55.GG Calorimetry measurements for Cross-Calibration of Neutron Diagnostics

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Outline

- Calorimetry goals
- System principles
- Algorithms alternatives
- Forward modelling results
- Futher plans

Calorimetry as ITER diagnostic system

- Calorimetry – determination of heat transfer associated with changes in thermodynamic state variables of a body
- Application in ITER:
  - Supplementary system for the measurement of Total Fusion Power during normal operation
  - Fully software system, based on the data from sensors belonging to other systems
  - Provides the measurement after each plasma discharge - cannot be used for online control
  - Main parameters of the Total Fusion Power measurement are summarized in the SRD-55 table

Condition	Range	Time Res.	Spatial Res.	Accuracy
Normal Operation	70 MW – 0.9 GW	1 s	None	10% + 10 MW

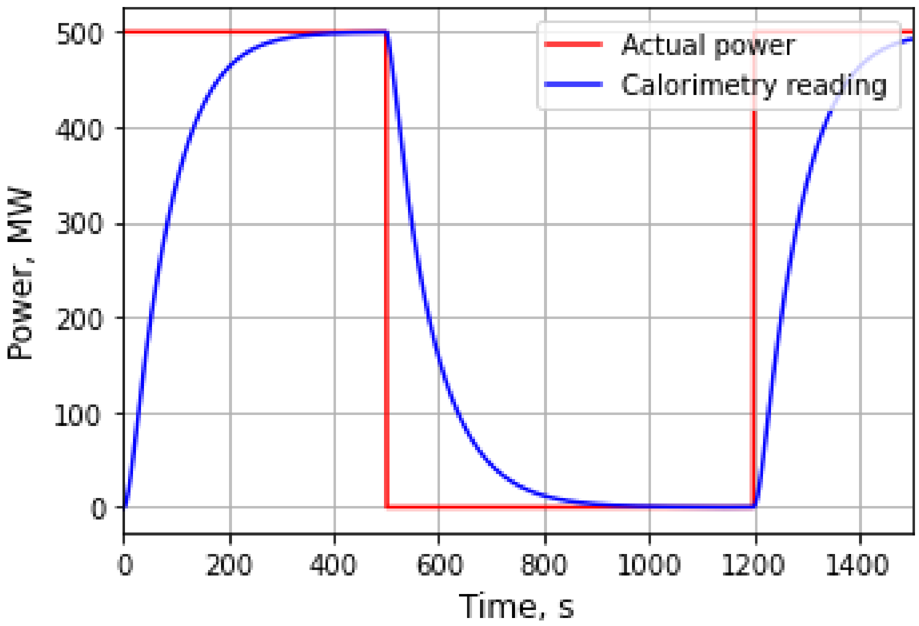
[55s2837-I] This measurement is provided for archiving after the discharge - not for online control.

[55s2838-R; Defined Requirement] The following diagnostic system shall be provided to contribute to meeting the requirement 55s2836-R:

- 55.B4 Neutron Flux monitor - Primary
- 55.GG Calorimetry - Supplementary

Calorimetry goals

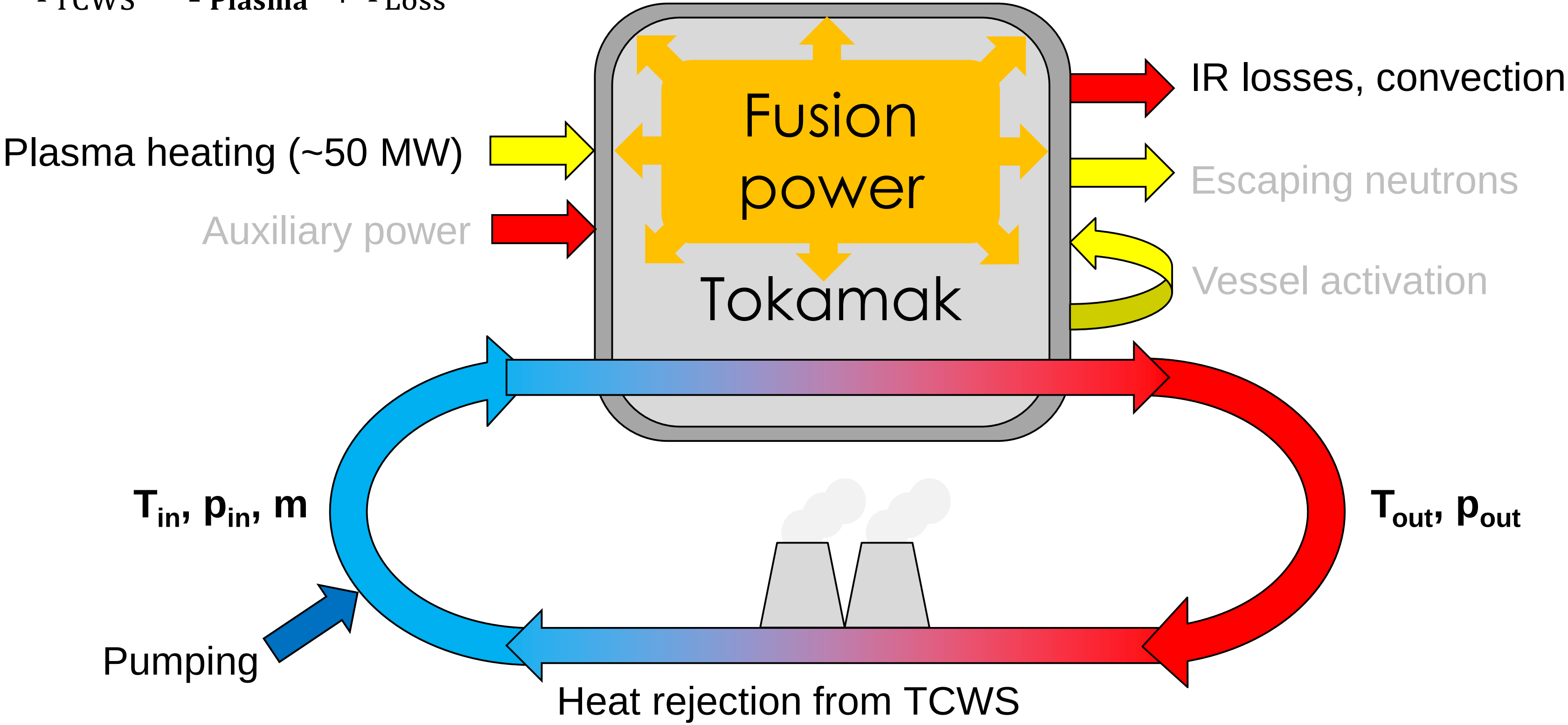
- Determination of integrated total fusion power complementary and independent from neutron flux measurement
- Cross-calibration with fast neutron flux sensors to provide reference point for their calibration
- Standalone measured value, better understanding of a pulse with the application of inverse algorithms



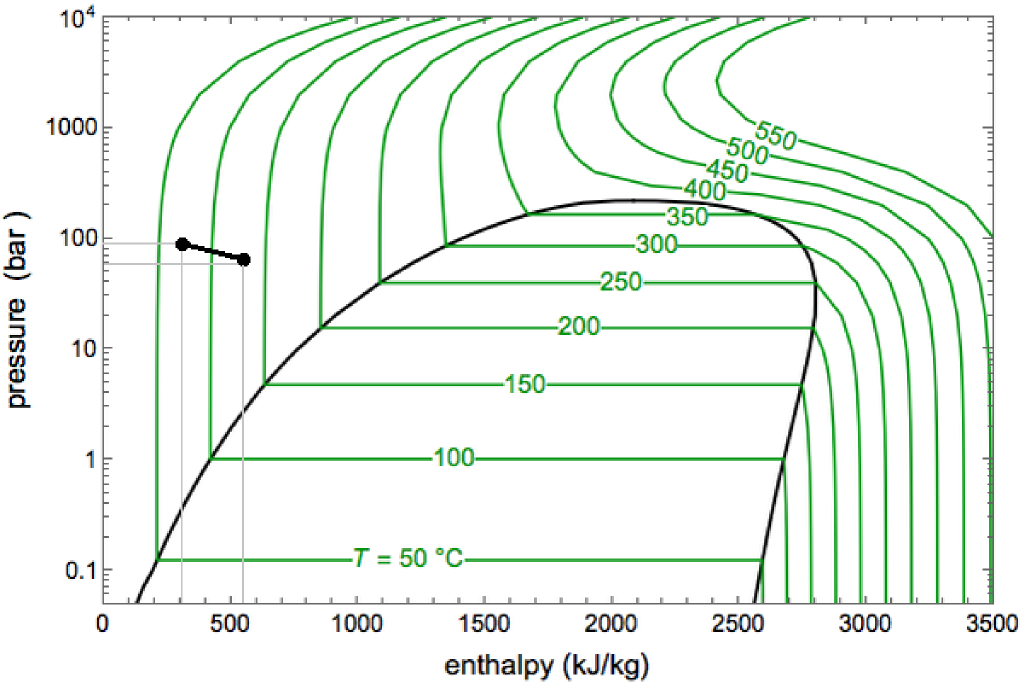
Simplified energy balance

$$P_{TCWS} = \dot{m} \cdot \left(h(\mathbf{T_{out}}, \mathbf{p_{out}}) - h(\mathbf{T_{in}}, \mathbf{p_{in}})\right)$$

$$P_{Fusion} = P_{TCWS} - \mathbf{P_{Plasma}} + P_{Loss}$$



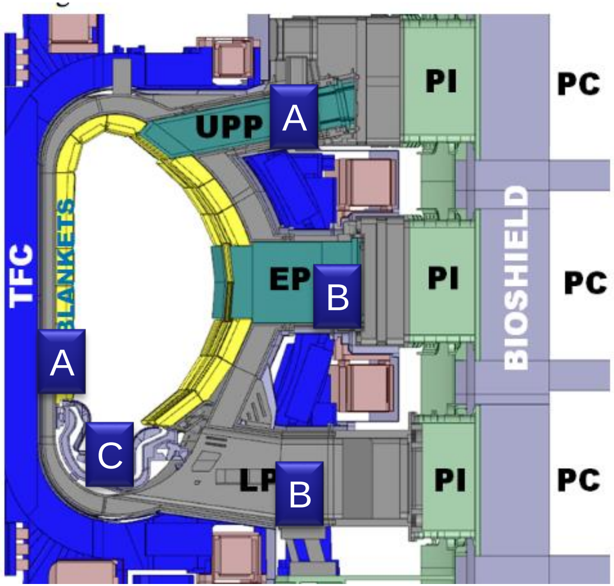
Total thermal power determination



- Thermodynamic properties of water very well known
- Compared to other thermal processes, ITER is relatively simple
- Dependence of enthalpy on temperature and pressure close to linear in considered region

Actively cooled IBED components

- 1 loop for Divertor Cassettes
- 3 loops for
  - Blankets First wall
  - Blankets Shield block
  - Edge localized modes (ELMS) coils
  - Vertical stabilization coils (VS)
  - Upper Port Plugs (level L2)
- 1 loop for Equatorial Port Plugs (level L1) and 3 LPP

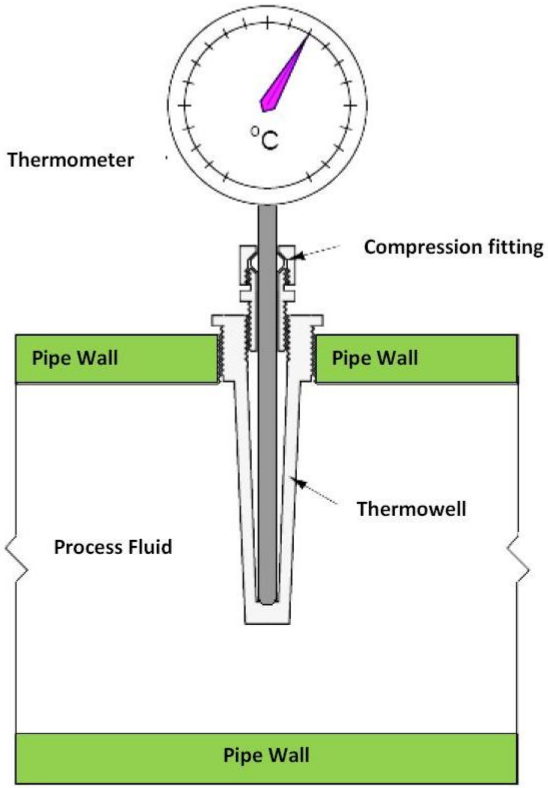


Total 5 loops of IBED PHTS

Ref- ITER_D_R89QZF

TCWS measurement Accuracy

- Flow measurement:
  - Performed with industrial flowmeters
  - Expected 1-2% accuracy
- Inlet and outlet temperatures
  - Thermo-well thermocouples (TC)
  - Expected 1% accuracy
- Pressure measurement – similar to temperature
- Redundancy in the number of sensors
- Senors time resolution ~around 1 sec



Algorithm alternatives – global energy balance

- Used in WEST, NBIs at EAST, JET, ASDEX
- Input signals
  - Set 1: P_{ohm}, P_{aux}, etc
  - Set 2: thermocouples and flow meters at cooling inlet/outlet
- Description:
  - First group of signals give all input power except fusion power.
  - The second group of signals allow calculation of total energy.
  - Difference is the fusion energy.
  - Once the different delays of the systems are characterized, 1st group could be used for time resolved fusion power

- Simplest approach which will be able to give a good read of total energy
- Applied already in plenty of plant systems
- Power time resolution is limited
- No spatial nor system resolution

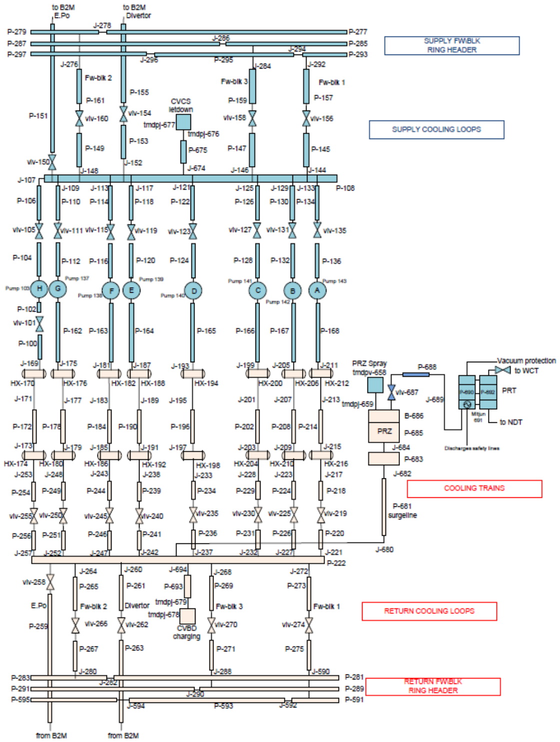
Algorithm alternatives – inverse algorithms

- Used in JET calorimetry, 55.GT thermal tasks
- Input signals:
  - Sets 1 and 2 from previous slide (engineering and plasma global measurements)
  - Additional temperature measurements (IR/TC at DFW/FW, VV, PPs, etc)
- Description:
  - Inverse reconstruction algorithms are able to reconstruct 0D-1D models or more complex 2D-3D fields
  - The system models used for forward analysis in this task are 0D-1D, very well suited for inverse analysis.
  - The algorithm gets a mix of measurements over time and gives back the accurate evolution of the neutron power, P(t)

- This approach is transient and could improve the time-resolution accuracy of approach #1
- Possible synergies with Physics (they are adapting the 2D-3D alg.) and maybe IR measurements
- Requires adaptation for use with TC signals at coolant inlet/outlets
- Heat transfer flow convection effects not tested, but currently in-work for 55.GT

Forward modelling – programmatical approach

- IBED RELAP5* system:

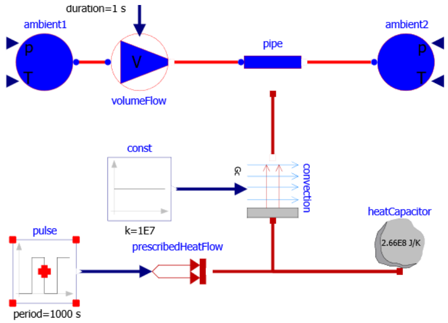


Needs simplification

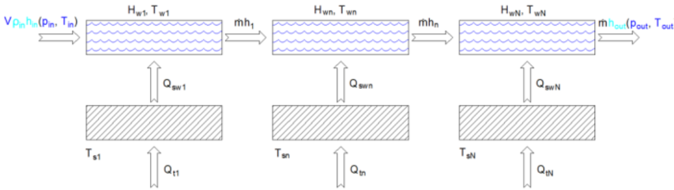
Cross-validation

Needs automation

- Modelica* system:

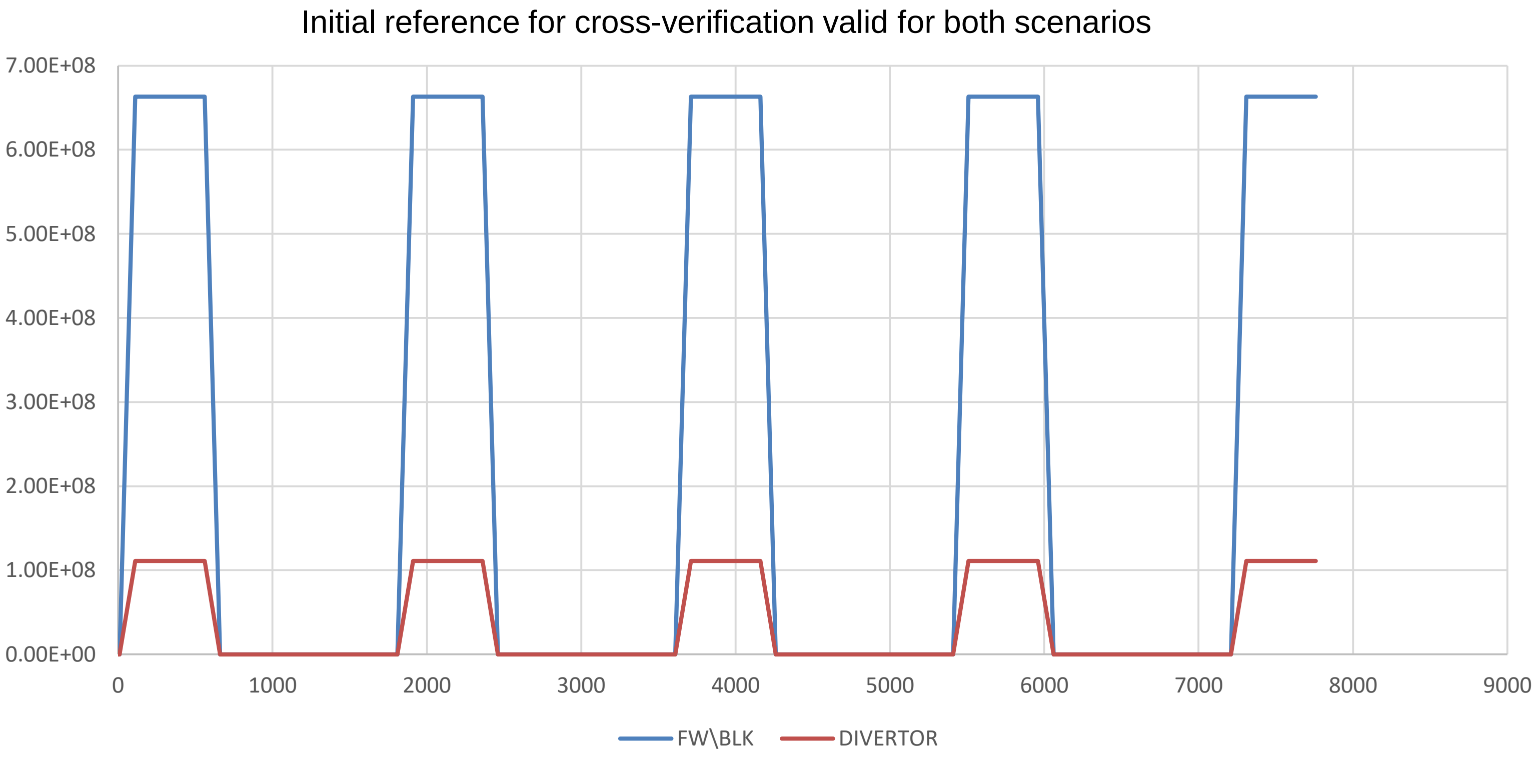


- Python coding



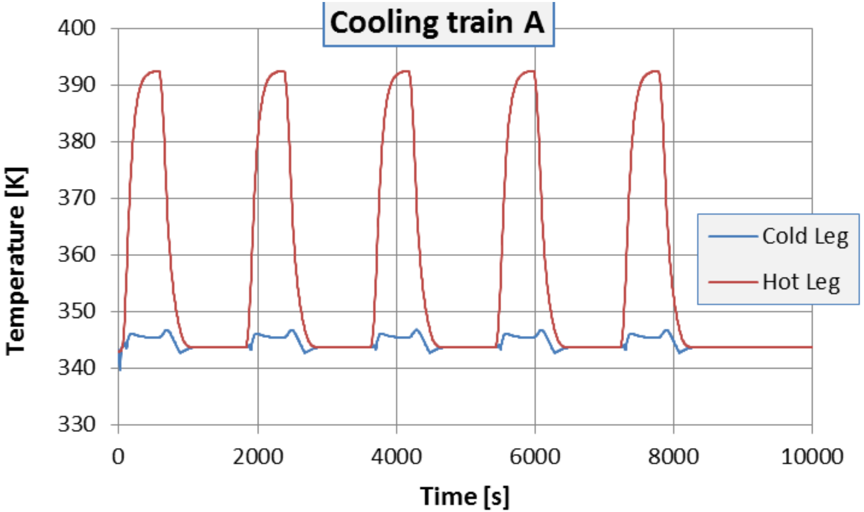
*Commercial thermal process modelling software packages

Forward modelling – heat inputs

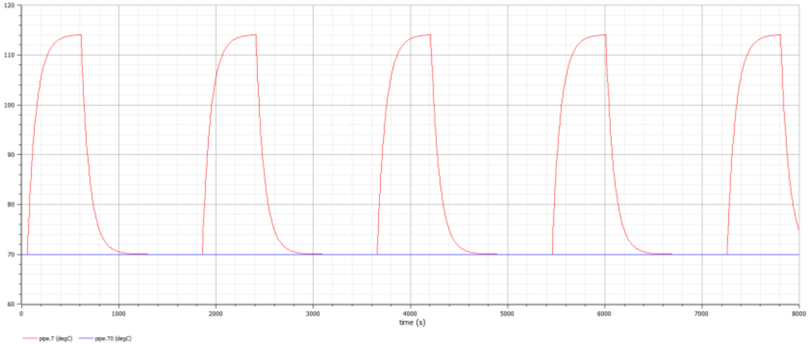


Forward modelling - results

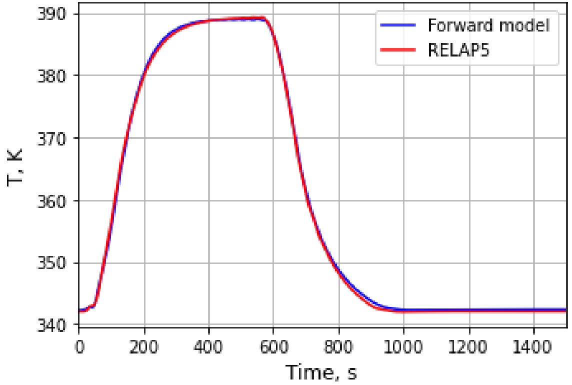
- Transient response:
  - Inductive scenario
  - Blanket ring (1/3 load)
  - RELAP5



- Modelica: Outlet peak T within 1 K (114˚C)



- Python: very good agreement with RELAP5



Calorimetry plan

- Two phases defined (progress, in-work):

Forward system modelling

- Simplified model(s) definition: (1) alg. development and (2) calibration
- Analysis and understanding of system response
- Cross-checking with more complex models (RELAP5, EcoSimPro)
- Selection of relevant input scenarios for simulation
- Model refinement and definition of all TCWS cooling loops
- Generation of synthetic signals and definition of calibration strategy

Measurement algorithm development

- Agreement on objectives: 1st order and 2nd order – preparation of sSRD
- Evaluation of alternative algorithms
- Definition of constraints, interfaces and workflow
- Description of mathematical underlying model based on Phase 1 model
- Code implementation and verification
- Release and deployment

Summary and outlook

- Management / strategy:
  - Create sSRD (individual requirements in preparation)
  - Facilitate communication with other systems (especially plasma heating) to obtain the needed data, discuss interfaces, and find synergies
  - Define strategy for use of calorimetry results for calibration of neutron flux sensors

- Modelling:
  - Model refinement and definition of all TCWS cooling loops (in-work):
    - Error analysis (in work)
    - Comparison to the EcosimPro model once its developed (expected 2022)
  - Generation of synthetic signals and definition of calibration strategy
  - Development of reconstruction (inverse) algorithms

- Measurement algorithm development:
  - Evaluation of alternative algorithms
  - Definition of constraints, interfaces and workflow