WPSA Code Management Area: modelling, synthetic diagnostics, operation related tools

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WPSA Code Management and modelling

Role Title	*Required Competencies*

Suite of codes manager	• Knowledge of numerical simulation tools in tokamaks
	• Knowledge of the simulation infrastructure and platforms
	• coordination skills
	• Activity goals will include:
	  • to coordinate selection, validation, adaptation and benchmark of simulation tools for application to JT-60SA in order to prepare, perform and analyze the future experimental campaigns
	  • Prepare and coordinate training activities for the application of the simulation tools

Simulation expert, data analysis tools developer	• Scenario development and analysis • Disruption and runaway, physics, consequences and mitigation • Synthetic diagnostics development, including image processing for scientific cameras, particularly but not exclusively for EU-led diagnostics EDICAM, Edge TS, Divertor VUV, FILD • Fast particles • MHD and Control • Edge and divertor modeling • Operation-oriented tools : (equilibrium, control, discharge fast simulator etc.) • Energy, Matter and Impurity Transport

- Adaptation/preparation of analysis tools (predictive, interpretative) to support
  - Experiment preparation
  - Experiment analysis
  - Interpretation of diagnostics data
  - New enhancements
- Strict relation with the Experiment Team before and during the campaigns

C.Sozzi | 8th WPSA PPM | 15 March 2021 |

FP9 : WPSA Code Management strategy

- Establish reliable modelling codes, workflows and **operation related tools** for routine use in the scientific exploitation starting in 2023
- Modelling **support to the enhancements and diagnostics** procured by EU, including control actuators
- Specific focus on **modelling the first operation phase scenarios**:

  Initial research phase I and II, in H and D, with reduced power and C-PFC

(!Divertor not actively cooled)

	Phase	Expected operation schedule		Annual Neutron Limit	Remote Handling	Divertor	P-NB Perp.	P-NB Tang.	N-NB	NB Energy Limit	ECRF 110 GHz & 138 GHz	Max Power
Initial Research Phase	phase I	2021 (5M)	H	-	R&D	USN Carbon	0	0	0	0	1.5MWx5s	1.5MW
		2023 (2M)				LSN Carbon Div. Pumping	3MW	3MW	10MW	23MW x 14s duty = 1/30	1.5MWx100s + 1.5MWx5s	19MW
	phase II	2023-2024 (6M)	D	3.2E19			6.5MW	7MW				26.5MW
		2024-2025										
	phase III	2025-2027								Real Injection : ~ 26MW x 2-3 sec limited by divertor cooling		
Integrated Research Phase	phase I	2029 - 2031	D	4E20		LSN Actively cooled Carbon Div.Pumping	13MW			20MW x 100s 30MW x 60s duty = 1/30	7MW x 100s	37MW
	phase II	2033 -	D	1E21		LSN Actively cooled Tungsten-coated Carbon Div.Pumping						

1 - Plasma operation oriented tools and synthetic diagnostics development

SA.CM TOPICS	2021 PROPOSED TASKS (milestones in red)
Discharge simulator	M1. Simulate JT-60SA discharge with the plasma discharge simulator coupling METIS-CREATE codes with controllers. (CEA Univ Nice, ENEA CREATE)
Breakdown simulators	Breakdown simulators, implementing burnthrough model (ENEA: CREATE, ISTP)
Integrated Data Analysis	Integrated Data Analysis and Validation (IDAV) : requirement capture and specifications (MPG-IPP Garching)
ECWC	Validate ECWC simulation tools on the first data from IC (ERM/KMS)
Synthetic diagnostics development	Synthetic diagnostics development for EDICAM (EK)
Synthetic diagnostics development	M2. Visible imaging analysis tool implemented on JT-60SA and tested (camera tomography) (IPP.CR)
Disruption prediction	Verification of the disruption database (provided in IC activity) for monitoring disruptions (NCSRD(NTUA) , CIEMAT, ENEA TorVergata)

DISCHARGE SIMULATOR

Objective: Tool for EU scientists or operators to develop experimental/operation scenario before proposing or implementing an experiment on JT-60SA.

- Light tool: accessible and « reasonable » CPU time.
- Friendly interface
- Capable of simulating a discharge from start of ramp-up to end of ramp-down, including X-point formation, heating, etc …
- Includes the machine operational constraints (current limits, controller, etc …)

J Joffrin et al (CEA Univ. Nice, ENEA CREATE)

TASK 2021 - 2022

- Deployment of the light coupling simulator on the Gateway for users
- Development of test cases for the simulator: Scenario 2 and 4.2
  - Design an optimised current ramp with a new shape sequence for reduced flux consumption
  - Provide Scenario 2 for usage of the core/edge scenario modelling (transient phases)
- Implement and test the convergence of the strong coupling procedure
- Assess computing time

SA AWP2021 SA.CM.D1: Report/publication on first simulation of a JT-60SA discharge with the plasma discharge simulator coupling METIS-CREATE codes with controllers.

BREAKDOWN SIMULATOR

M Mattei D Ricci (ENEA CREATE ISTP)

Modelling of the EC assisted start-up for JT60-SA

Plasma breakdown simulation, optimization and control with the suite of codes developed by CREATE and ISTP for plasma breakdown simulation:

- CREATE-BD (M. Mattei et al, 2015 IEEE Conference on Control Applications)
- BKD0 (G. Granucci et al 2015 Nucl. Fusion, 55) 0D breakdown model
- GRAY (D. Farina, 2007, Fusion Sci. Technol. 52) EC absorption calculation

✓ A coupling between magnetic and kinetic models works and different scenarios have been produced for JT60-SA. Latest application to JT-60SA (25% CS current).

Possible future development activities under WPSA

- Increase the numerical efficiency of the code and the automatic optimization capabilities with the adoption of a nonlinear optimization algorithm
- Increase the level of integration with other codes (e.g. burnthrough) in the ITER perspective (WP-PrIO tbd)
- Routinely use (part of the code) for engineering studies (JT60SA, DEMO WPDES, DTT)

Integrated Data Analysis and Validation

R. Fischer et al MPG IPP-Garching

IDA for JT-60SA

plasma operation and physics exploitation oriented tool:

requirement capture, specifications and to adapt modular IDA (ITER) python code to JT-60SA diagnostics

1st IDAV meeting (10th Dez 2020) prior to the WPSA call: A. Bock (IPP), R. Fischer (IPP), Keisuke Fujii (Kyoto Univ.), D. Nille (IPP), Hiroshi Tojo (QST), C. Sozzi (ENEA ISTP-CNR Milano)

- JT-60SA:
  - ➢ start with commissioning diagnostics (PO-1):
    - ➢ interferometry → n_e
    - ➢ soft-X ray → $T_e(n_e, Z_{eff})$
    - ➢ visible spectroscopy → $Z_{eff}(n_e, T_e)$
  - ➢ augment with PO-2 synthetic diagnostics:
    - ➢ Thomson scattering → n_e, T_e
    - ➢ ECE → $T_e(n_e)$
- start: in 2021 (campaign independent)
- goal: IDA for physics exploitation in 2023
- manning (IPP): 12pm/year (postdoc); visits: 1st 2 weeks, 2nd 6 months in 2021/22 (?)
- IMAS at JT-60SA?

DISRUPTION PREDICTION

J Vega (CIEMAT) + M Gelfusa et al. (TorVergata) + T Cracinescu (IAP)

« Disruption predictor tool » proposal

- develop a specific tool (ML) to classify disruption types (eg radiation collapse)
- the classifier can help in the real-time decision of triggering avoidance, prevention or mitigation actions when any predictor identifies an incoming disruption
- comparison of different adaptive strategies
- Medium term: implementation of Maximum Likelihood Tomography

Dr. Aristeides Papadopoulos Dr. Fotis Bairaktaris (NTUA)

Expertise in ML for fusion: constructing disruption prediction hybrid models, not solely data-driven, but also physics-driven.

- Physics-guided Neural Networks (PGNN): Modify loss function to incorporate physical knowledge in the training process, penalizing deviations from laws that must not be violated.
- Used in applications, improving accuracy and reducing training time.
- These hybrid models bridge the gap between black box models and theoretical ones.

2021-22 TASK

AIM: **Prepare the monitoring of disruptions with a well thought database (ongoing under IC).**

Points discussed:

- Verification of the disruption database signals
- Training of the predictors with ML on the database
- Explore usage of other data than bolometry for disruption prediction

Camera tomography tool

J. Cavalier (IPP.CR)

- ✓ Camera tomography tool developed in python
- ✓ Code benchmarked on TCV and COMPASS plasmas
- ✓ Camera tomography tool implemented on Naka server tested on JT-60SA EDICAM camera data (under IC)
- ✓ Code ready to be used by local user on QST server

Activities in 2021:

- ➢ Release of the camera tomography python too for JT-60SA, calibrated to EDICAM
- ➢ Consideration to use the QST visible cameras
- ➢ Provide input to ECWC modelling

ECWC modelling

T Wauters J Buermans(ERM/KMS)

Modeling of ECWC to complement experimental observations in JT-60SA

- Partially ionized plasma: He, H2 (CI-V)
- Reaction-Diffusion-Convection model (1D radial) output: transport coefficients and absorption
- ✓ Validated on TCV He-ECRH plasma
- ✓ Ready to start working with JT-60SA input

Workplan

- ➢ Insight on Transport processes ➔ Particle fluxes to HFS and LFS
- ➢ Required coupled power to equilibrate the power balance ➔Estimation of stray radiation
- ➢ Camera tomography will complement plasma diagnostics : plasma emissivity profiles as input to TOMATOR-1D model

Activity in 2021

Validate ECWC simulation tools on the first data from IC

EDICAM SOFTWARE

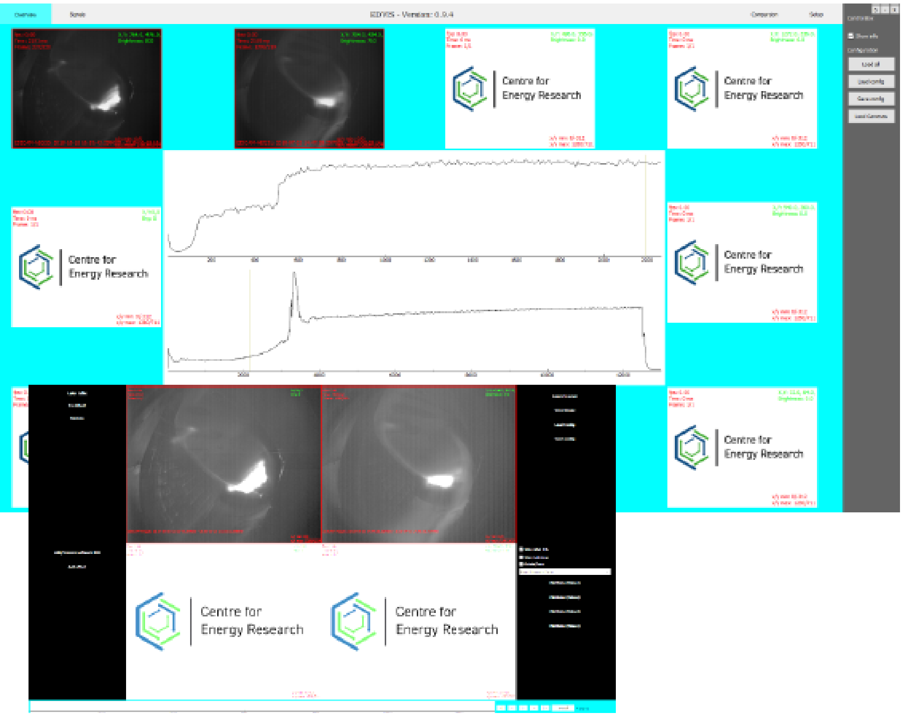
T. Szepesi et al (EK) Centre for Energy Research www.ek-cer.hu/en

Centre for Energy Research

EDICAM: Activities and deliverables for 2021

Code development

- develop a GUI-based software package for camera data visualization
- include FLAP (Fusion Library of Analysis Programs) package support, developed by EK



EDVIS: EDICAM Data Visualization Software

- display up to 10 movies, time-synchronized
- several playback options
- display other diagnostic data*
- basic image manipulation
- export to several movie/image formats

New features / enhancements

- adapt layout to JT-60SA (e.g. portrait orientation)
- develop data input/output for JT-60SA data

2 – Modelling for JT-60SA Initial Research Phase

SA.CM Topics	2021 PROPOSED TASKS
Scenario development and analysis	Validation of IM simulators on the nominal scenarios and identification of viable high-radiation long discharge scenarios for the initial phase (Scenario 2 / transient phases) (CCFE, CEA, IPPLM, VR)
Scenario development and analysis : turbulence	E.M. gyrokinetic study of anomalous transport in a JT-60SA high-beta representative plasma discharge (EPFL)
Edge and divertor modeling	Investigate conditions for divertor detachment for the initial phase scenarios, including impurity seeding impact (CEA, ENEA (Univ Tuscia RFX), MPG IPP-Garching)
Fast Particles modelling	Investigate the stability of high-energy ions for the initial phase scenarios (MPG IPP-Garching, IST, VTT)
MHD and control	MHD stability workflow: demonstrate routine application on Initial Phase (reduced power) scenarios (IST, ENEA RXF)
Disruption and runaway physics, consequences and mitigation	Validation on mechanical measurements (ENEA CREATE) Disruption mitigation and RE current studies on the initial phase scenarios with DMV (> 2021) (IPP.CR MPG)
Non-linear MHD modelling	Non–linear ELM + pellets modelling with JOREK (CIEMAT)

Scenario modelling

L Garzotti et al. (CCFE)

JINTRAC scenario modelling JT-60SA research phase I and II

A series of simulations of scaled-down versions of the main operational scenarios for JT-60SA, has been performed . The simulations have been catalogued and are available.

FUTURE PLANS

- Improve availability of tools for heating and current drive (ASCOT and GRAY). Need collaboration with code developers.
- Continue/complete modelling of scenario 4.2.
- Exploratory look at steady state, non-inductive scenario.
- Provide integrated scenario modelling in support of:
- Initial plasma operation and scenario development.
- Experiment proposals if needed (probably further down the line).
- Other areas (such as turbulence, edge physics and fast particle physics).
- Diagnostics (and other enhancements, already applied to polarimeter, pellet injector and spectrometer).
- Ramp-up and down.

Proposed task 2021

- ➢ Model the initial phase scenarios (with full field) using the equilibria provided by the discharge simulator: focus on Scenario 2 / transient phases

Scenario modelling

S Yadykin et al (VR) + Ph Huhyn (CEA)

- ETS6 IMAS version will be the modelling tool
- Validation ongoing for different tokamak devices (ITER, JET, AUG, TCV)
- JT-60SA is supported in ETS5, upgrading machine description for IMAS version
- Extensive set of physics actors available
  - Equilibrium: CHEASE • Transport: TCI package(NCLASS,TGLF,QLK,NEO..)
  - HCD: ASCOT package (BBNBI, ASCOT, AFSI), Gray,.. • Edge: PENN, etc

Time plan (2021)

- ➢ Setup, demonstrate and deploy ETS for scenarios modelling
- ➢ input data conversion mechanism should be clarified
- ➢ verification with available modelling results

Interests: Scenario modelling:

•interpretive simulations using precalculated profiles
•predictive modelling including current ramp-up/down
•various heating schemes
•different operational regimes (L-mode, H-mode)
•impurity transport
•New activity for us: very keen on getting involved

Proposed task 2021

➢ Validation of ETS on the nominal scenarios

Turbulence modelling (PCI design / validation)

Aylwin Iantchenko (EPFL)

Gyrokinetic turbulence modelling for JT-60SA DN Scenario with 41MW (34 NBH + 7 ECH)

- ✓ non-linear local GENE EM simulations: e,D,C+ fast D, including collisions, β=2.7%, $\delta B_{//}$
- ✓ Simulations at nominal parameters : too low heat flux

Post-process simulations with a synthetic diagnostic to model measurements from a Phase Contrast Imaging (PCI) diagnostic.

- ✓ Synthetic diagnostic already developed for post processing GENE results.

- Interest from BES team (Dunai, Asztalos, EK) to eventually interface to GENE for BES validation

Proposed work:

- ➢ Compare to GENE simulations by S. Mazzi to conclude on the physics results ?
- ➢ Explore an actual scenario of the first phase

Edge/divertor modelling

L. Balbinot P Innocente (ENEA RFX) + CEA

Edge modelling of C-Wall JT-60SA with SOLEDGE2D-EIRENE (Secnario 2)

Outlook

- ➢ Study initial research phase scenarios
- ➢ Development of synthetic diagnostics (ex. VUV)
- ➢ Development of tools for experimental data analysis for edge modelling

Future area of interests (2022+):

- ➢ Studying the effects of drifts on plasma radiation and divertor power load distribution
- ➢ Modelling of DN

G Rubino et al (ENEA Tuscia Univ + IPP Garching)

SOLPS-ITER modeling of JT-60SA with metallic wall

- ✓ The assessment shows the possibility to operate JT-60SA in the high density scenario
- ✓ A wide operational windows can be defined

OUTLOOK

- ➢ A more sophisticated analysis is ongoing with drift terms taken into account
- ➢ Same procedure with a definition of the transport coefficients with a more recent JET experiment
- ➢ Benchmark with SONIC code (in collaboration with QST) ongoing

EDGE/DIVERTOR modelling

- Very lively and interesting discussion (thanks to Sven Weisen et al.)
- **K Galazka (IPPLM):** ongoing development of an improved COREDIV version

Discussion points

- Exploit cryo-pump measurements for input/ code validation
- How to provide separatrix density / scalings derived from edge codes for the core modelling

Proposed task 2021

➢ Investigate low n /current drive scenarios in C with SOLEDEG3X-EIRENE (in 2D) and SOLPS-ITER

➢ Interact with WPDIV on design/geometry of C divertor (not / actively cooled) and needs for W-divertor design

Dedicated meeting on scenario modelling proposed with the involved modelers
S Weisen offered to present procedures devised for consistent core and edge modelling eg for ITER Predictions

High –beta MHD stability analysis (and control)

R Coelho (IST)

- ✓ Linear MHD Stability Workflow operational (IMAS 6.2.0)
- ✓ Preliminary results of the 2 variants of the advanced hybrid Scenario
- Infernal / ballooning analysis of pressure driven core modes shows that these modes are unstable.
- Growth rate scaling with n-mode coherent with a dominant ballooning character lower n are nonetheless closer to infernal.
- Do Scenarios 2,3 also bear similar limits/modes ?

L Pigatto et al (ENEA RFX)

- RWM modelling (MARSF/K) and control (CARMAD)
- 3D plasma response to RMP

Proposed work

- ➢ Demonstrate routine application of linear MHD stability workflow on Initial Phase scenarios (reduced power)
- ➢ MHD stability modeling for high β
- ➢ Plasma response in fast ion distribution
- ➢ MARS-F Integration in EQSTABIL?

Non-linear MHD modelling : ELM and pellets

Shimpei Futatani (CIEMAT) et al.

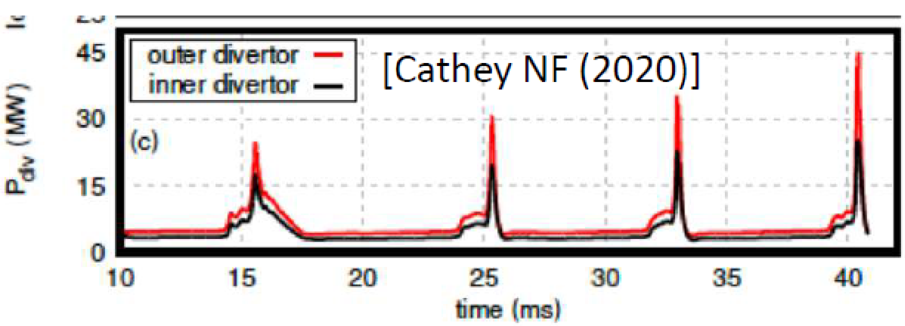
Non-linear MHD simulations with JOREK of pellet triggered ELM in JT-60SA

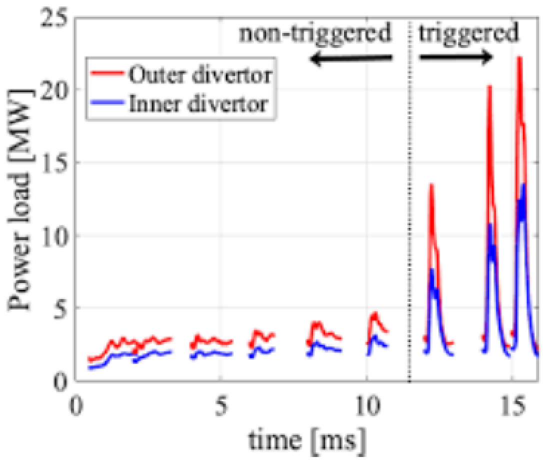
Summary 2020

- Now, we know that the 0.8×10^{20} D pellet (reference pellet size for ELM pacing)
  - triggers an ELM in the plasma which has 55.5 kPa pedestal pressure.
  - Does not trigger an ELM in the plasma which has 27 kPa pedestal pressure.

Plan 2021

- It may be nice to know if 0.8×10^{20} D pellet triggers an ELM in a 40 kPa pedestal pressure plasma.
- It would be nice if the realistic plasma flow (diamagnetic term, neoclassical term, etc) can evolves the pedestal profile. [Cathey, Hoelzl, NF 2020]
- The pellets will be injected inter-ELM phase (same approach with [Futatani et al., NF 2021]).





Energetic particle modelling

TSVV#10 and ENR project ATEP (Advanced Transport models for EPs) will include SA scenarios into the set of reference scenarios to validate and benchmark the participating tools and models (couple to ETS within TSVV#10, J. Ferreira)

R Coelho P Rodrigues (IST)

Calculate the NBI energetic particle deposition profiles and distributions using ASCOT

- Discriminate by P-NBI and N-NBI
- Estimate drive/damping contribution from NBI ions using CASTOR-K hybrid MHD drift kinetic code. Estimate also thermal ion damping.

Ph Lauber et al (MPG IPP-Garching)

✓ compare LIGKA results with MEGA results on ramp-up discharge

✓ new interface LIGKA-PIC code output established

✓ HELENA- HAGIS-LIGKA IMAS python workflow; not yet fully automated for SA

Outlook

- apply to time-dependent scenarios and investigate ramp-up phases (HAGIS/LIGKA), in particular first plasma scenarios
- start to involve broader set of codes: collaboration on MEGA (QST), ORB5, TRIMEG

Energetic particle modelling

Taina Kurki-Suonio A Snicker et al (VTT)

ASCOT for JT-60SA: 2021->

What would be the best ways to complement the work carried out by our Japanese colleagues:

- ★ Effect of non-axisymmetric magnetic field and/or various MHD modes on fast ion dynamics
- ★ Evaluation of NBCD and/or rotational drive?
- ★ Power load simulations including identification of possible hot spots?
- ★ Evaluation of neutron fluxes?
- ★ Synthetic diagnostics (IR, FILD, neutron & gamma diagnostics)?
- ★ Estimation of shine-through losses with high energy NBI?

Disclaimer: the extent of VTT activities in 2021 will be in part limited by national funding decisions.

Aalto University
School of Science

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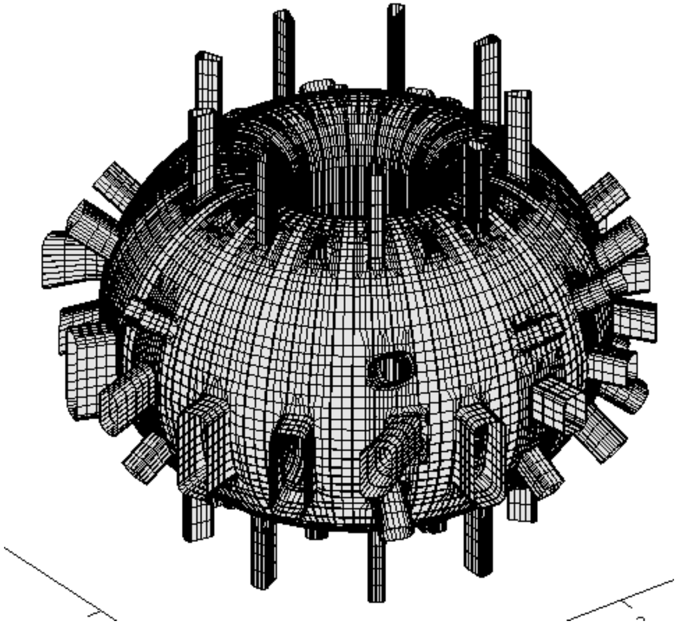
Disruption modelling

F Villone et al (ENEA CREATE)

- ✓ Disruption modelling for JT-60SA up and running with CARIDDI code
- ✓ Both symmetric and non-axisymmetric events (AVDEs) covered
- ✓ CarMa0NL: able to describe the evolutionary equilibrium of axisymmetric plasmas, in presence of three-dimensional volumetric conducting structures
- ✓ A detailed 3D mesh of the vacuum vessel has been produced, by removing the passive plate.
- ✓ Geometries/configurations relevant for IC and early phases addressed
- ✓ Synergy with breakdown studies



Outlook

- Further disruption simulations (symmetric & asymmetric) (to be agreed)
- Compare to / validate with experimental data
- Coupling with mechanical models/measurements

Proposed task 2021-22

Validation of halo-current predictions on halo-current measured data (after IC) and strain gauges measurements

Runaway modelling

Oliver Linder et al (MPG –IPP Garching)

Transport modeling of electron runaway with reduced kinetic tools for JT-60SA:

Application of transport codes ASTRA-STRAHL for simulations of RE mitigation by MGI

Synergy with TSVV9 goals: Develop self-consistent, robust and validated models to simulate RE dynamics & mitigation

- Predictive simulations prior to H.I.2. & H.II.3.; prior model validation within TSVV Task 9 (2022/23)
- Interpretive simulations of experiments from H.I.2. and H.II.3.(mid 2023 onwards)
- Model refinement and extrapolation to ITER(2024 onwards)

Jakub Caloud (IPP.CR)

Simulations of heat loads to PFC caused by Runaway Electrons

- COMSOL simulations of heat transfer in PFC: temperature measurements used for estimation of RE impact energy and the incident power
- FLUKA (MC code for interaction and transport of high energetic particles) simulations of RE interactions with PFC material
- Simulations of energy deposited by REs in COMPASS LFS limiter ongoing

R Bonifetto (ENEA PoliTo) advertisement of similar modelling

New activity : priority modelling needs to be identified and task to be agreed

Next steps

- Confirm tasks and activities for 2021
- Define SMART deliverables

Thank you for your interest
your contributions
and lively discussions