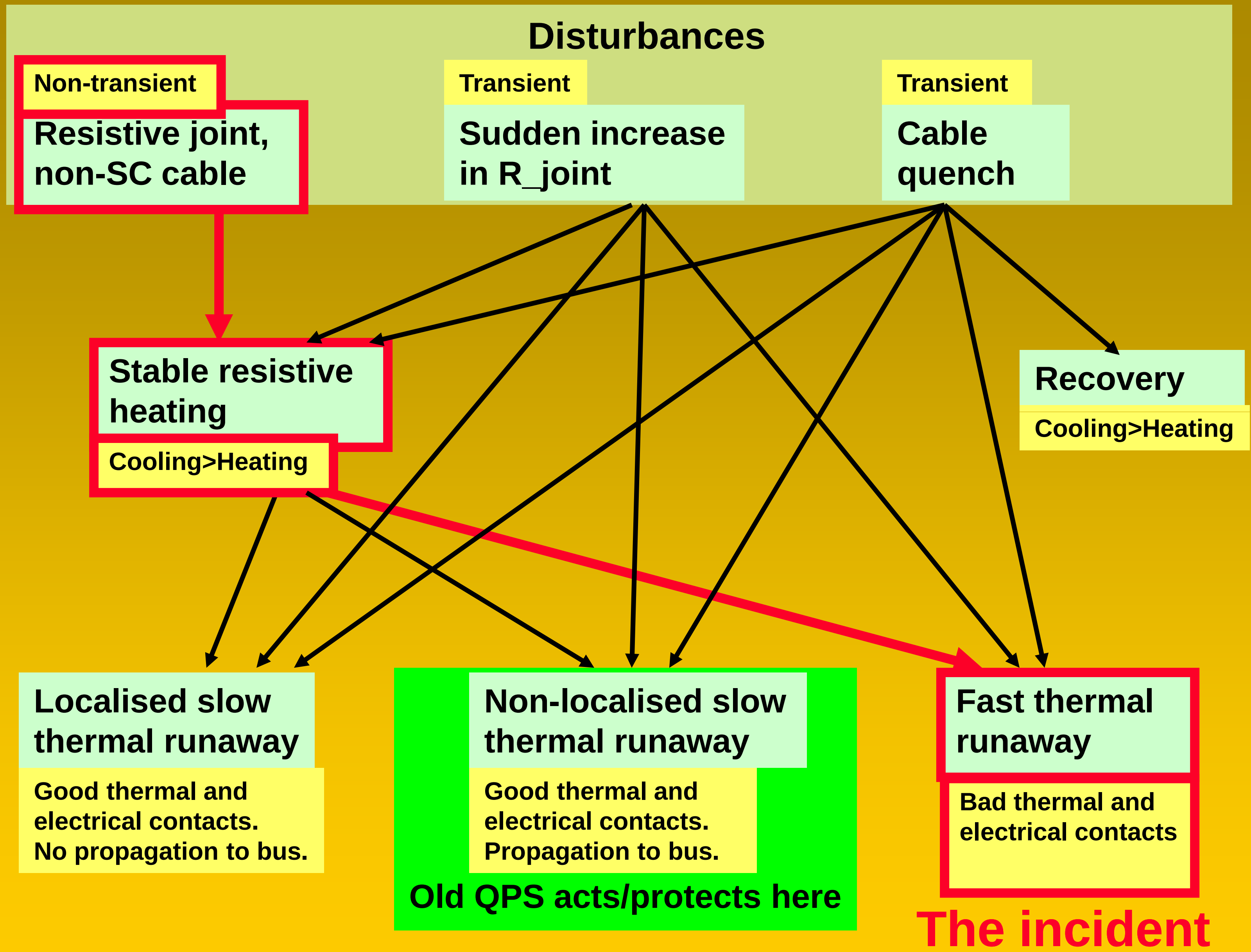
2.
Maximum current of 8715 A.

3.
Fast voltage increase during incident: ~0 to 1 V in about 1 sec.

4.
Possible small voltage increase (about 10 mV) during 30 sec before incident.

5.
Busbar QPS threshold reached before any voltage increase on the magnets.

6.
Origin probably in or near busbar joint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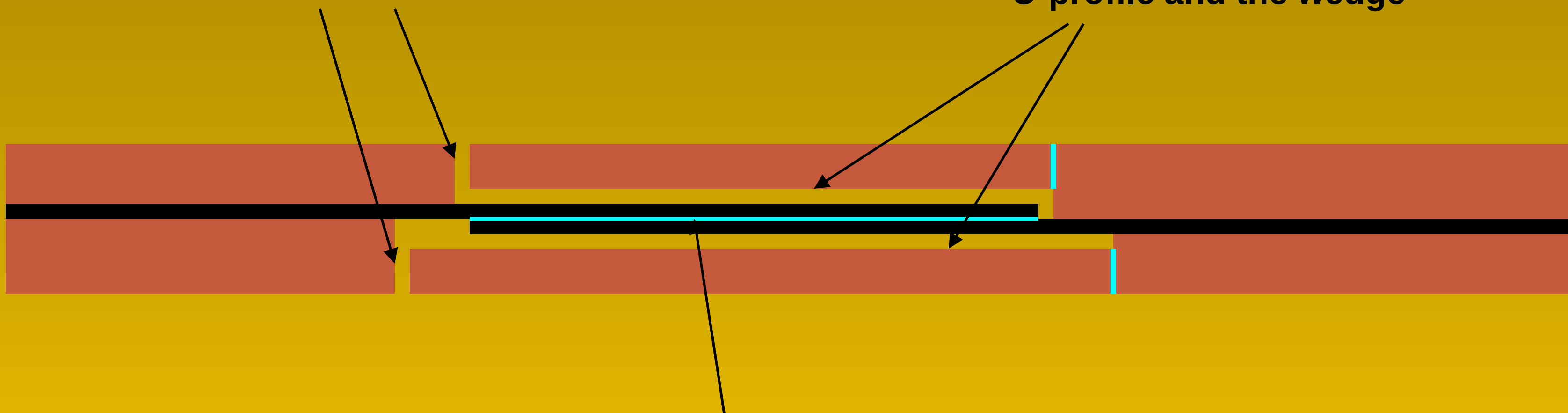
# The incident: most likely scenario

**Bad electrical contact between wedge and U-profile with the bus on at least 1 side of the joint**

**Bad contact at joint with the U-profile and the wedge**

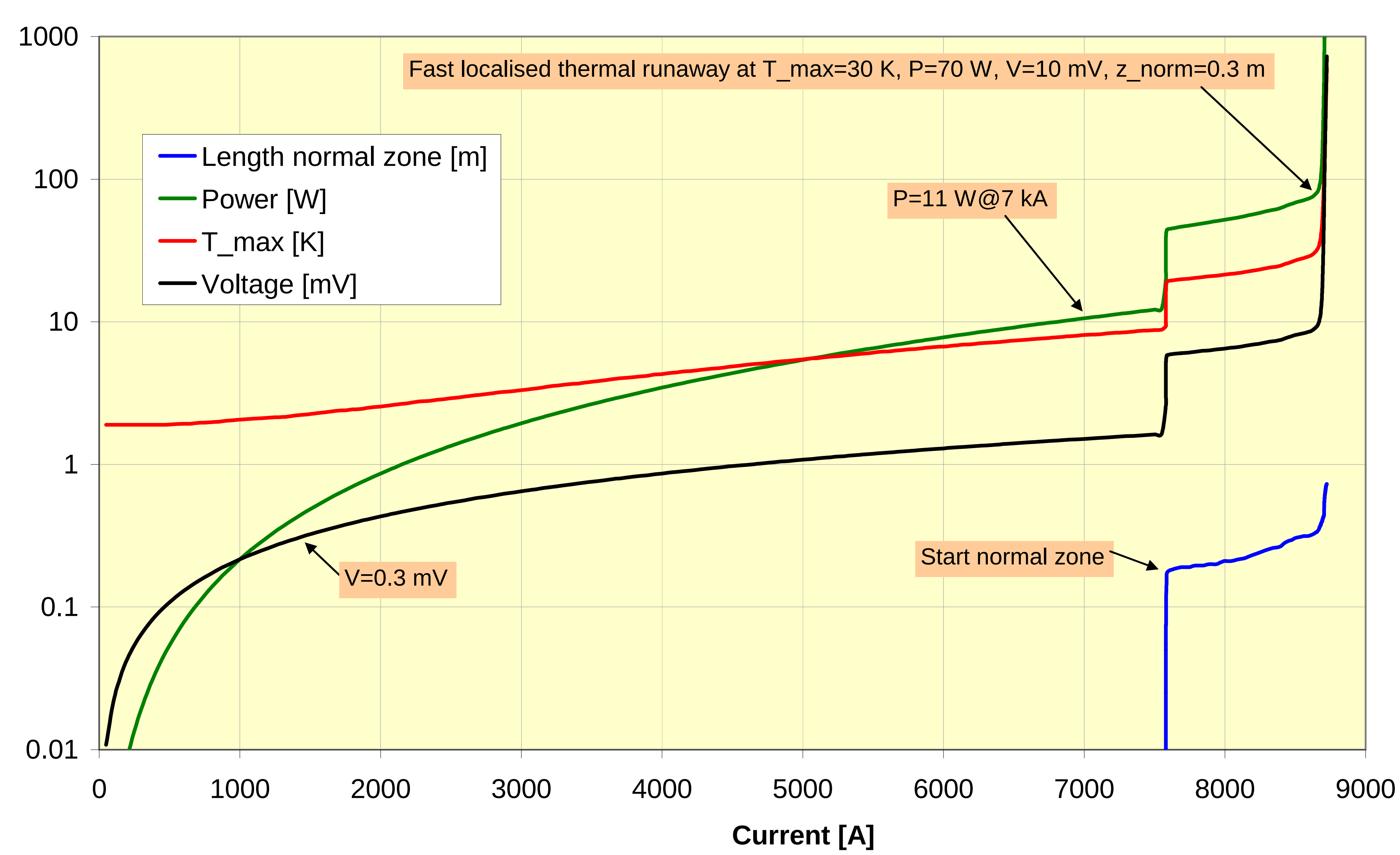


**Resistive joint of about 200 nΩ**

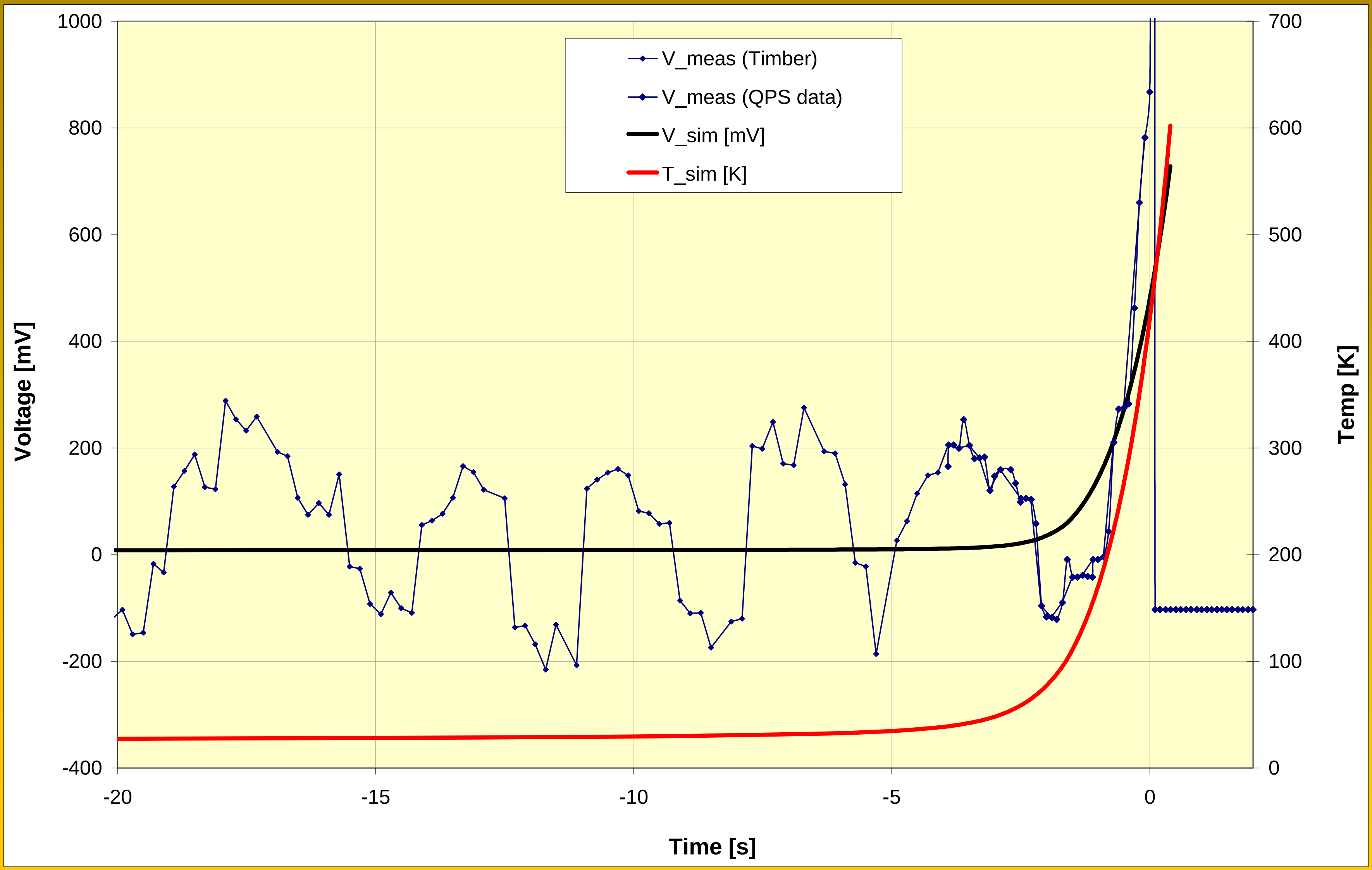
**=**


**An electrical fuse is a current interrupting device which protects an electrical circuit in which it is installed by creating an open circuit condition in response to excessive current. The current is interrupted when the element which carries the current is melted by heat generated by the current. Most types of fuses are designed to minimize damage to conductors and insulation from excessive current.**

# Simulation of the incident

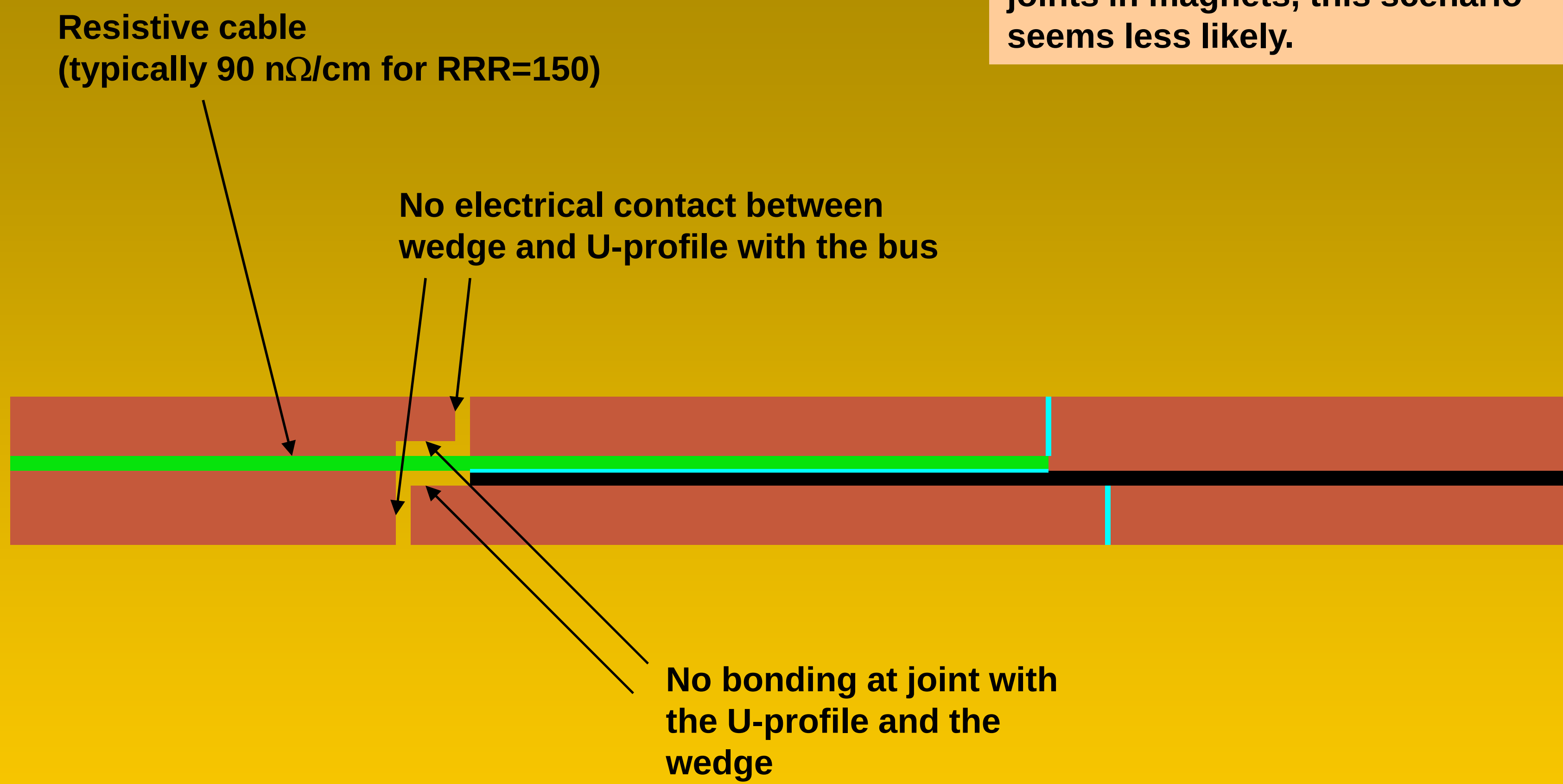


# Simulation compared to (noisy) measurement

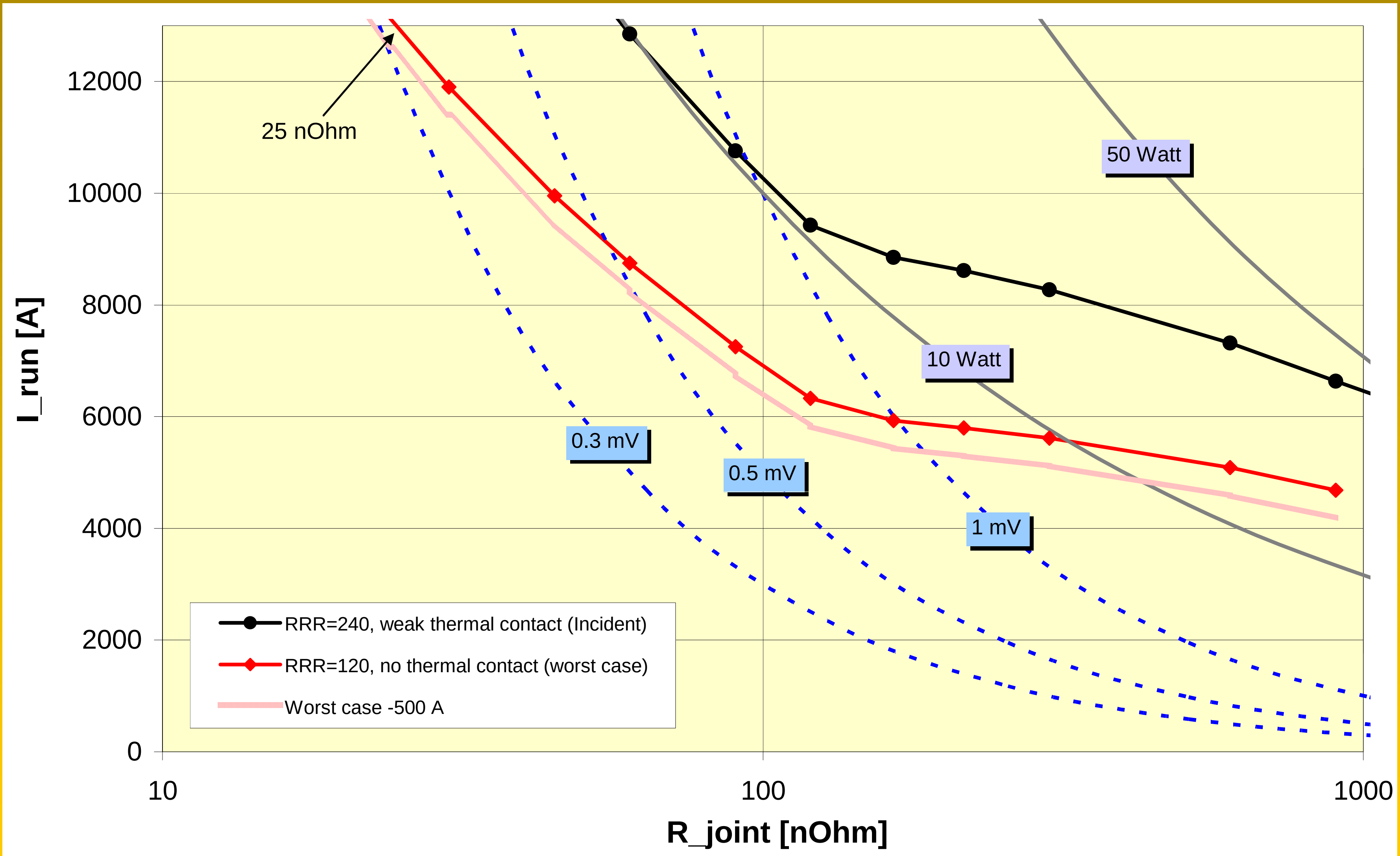


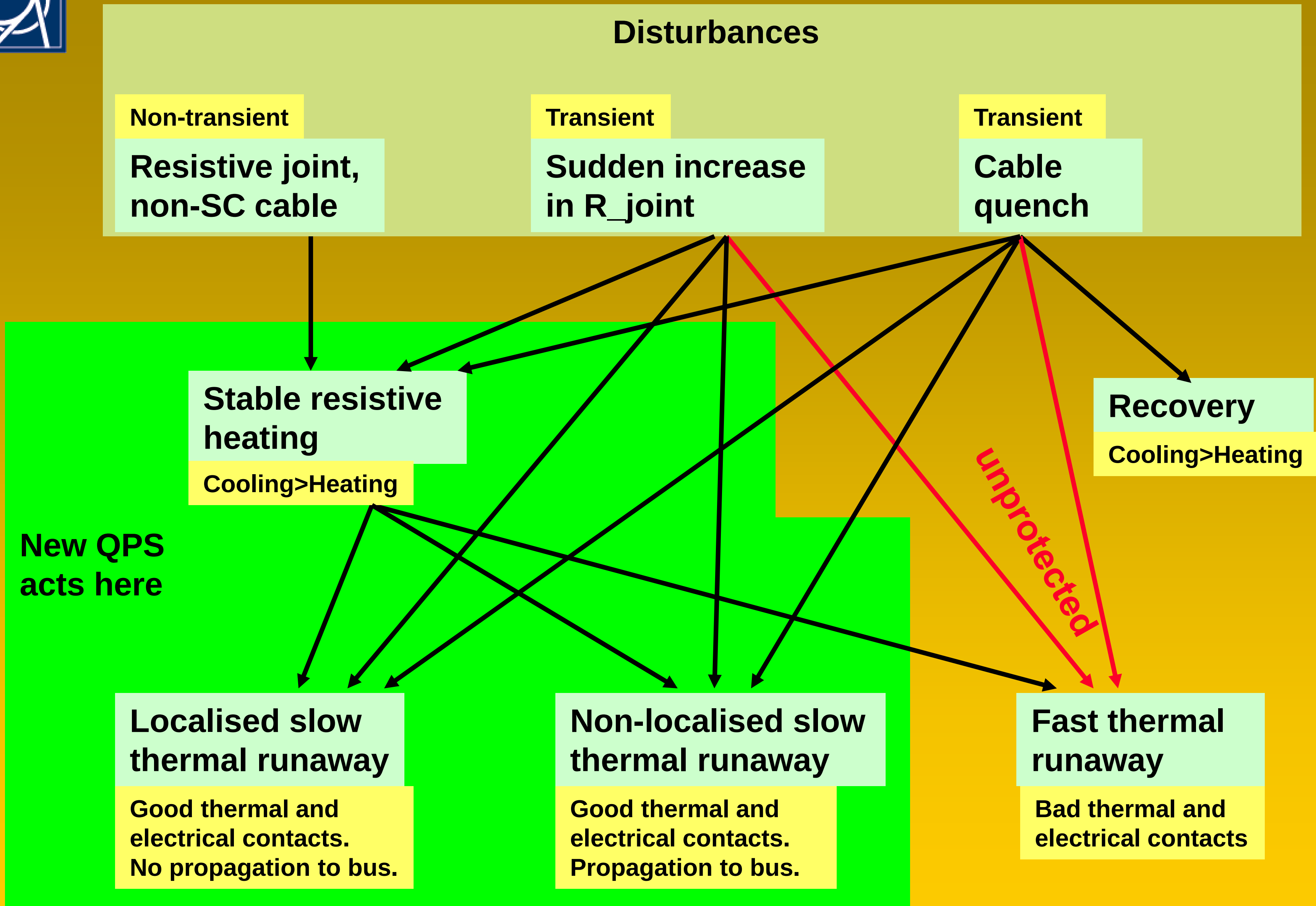
# The incident: another scenario

**Having seen the non-soldered joints in magnets, this scenario seems less likely.**



# Setting for the new QPS upgrade

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New QPS acts here
unprotected
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# Conclusion

The original design 1 V QPS threshold was **much** too high to safely protect the dipole busbars. The possibility of combined production errors (e.g. longitudinal discontinuity and high joint resistance) and the effect of “quench stoppers” were at the time not properly taken into account.

Two possible origins of the incident are identified, that fulfill the observed facts (about 11 W @ 7 kA, Imax=8.7 kA, $\Delta$t_runaway$\cong$1 s), namely:

1) Resistive joint with very bad bonding to wedge and U-profile, **and** longitudinal discontinuity of the copper (bus).

2) Resistive cable with bad contact to bus at the start of the joint, **and** longitudinal discontinuity of the copper (bus). The cable can be resistive due to strongly reduced critical current or due to mechanical movement below 7 kA.

Both origins would have been detected with a QPS threshold voltage <1 mV long before the start of the thermal runaway.

A QPS threshold of 0.3 mV is needed to protect the RB bus and the joints in all investigated conditions. This value can possibly be slightly modified when more experimental data (RRR, cooling, propagation speed) become available.

# Conclusion

A small gap (up to a few mm) between bus and joint is acceptable as long as there is a good thermal contact between joint and U-profile/wedge.

<u>Remaining risks with the new QPS upgrade:</u>

- **Fast** thermal run-aways resulting from sudden transient disturbances (without intermediate stable heating). Also the SC-normal transition of the joint by thermal propagation due to an adjacent quench should be regarded as a transient disturbance. To avoid such fast thermal runaways one needs to assure a good thermal/electrical contact between joint and U-profile/wedge (by means of clamping) **or** between bus and joint (perfect soldering between bus and joint).

- Sudden mechanical opening of the joint. Note that having a relatively low electrical joint resistance does not automatically mean that the joint is perfectly soldered. Solution: Clamping

**Very similar conclusions hold for the RQF/RQD circuits, but what about all the other joints, busbars, pigtails, ........**