TRANSIENT STUDIES for TRIGA Reactor Types

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ECATS : Feasibility Study

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Topics:

1. Purpose of Benchmarking Transient Codes to TRIGA Reactor
2. Experimental Data Acquistion Campaign at Cassacia from Nov 2004-Feb2004
3. Heat Transfer Coefficient Issue
3. Temperature Reactivity Coefficient Issue
4. Current Status of Benchmarking Transient Codes to Casaccia Transients
5. Data from RACE to benchmark codes to RACE

1. Purpose of Benchmarking Transient Codes to TRIGA Reactor

1. Our primary mission is to study the dynamic behaviour of sub-critical systems under fairly realistic operational conditions in order to:

   a. validate our predicitive code capabalities,

   b. to assure that these systems can be operated safely.

2. TRIGA reactors are almost ideal test beds for studying the dynamics (safety) characterisitics that are specific to sub-critical systems, because of their :

   a.) proven, inherently, very large, prompt temperature reactivity feedback coefficient(s), and

   b.) its normal operating condition being very close to “ambient” temperatures, and

   c.) the large allowable reactivity insertions (+ 83 cents) due to the unique nature of the TRIGA fuel (ZrH-based).

1. Purpose of Benchmarking Transient Codes to TRIGA Reactor

3 The RACE TRIGA reactor and the Casaccia TRIGA reactor are almost identical in co design (the small differences can be consiedered to be of minor importance for transient studies).

4 The Casaccia experience can be thus almost completely translated to RACE. This of cource needs confirmation by comparing transients run in Casaccia to those run unde similiar boundary conditions in RACE (this data needs to be collected).

5 Transient codes need specific adaptation to TRIGA cores since „TRIGA physics“ is nonconventional compared to other reactor types.

6 Issues needing particular attention are:

- thermal-hydraulic characterisation of the TRIGA core,
- reactivity temperature coefficient(s).

1. Purpose of Benchmarking Transient Codes to TRIGA Reactor

7 Transient Code Benchmarking activities started ~ June 2003 within TRADE. These activities are still in progress.

8 Current activities include :

1 Analysis of the transient data collected in Casaccia during Nov2003 – Feb2004 continues,

2 Improvement in modelling TRIGA „reactor physics“

3 Developing a fully coupled neutronic-thermohydraulic multi-node, TRIGA specific transient code version within SIM-ADS.

4 This model is operational and currently in the test (i.e validation) phase :

a. the code shows good agreement to plant data when testing under quasi-static transient conditions,

b. next phase will be testing / validating the code under aggressive transient conditions.

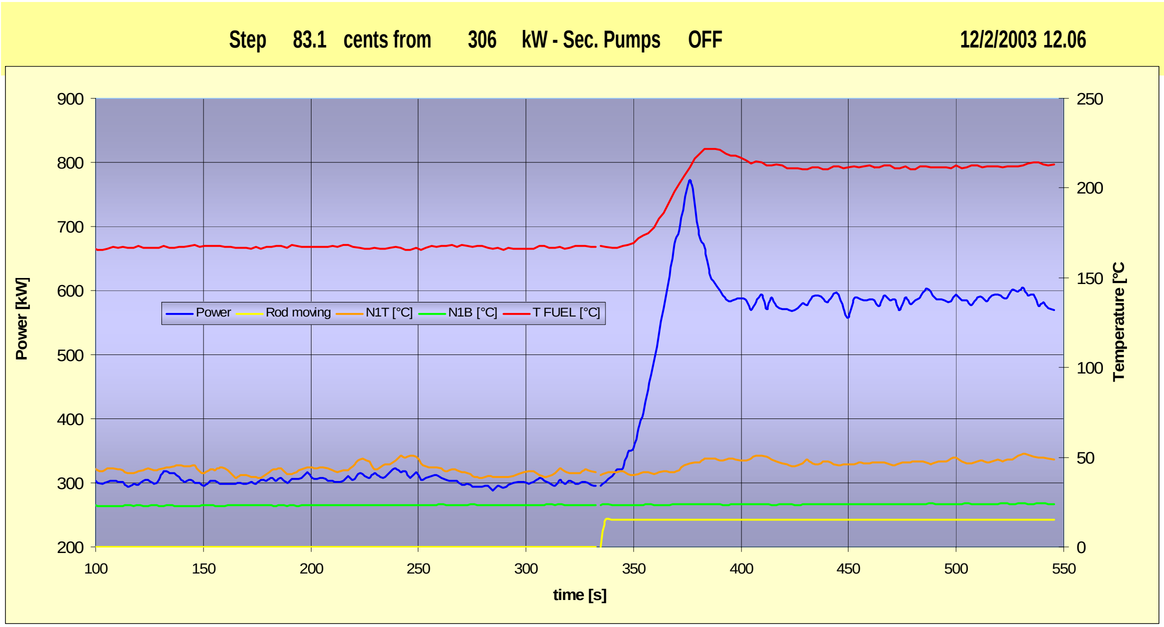
2. Data Acquisition Campaign at Casaccia for Code Benchmarking

1. An extensive campaign was performed Nov 2003 – Feb 2004 to collect a „complete“ set of experimental data that should allow us now an unambiquous description of the nuclear and thermo-hydraulic characterisitcs of the critical TRIGA reactor under steady state and transient conditions.

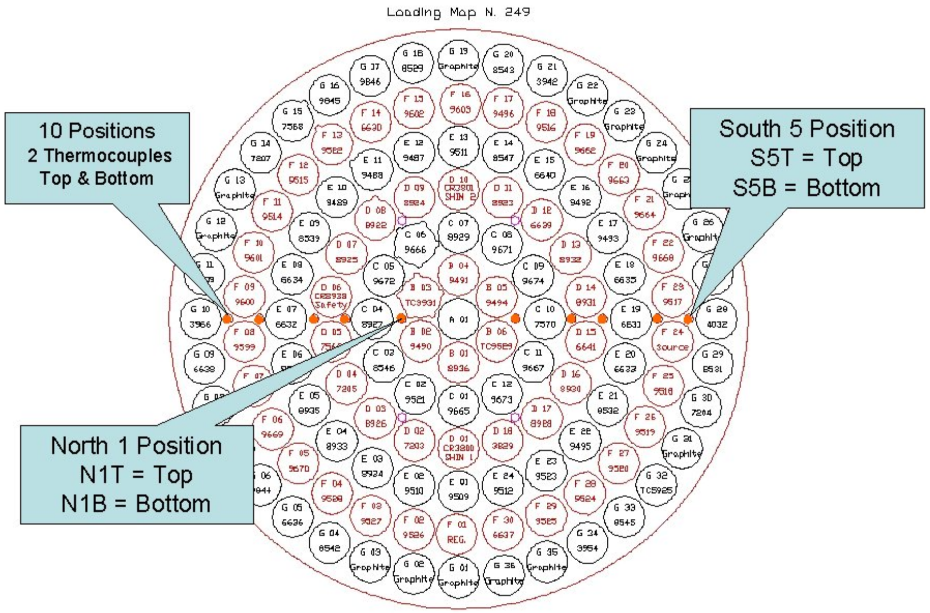
    a. Measured core **inlet** and core **outlet** tempeatures at 10 different radial positions to determine flow rate characterisitcs of the natural convection driven cooling as a function of core power and other parameters.

    b. Performed over 70 different reactivity insertion transients under well defined conditions measuring and collecting data on the response of power level, fuel temperature, and coolant temperatures.

    c. Evaluation of this extensive data is still ongoing trying to sort out the various parameter interdependencies.



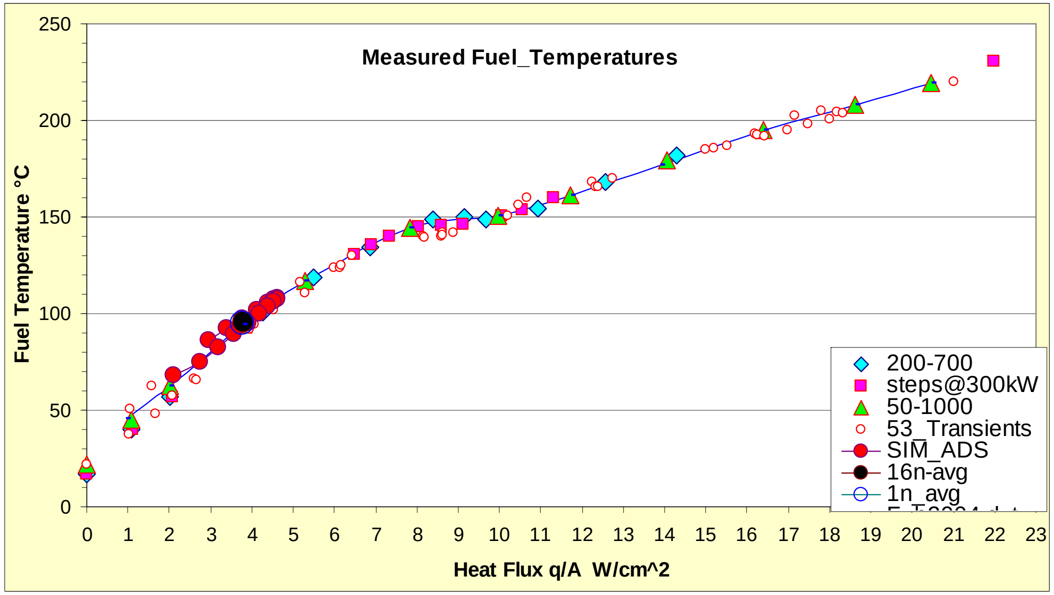
Example of a Typical Data Set :

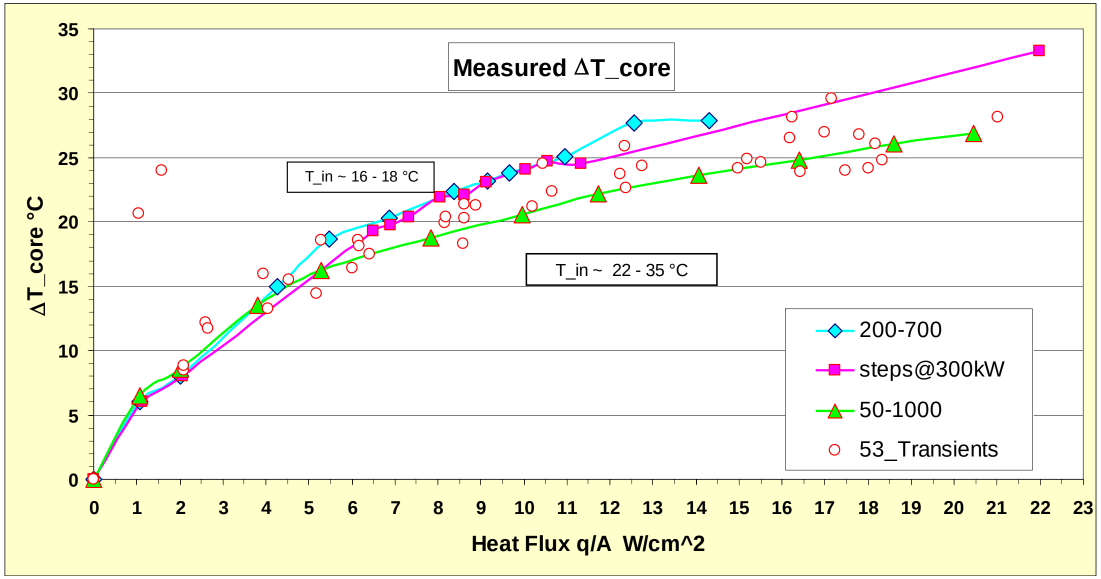


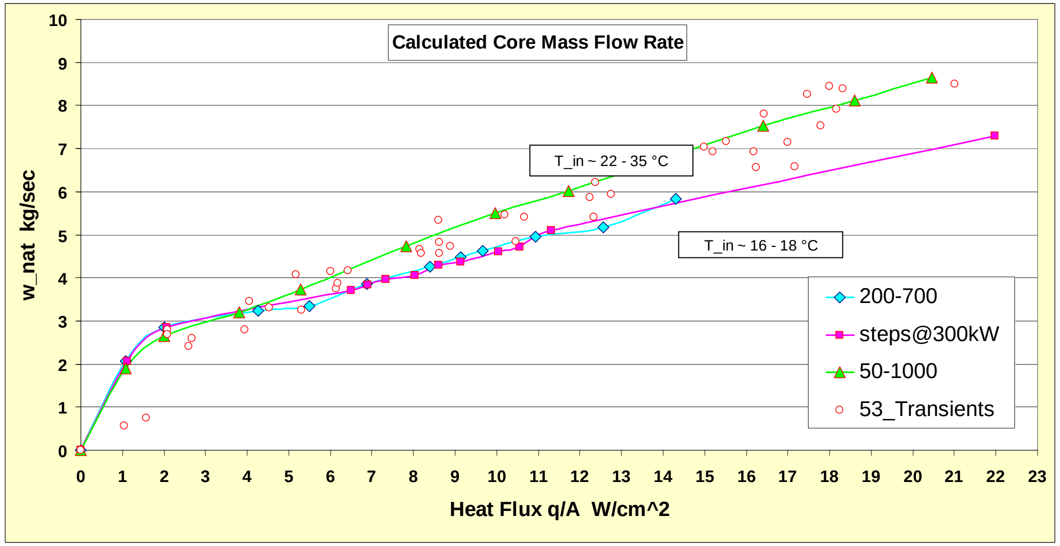
Measured data during Transients :

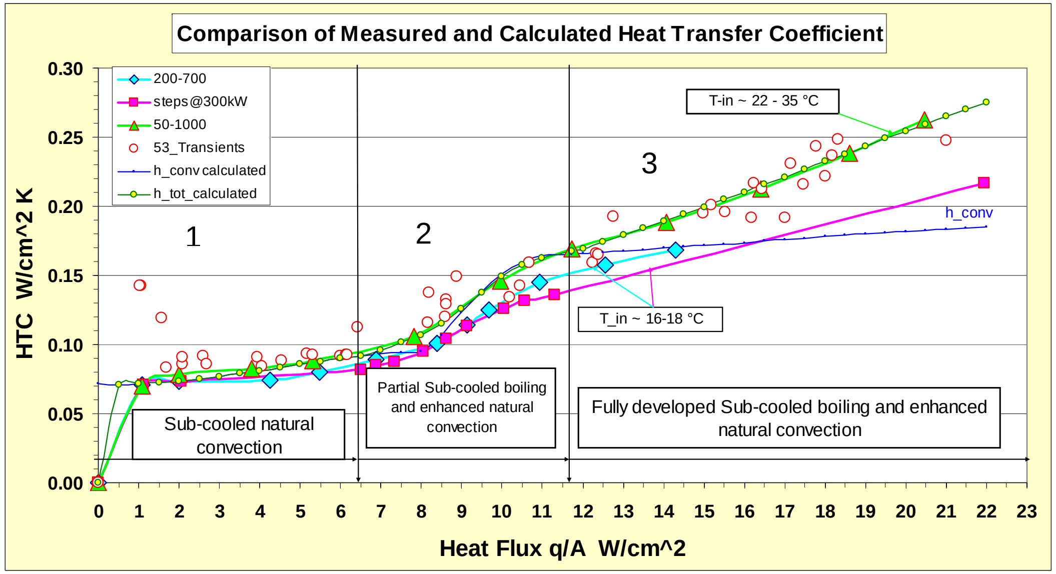
1. Power Level – blue line
2. Fuel Temperature at posit. B06 – red line
3. Rod Position – yellow line
4. 10 Coolant Inlet Temp. Positions – green lin
5. 10 Coolant Outlet Temp. Positions - brown

2. Data Acquisition Campaign at Casaccia for Code Benchmarking









Thermal-hydraulic Issues :

1. Some paramters such as fuel temperature could be nicely correlated to the heat flux for all the different experimental runs.

2. Other parameters such as delta_T_core show additional dependencies aside of power (or heat flux), such as core inlet temperature (etc.) that makes life difficult.

3. Conventional heat transfer correlations are not applicable for TRIGA reactors because of the enhanced natural convection laminar flow conditions. Need to „generate“ TRIGA specific correlations using the experimental data.

4. The impact of additional dependencies (i.e. core inlet temperature) on

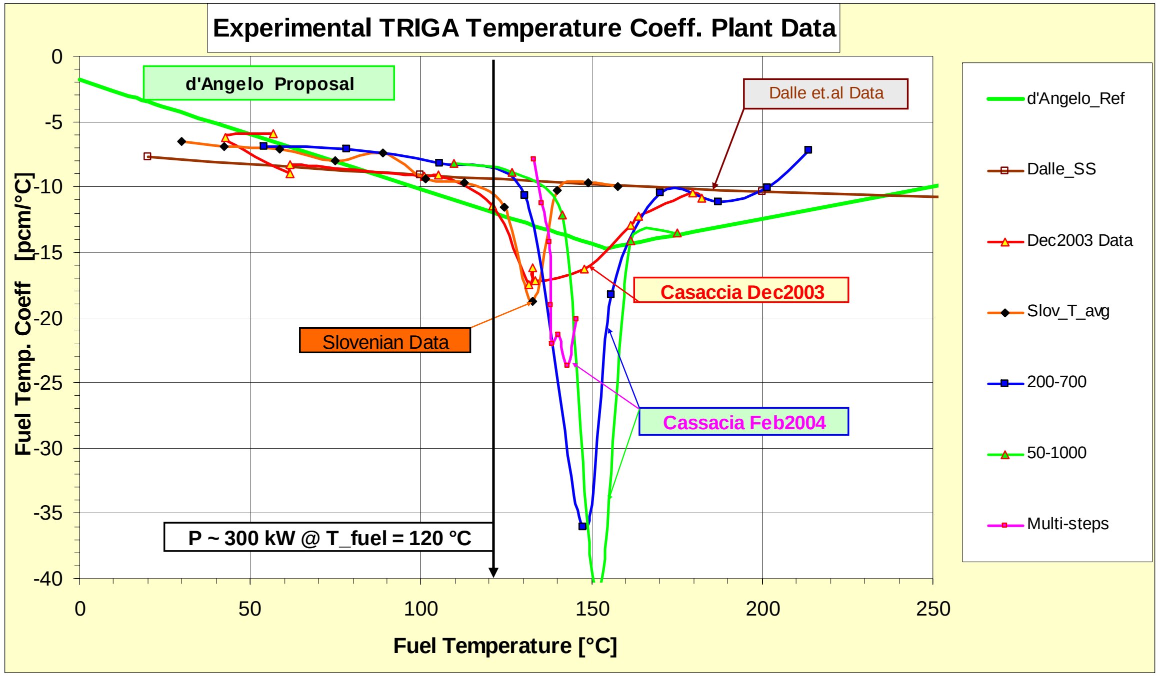
   a. the natural convection mass flow rate, and

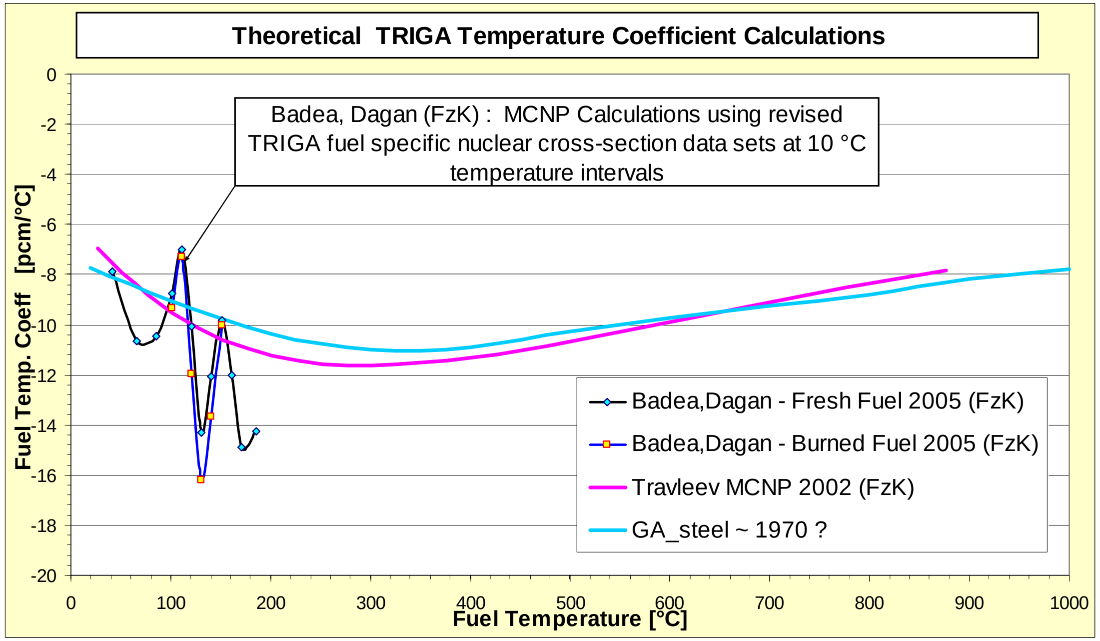
   b. the heat transfer coefficient calculation – i.e. Nusselt number correlations in the natural convection (laminar) flow range and in partial and fully developed sub-cooled boiling flow range.

This still needs further assessment (search for predicitve functional interdependencies)

Current Status on Reactivity Coefficient Issue:

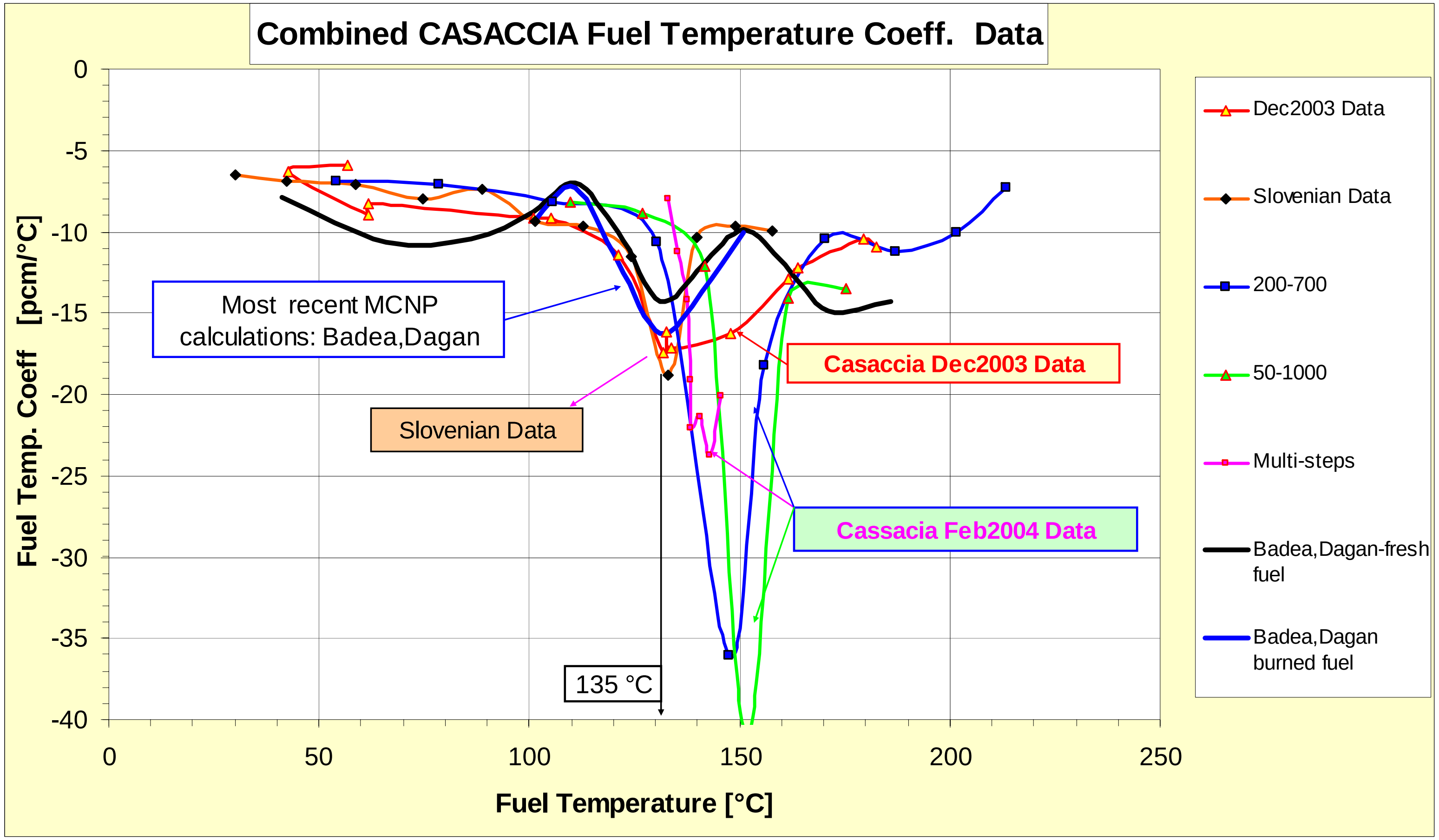
Compare to Casaccia experimental data (Nov/Dec2003 – February 2004) to most recent theoretical results.





1. **All Casaccia data indicate that something is happening at around T_fuel ~ 130 °C.**
2. **Published Slovenian TRIGA data also shows a similar effect.**
3. **The Casaccia data sets are however not consistent. The big question is : Why ??**
   a. **Again core inlet temperature dependency ??**
   b. **Due to only single fuel temperature measurement ??**

4. **Most recent MCNP calculations from Badea,Dagan (FzK) indicate, that when using a very fine nuclear data set structure, neutron upscattering in the ZrH-fuel matrix shows a spike in the fuel tempeature coefficient at T_fuel = 135 °C.**



1. **Theoretical calculations indicate a spike in the fuel temperature coefficient at T_fuel= 135 °C**
2. **Calculated area under the peak however not large enough to fully account for the observed effect(s) in CASACCIA.**
3. **Observed effect most likely due to the sum of two superimposing effects, one fuel dependent, and one additional effect most likely due to sub-cooled boiling (voiding) which also happens to start in the range of T_fuel ~ 135 °C.**
4. **This definitly needs further analysis, both theoretical as well as reanalysing the experimental data.**

5. Current Status of Benchmarking Transient Codes to Casaccia Transients

5. Current Status of Benchmarking Transient Codes to Casaccia Transients (1) :

1. **We can retrace Casaccia transients below 300 kW and above 600 kW quite well with current computer models. Below 300 kW only subcooled natural convection takes place. Above 600 kW fully-developed sub-cooled boiling is encountered. Both operational modes allow well understood modelling.**

2. **Transients between 300 and 600 kW are still not retraced quite satisfactorily (transient response of the fuel temperature not quite ok) due to the still existing uncertainties associated with the 1. reactivity coefficient, 2. heat transfer coefficient, and 3. effects associated with the onset of local, partial sub-cooled boiling between 300 kW and 600 kW.**

3. **Understanding the response of the TRIGA in this power range is still important and needs continued improvement (i.e. refinement) because large reactivity insertion transients run in the sub-critical configuration (starting at ~ 50 kW) might take the core into the 300 – 600 kW power range.**

5. Current Status of Benchmarking Transient Codes to Casaccia Transients (2) :

4. **Last year Antonio d'Angelo from ENEA proposed that the observed anomalities within the 300 – 600 kW range are ascribable to local (spatial) sub-cooled boiling effects.**

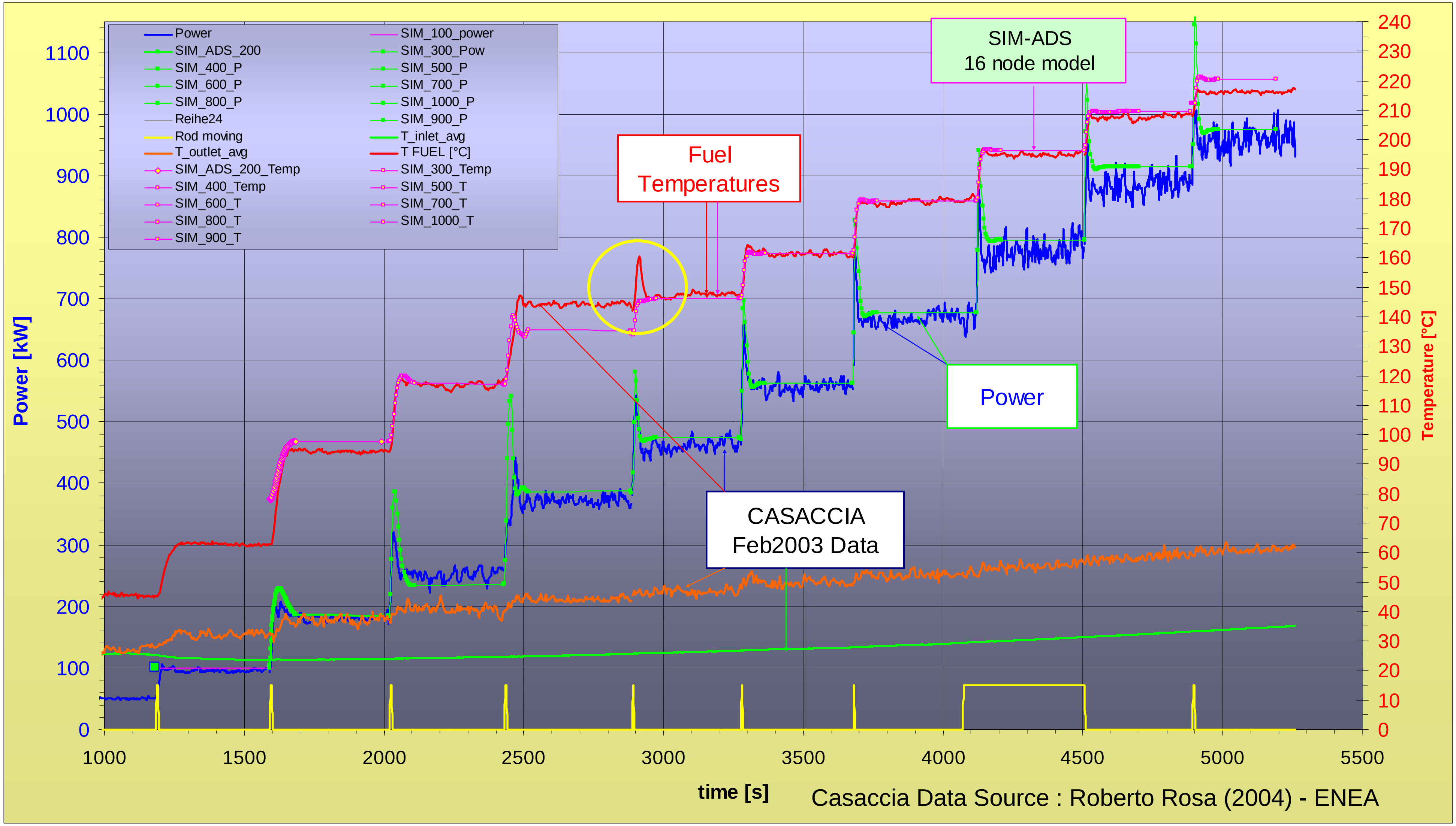
5. **The single fuel temperature transmitter (only 1 transmitter was available), located in the zone in which sub-cooled boiling is initiated, is believed to lead to a masked (i.e distorted) fuel temperature signal in the 300 – 600 kW range.**

6. **Resolving local (spatial) anomalities requires a fully coupled neutronic – thermal-hydraulic transients code. (RELAP, TRAC, TRACE etc. are not fully coupled codes since they assume a constant non-changing axial power distribution in the core during the transient).**

7. **During the last months, FzK developed an upgraded space-time dependent, fully coupled multi-nodal TRIGA dedicated transient SIM-ADS model (16 axial nodes), coupling thermal-hydraulics and neutronics in each node. This allows changing axial power distributions during the transient (normally assumed as fixed) as control rods (shims) are inserted into the reactor , a more exact resolution of local sub-cooled boiling effects on the fuel temperature, and a more exact local characterization of the neutron source in the sub-critical mode. It is hoped that this model allows unfolding the various issues in the 300 – 600 kW power range.**

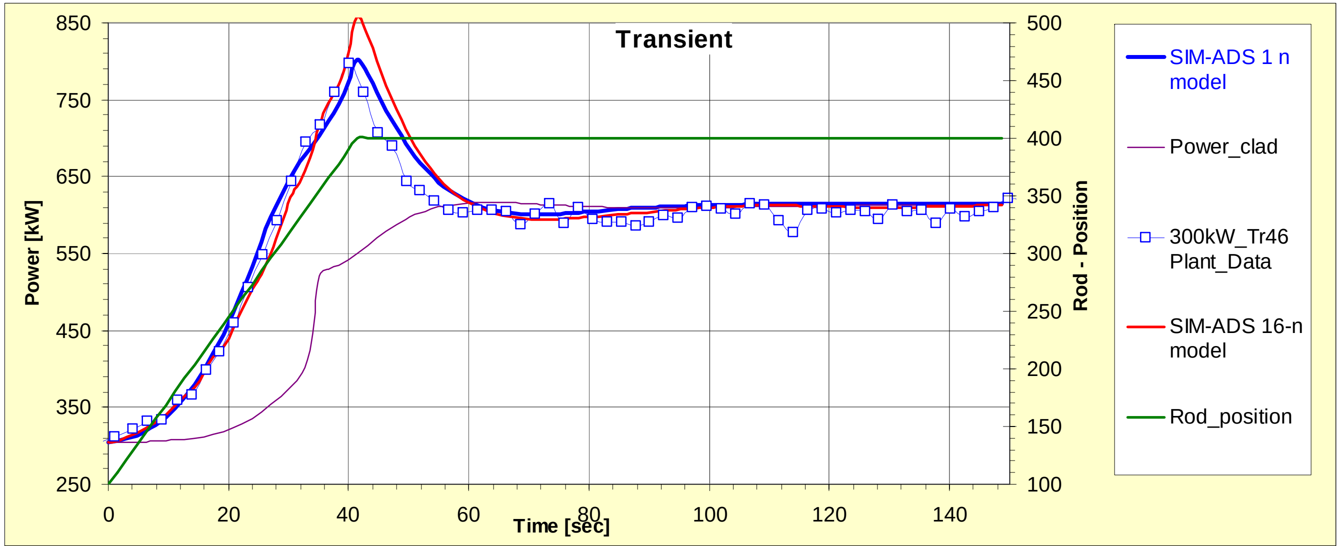
8. **This model is currently tested, i.e. validated by comparing results to Cassacia steady state and transient data.**

Power Runup from 100 kW to 1 MW by stepwise withdrawl of rods (shim1 and shim 2) : Comparison of fully-coupled SIM-ADS to Cassacia experimental data (Feb.2003)



Conclusion : Problem still in power range 300 to 600 kW as seen in difference in fuel temperature.

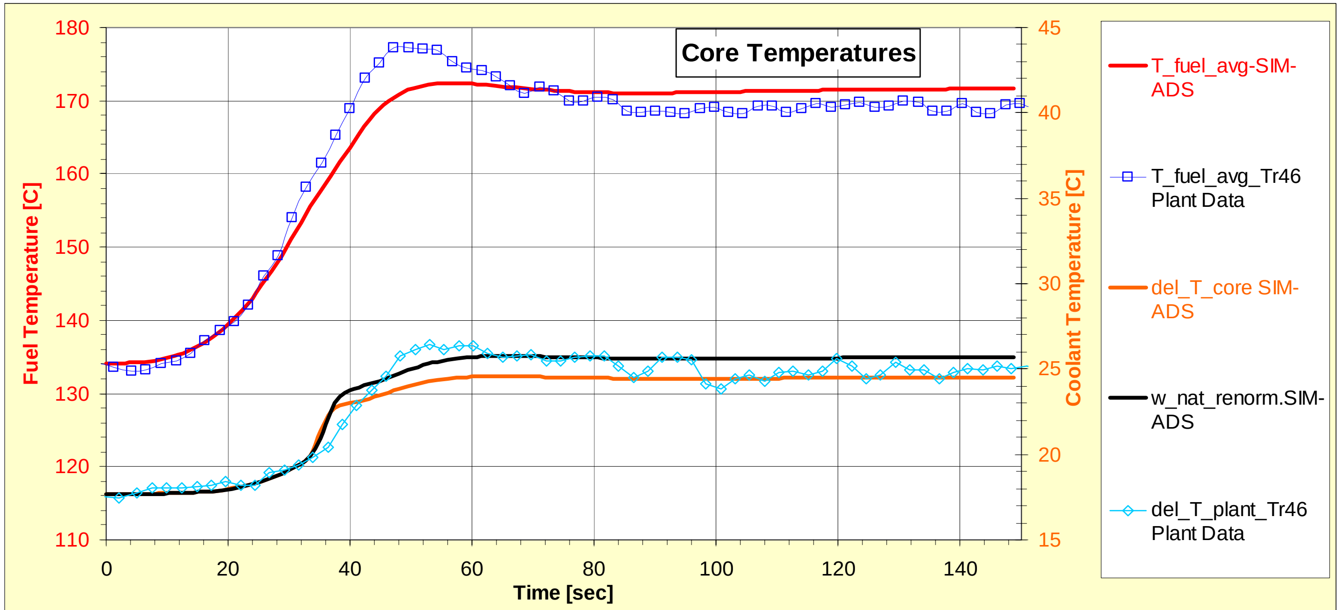
Comparison of Calculated Transient Response to Experimental Data



Transient Conditions:

Starting at 305 kW

Control Rod (Shim1) was withdrawn from Position 100 to 400 inserting 575 pcm of reactivity into the core



Relatively acceptable response in the calculated power of the 1 node and the 16 node model

Response in the calculated fuel temperature needs improvement.

Current Conclusions on Casaccia Transient Studies :

1. We have sufficient experimental data available to be able to “deduce / infer / derive“ Casaccia specific heat transfer correlations (i.e., Nusselt Number correlations) for the various observed heat transfer regimes, namely

   – Sub-cooled natural convection regime,
   – Sub-cooled enhanced natural convection regime,
   – Partial sub-cooled boiling regime,
   – Fully developed sub-cooled boiling regime.

- Still need to assess the interdependencies of these derived heat transfer correlations to other parameters, in particular for example : changing **core inlet temperatures !!**

2. The reactivity coefficient(s) issue still unresolved. Work is in progress and must be continued.

3. Benchmarking of upgraded codes / models still in progress.

Current Conclusions on Transient Studies :

4. For Benchmarking to RACE we would like to have a series of reactivity insertion transients similar to those performed at CASACCIA monitoring:

   - Power level,
   - local fuel temperatures (at different core locations),
   - radial traverses of :
     - core inlet temperatures and,
     - core outlet temperatures .