THEMATIC WORKSHOP AI/Digital transformation



Jean-Daniel DELAPLAGNE

He oversees the delivery and support of various solutions for CAD, engineering, PLM, construction, manufacturing, and quality.



Anders WALLANDER ITER Head of Control System Division

He joined ITER to implement the Control, Data Access and Communication system designed to play conductor to ITER Operation.



Simon PINCHES ITER Plasma Modelling & analysis Section Leader

He coordinates worldwide research as co-chair of the International Tokamak Physics Activity Topical Group on Energetic Particle Physics.







María ORTIZ DE ZÚÑIGA

F4E Head of Project Engineering, CAD & Data Management

Passionate about AI, she has a strong background in multinational environments, and an expertise in project management, risk analysis, and technical documentation.



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Moderator:

Alain Bécoulet ITER Project Chief Scientist Deputy Director-General

25/04/2025



AI – DIGITAL TRANSFORMATION



Alain Bécoulet, J. D. Delaplagne, A. Wallander, S. Pinches,

ITER Organization



Maria Ortiz De Zuniga

Fusion For Energy

FRIDAY APRIL 25th

Disclaimer: the views and opinions expressed herein do not necessarily reflect those of the ITER Organization





Alain BECOULET



Jean-Daniel DELAPLAGNE



Maria ORTIZ DE ZUNIGA



Anders WALLANDER









ENGAGEMENT WITH PRIVATE SECTOR FUSION INITIATIVES

- Requested by ITER Council, Nov. 2023
- > Initial workshop held at ITER, May 2024
 - > 350 participants
- Second Edition 22-23 April 2025, same interest!
- Establishing channels for further engagement and knowledge sharing
 - ITER Design Handbook
 - Access to ITER documents
 - Requests from 13 entities so far
 - > >500 documents (topics) requested so far
 - Open-sourcing IMAS
 - Agreements
 - Catalogues of fusion resources
 - Technical visits
 - Discussions with ITER experts
 - Access to ITPA committees
 - Industry secondees
 - Help desk















DJ1 What role(s) for AI / DIGITAL SOLUTIONS?

The long duration of the ITER lifecycle, combined with the unprecedented high degree of science and technology sophistication, as well as the emergence of new information technologies, are calling for a careful consideration of the capabilities now offered by digital tools to further augment its global reliability, availability, efficiency and secure its knowledge, notably by

- Assisting Systems Engineering Processes
- Assisting all phases of Construction Project, incl. Quality Management, and Corporate Functions
- Assisting Preparation to the Physics Operation
- Exploring domains of **Plasma Science & Operation**
- Cross-generation training and education
- Managing Knowledge and Know-how





Diapositive 7

- DJ0 fix up logo bg, missing ones gamma, cintoo, autodesk, Delaplagne Jean-Daniel; 2025-04-09T21:14:15.819
- DJ1 visual on how we structure partnerhsip IO vs editor, vs integrator, univ Delaplagne Jean-Daniel; 2025-04-09T21:30:26.018

Outline

- 1. Introduction (A. Bécoulet)
- 2. Digital assistance to ITER Construction Project (J.-D. Delaplagne)
- **3.** Al models for Fusion Engineering(*M. Ortiz de Zuniga*)
- 4. ITER Control System and System Commissioning - Application of Al and Machine Learning? (*A. Wallander*)
- 5. Al for ITER Science (S. Pinches)
- 6. Q/A(*all*)



Digital assistance to ITER Construction Project

Jean-Daniel DELAPLAGNE



Overview

- IT within the Central Integration Division
- Tailor, integrate and support ITER Project Tools (CAD/PLM, ERP, CMMS, Collaboration)
- Close collaboration with business units SID, CP, ESD, ADM, ODG
- 3 main pillars: Improve knowledge management, Increase collaboration & efficiency, Enhance user experience
- Large number of use cases identified
- Classified into 6 streams with priority given to Engineering & Construction
- Large transformation on the way: P6 Cloud, ICP4, S4HANA, etc ...
- Accelerate innovation through dedicated centers of excellence



Diapositive 10

DJ0 use case bar chart -- need to see the streams -- need to mention link to project control too

need to see the number of use case delivered vs ongoing on those streams Delaplagne Jean-Daniel; 2025-04-09T21:27:43.871

DJ0 0 revise list based on recent Al group feedbacks Delaplagne Jean-Daniel; 2025-04-09T21:46:38.978

Streams

Stream	Description
Engineering Construction Excellence	Maximize engineering know-how and support effort for ITER machine & plant systems design and construction
Digital Administration & Organization Project Efficiency	Streamline financial data integration, admin delegation adapting our tools to matrix organization and digitalize HR, Procurement and financial processes
Operations & Maintenance Excellence	Optimize maintenance & operation execution including predictive analysis, detection and resolution
Augmented Employee	Maximize staff efficiency, low-value added task and support with decision-making insights
Safety & Security First	Comply with authorities obligations and recommendations, enhance health & safety, quality for construction
DA/Public/Private Sector Integration	Facilitate integration and cooperation between ITER and its partners (private, public or DA)





AI/Automation & Digital Plant CoE

- Launched end of 2023
- Offer, Organization, Partners, Resources and 3months lookhead Roadmap
- In support of the use cases but also investigation & innovation
- RPA, RAG evaluation, Multi-agent, Graph Vector combination / LazyGraphRag, Open sources models, Fine-tuning
- VR/AR/XR, Laser scanning, Photogrammetry
- 30 projects delivered including organization wide such as Lucy, our AI driven enterprise search bot, and the As-Built 3D model app



LUCY: AI-DRIVEN ENTERPRISE SEARCH CHATBOT

- IDM: +1M documents, 20 years knowledge, search challenge
- Lucy Al-driven chatbot to help find information in IDM
- RAG based with multi-agents architecture
- Semantic search + Document-level access control
- Integrated to IO other systems (e.g. HOP, SMDD)
- 1100+ users, 25k queries, 750 feedback since launch

ION NETWOR

More info: www.iter.org

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Ξ Q Search

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AS BUILT 3D MODEL

- 500 partners / 1100 CAD users collaborating on the different CAD platforms
- Bring as-design to site and capturing reality with 3D scans
- Support to design, construction, configuration control, operation and maintenance teams
- Daily automatic CAD extraction in neutral format
- Federation of MultiCAD Models per system / per area / per building
- 5000 MultiCAD models refreshed on weekly basis
- Load of 3D Scans for B11 / B74 L3 / B15 / B32 and associated 3D models completed
- Loading of engineering data/attributes



Parternships

- Ecosystem of software, integrators, innovation partners
- Regular call for tenders for support needs
- Strong expertise on niche technical topics
- Contribute to software editors product vision
- Further develop with universities and research
- Collaboration agreements (e.g. Microsoft Research)







Diapositive 15

- DJ0 fix up logo bg, missing ones gamma, cintoo, autodesk, Delaplagne Jean-Daniel; 2025-04-09T21:14:15.819
- DJ1 visual on how we structure partnerhsip IO vs editor, vs integrator, univ Delaplagne Jean-Daniel; 2025-04-09T21:30:26.018

DJ0

And next...

- Continuous delivery on Engineering & Construction and other streams
- Accelerate on adoption & change
- Embrace new opportunities from large transformation projects
- Scaling up on AI and on R&D topics
- Increase parternship with Private, Academics and Research ! Contact us !





DJ0 some illustration of our ongoing roadmap would be good Delaplagne Jean-Daniel; 2025-04-09T21:28:45.232

3 Al models for Fusion Engineering

Maria ORTIZ DE ZUNIGA





"Every cloud has a silver lining."



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The cloud with silver lining

Recipe for new ingredients:

- Vacuum Vessel: first-of-a-kind nuclear vessel for fusion
- Advanced manufacturing: electron beam welding
- New material: 316LN-IG
- Tight tolerances



Difficulties:

- Find trend
- Identify cause
- Identify key factors





3.2 A Learning Process



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1. EB welding

•Success rate prediction •Real Accuracy: 100%



2. PAUT for T-welds

•Data processing •Testing Accuracy: 83%-100%



3. TIG welding of outer shell

•Success rate prediction •Testing Accuracy: 100%



4. PAUT for linear Butt welds (outer shell)

Data processing
Accuracy: 99.9%
Speed improvement: days
→ minutes

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Microsoft Teams

AI PAUT processing

2025-04-22 15:14 UTC

Recorded by

Organized by

Ortiz De Zúñiga Maria (F4E) Ortiz De Zúñiga Maria (F4E)





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Technology Development Programme

Artificial Intelligence Mapping Workshop 8 April, 26-27 May





Converging towards a technology map

Maria Ortiz de Zuniga – 08/04/2025



ITER Control System and System Commissioning -Application of Al and Machine Learning?

ANDERS WALLANDER





Content

- Brief Introduction to ITER Control System
- Current status of Integration and Commissioning
- Data generated by Commissioning and Temporary Operation
- Applying Machine Learning
- Conclusions



ITER Integrated Control System Architecture and Infrastructure

- Hierarchical with 21 subsystems and 205 local control system (supplied "in-kind")
- Vertical segregation of (1) conventional control and operation, (2) protection and (3) safety
- Dedicated networks for (1) control and monitoring, (2) time synchronization, (3) distributed real-time control, (4) high throughput data acquisition, (5) protection and (6) safety
- Redundant dual star network cable infrastructure
- Virtualized central servers for supervision, automation, configuration, plasma control and data handling
- Data streamed to HDF5 back-end storage accessible on the intranet







Integration and Commissioning Status

First local control system delivered in 2019. Over the last 7 years systems have been integrated incrementally, followed by commissioning and temporary operation.

In-kind local control systems integrated

- Steady state electrical network (20)
- Buildings and site services (13)
- Cooling water (6)
- Cryoplant (2)
- Pulsed power electrical network (2)
- Reactive power compensation and harmonic filtering (1)

In progress or imminent

- Electron Cyclotron Heating
- Coil Power Supplies
- Magnet Cold Test Bench
- First Diagnostics

Central functions

- Supervision
- Configuration
- Orchestration and sequencing
- Data archiving and data access



Temporary Main Control Room in HQ in operation since 2021

Main Control Room in Control Building to take over this summer



Electrical Network

- Started integration and commissioning • in 2018
- Four 400 kV/22 kV transformers feed • medium and low voltage load centers distributed over the site
- Today more than 50 % of total system ٠ in 24/7 operation
- Top level Human Machine Interface • (HMI) gives geographical overview and instant power consumption
- Electrical components and high voltage • cables animated using color coding













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Cooling Water

(need electricity, demineralized water and N₂)

- Started integration and commissioning in 2021
- Provides heat rejection through cooling towers, component cooling, chilled water and blowdown
- Today heat rejection, chilled water and 2 component cooling loops are in temporary operation with 2 additional loops in commissioning
- Top level HMI gives geographical overview over cooling water and distribution as well as main parameters such as flows, pressures and temperatures
- Equipment status and flows in pipes are animated using color coding
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Cryoplant

(need electricity, compressed air and cooling water)

- Started integration and commissioning in 2022
- Produces and supplies liquid helium to the superconducting magnets etc.
- Today in commissioning with a main milestone reached on October 29, 2024, when first liquid helium at 4.5K was produced
- Data extracted from backend archive show status of compressors, turbines and pumps, cooling water and cryogenic temperatures, power consumption and LHe production
- Good example of plant system dependencies and software integration across multiple systems















(need electricity and cooling water)

- Started integration and commissioning in 2022
- Three 400 kV/66/22 kV transformers feed RPC, Coil Power Supplies and Additional Heating. RPC protects the grid and optimizes the power transfer
- SAT completed on November 25, 2024 with three hours energization of all three RPC units in parallel
- HMI gives view of the top-level state machine
- Fast data acquisition (DAN) and realtime control (SDN) at 6 kHz





Data

My definition of commissioning: When you switch on nothing works, then you must find out why and fix it.

- The most important asset you have is data
- Data, not energy, is the output of the ITER project
- Today ITER Controls acquire one million process variables with sampling rates from fraction of Hz to MHz
- Today the data archive size is 10 TB for slow data and 21 TB compressed for fast data

What can we do with this data?

Can Artificial Intelligence (AI) help?







Artificial Intelligence

4

- Al seems to be everywhere these days •
- The marketing hype often gets ahead of capabilities
- Distinguishing what's useful and • practical from the rest can be difficult
- Today the most commonly known • application of AI is Chatbot
- Let's ask a question ٠ (in this case to OpenAI ChatGPT)
- ITER first plasma was achieved in December 2020 !
- Caution is advisable when applying AI





Machine Learning and Deep Learning

"Machine learning is a field of study in artificial intelligence concerned with the development and study of statistical algorithms that can learn from data and generalize to unseen data and thus perform tasks without explicit instructions.

Deep learning is a subset of machine learning that focuses on utilizing neural networks to perform tasks such as classification, regression, and representation learning." Wikipedia

Corporation agreement established between ITER Organization and Nippon Telephone & Telegraph (NTT) in 2023 to investigate if it is possible to detect and predict failures of ITER devices from operational data using deep learning

Goal: By predicting failures in advance corrective actions can be taken before failure occurs As a result, availability and reliability of ITER can be increased



Failure Prediction

Cooling Pump motors Vendor: KIRLOSKAR ELECTRIC CO. LTD Rated output kW: 130 kW Weight: 1300 kg Protection: Vibration, Temperature, Reverse rotation.



PUMP tripped Apr 17 13:02 Apr 18 12:41 Apr 19 11:24 Apr 20 11:33



Input data

- Pumps status
- Water flows
- Winding temperatures
- Bearing temperatures
- Consumed currents
- Ambient temperature



If we set a threshold at 10 anomaly degrees, then 3 out of 4 trips are detected about 4 hours before they occurred



Failure Prediction

Cooling Tower Fans Vendor: Marathon TerraMax Rated output kW: 160 kW Weight: 1600 kg Protection: Vibration, Temperature, Reverse rotation.



FAN tripped Sep 28 10:59:55



Input data

- · Fans status
- · Fans interlocks
- Winding temperatures
- · Bearing temperatures
- · Oil temperatures
- Consumed currents
- Cooling water temperatures
- · Cooling water pressures
- · Cooling water flows
- Cooling water bypass valve
- Ambient temperature



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Anomaly degree increases 30 minutes before trip occurred



Caveats

But, in most cases we have no signature of failures in the available data

- Constrained by data availability (whatever the supplier delivered), e.g. vibration measurements would have been very interesting, but not available
- Constrained by acquisition sampling rate (whatever the supplier delivered), e.g. fast in-rush current would have been very interesting, but not available
- Constrained by piggy-backing on commissioning and temporary operation. Cannot intentionally generate failures.
- Constrained by commissioning activities. Failures due to operator errors not necessarily captured in the data. System is changing with time as understanding how to operate increases,...





Conclusions

- ITER integrated control system is in commissioning and temporary operation with 1 million process variables
- Data is acquired 24/7 (slow) and on demand (fast) with a data archive size of 30 TB and growing
- Through a corporation agreement with Nippon Telephone & Telegraph (NTT) a first attempt to apply machine learning for device failure prediction has been made
- Some successful results have been achieved although much more work must be done before practical application
- Without doubt, in the long run, machine learning will play a role in optimizing operation and increase availability for the ITER machine



5 Alfor ITER Science

Preparations for Physics Operations

SIMON PINCHES



Using AI to prepare for ITER's Scientific Exploitation

1. Accelerating physics simulations

ML and AI surrogates to predict behaviour and interpret data

2.Lowering the scientific software maintenance burden

Refactoring legacy code for maintainability and portability

3.Creating a standard fusion data model

Using AI and LLMs to define / refine standards

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Accelerating simulations of plasma heating

Holistic (integrated) modelling of ITER plasmas requires coupling many different physics models together

Many of these well-validated models have a computational burden that means a full highfidelity simulation of ITER takes around a month to complete

Machine Learning (ML) has allowed the creation of surrogate models based on Neural Networks that can retain appropriate physics fidelity but are tens of thousands of times faster, if not more!



Sjors Peterse, ITER Intern, March 2021

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Turbulent transport models that are hundreds of thousands of times faster

Properly describing turbulent transport is crucial for understanding how heat, particles, and momentum are confined in fusion-relevant plasmas

First-principles models like gyrokinetic simulations are highly accurate but computationally expensive – ITER simulations are run on the world's fastest supercomputers

Reduced models (e.g. TGLF, QuaLiKiz) offer a faster alternative but still have limitations in speed and scope

AI (ML) can be used to build surrogate models that emulate complex transport models but are *much* faster ($\times 10^3 - 10^5$) than even the reduced models

K.L. van de Plassche et al., Phys. Plasmas 27, 022310 (2020) THE WORLDWIDE INDUSTRIAL FUSION NETWORK



Using GitHub Copilot to help refactor legacy Fortran code

Not a turn-key solution: lack of open-source Fortran code causes difficulty's for LLMs

Original source code, created in 1985

Includes common blocks and nested go to statements

L /		
.8	c** RECORD OF MODIFICATION:	**
9	c** 05 03/85first created	**
	C**	**
	C**	**
	C*************************************	*****
	dimension nsi(numb) sia(numb)	
	common /hunomn /m n s shift dn dz	
	commony burlenny mynysystici cydr ydz	
	c conu nei into cia norrigo	
	c copy psi into siu rowwise	
	do 2 1 = 1, nwb	
	ii = (i-1)*nhb + 1	
	do 2 j = 1, nhb	
	<pre>sia(i+j*nwb-nwb) = psi(ii-1+j)</pre>	
	2 continue	
	ia = nwb+nwb	
	iu = n*nwb	
	<u></u>	
	c set un for ranois	
	c set up joi 12pors	
	de D i – ie iu nub	
	00 3 1 = 1a, ju, nwb	
	$sia(1-m+1) = sia(1-m+1)+(.5+.25/(1.+shift/dr))^*$	sla(1-m)/s
	intial intiality or the anality dallant	/2//-

Code refactoring using Copilot...

Benefits from increased readability and a reduced maintenance burden

1	! bunema.f - Modernized version with module-based approach
2	! Refactored to remove common blocks and use modern Fortran standards
3	2. Чт. • сочение и на приметри создатии от постатии со правод и различника создени на приметри на постати со постат Постати со постати со по Постати со постати со п Постати со постати со постати Постати со постати со по Постати со постати со постати Постати со постати со по Постати со постати со пост Постати со постати со по
4	program main
5	use bunema mod
6	implicit none
7	
8	! Declare variables
9	<pre>double precision, dimension(:), allocatable :: psi, sia</pre>
10	integer :: nwb, nhb, nwnh
11	
12	! Initialize variables
13	nwb = 10
14	nhb = 10
15	nwnh = 100
16	
17	! Allocate arrays
18	<pre>allocate(psi(nwnh), sia(nwnh))</pre>
19	
20	! Initialize arrays
21	psi = 0.0d0
22	sia = 0.0d0
22	



The Data Dictionary is a core component of IMAS

Definitions are stored in multiple files using markup language

- The Integrated Modelling & Analysis Suite (IMAS) is the collection of physics software used at ITER
- Development of the Data Dictionary is a multiinstitute physics-led activity spanning ~20 years
- The IMAS Data Dictionary schema is stored across many XSD files that are difficult to understand
- A single large XML file (close to 400k lines) is derived from the XSD files and used to generate HTML documentation and data access APIs
- The IMAS Data Dictionary became Open-Source at the start of this year

LLM models are not familiar with the IMAS Data Dictionary...

5	<pre><xs:schema elem<="" pre="" xmlns:xs="http://www.w3.org/2001/XMLSchema"></xs:schema></pre>
69	<xs:complextype name="equilibrium_contour_tree"></xs:complextype>
76	<xs:sequence></xs:sequence>
85	<pre><xs:element name="edges"></xs:element></pre>
97	
98	
99	
00	<pre><xs:complextype name="equilibrium_gap"></xs:complextype></pre>
01	<pre><xs:annotation></xs:annotation></pre>
02	<pre><xs:documentation>Gap for describing the plasma</xs:documentation></pre>
03	
04	<xs:sequence></xs:sequence>
05	<pre><xs:element name="name"></xs:element></pre>
06	<pre><xs:annotation></xs:annotation></pre>
07	<pre><xs:documentation>Short string identifi</xs:documentation></pre>
08	<xs:appinfo></xs:appinfo>
09	<type>dynamic</type>
10	
11	
12	<xs:complextype></xs:complextype>
13	<xs:group ref="STR_0D"></xs:group>
14	
15	
16	<pre><xs:element name="description"></xs:element></pre>
17	<xs:annotation></xs:annotation>
18	<pre><xs:documentation>Description, e.g. mid</xs:documentation></pre>
19	<xs:appinfo></xs:appinfo>
20	<type>dynamic</type>
21	<pre><introduced_after_version>3</introduced_after_version></pre>
22	
23	
24	<xs:complextype></xs:complextype>
25	<xs:group ref="STR_0D"></xs:group>
26	
27	



Making Microsoft's GitHub Copilot aware of IMAS

An on-site IMAS **Model Context Protocol** (MCP) server provides Al-agents with ITER relevant context

- The MCP is an open standard that creates a two-way connection between LLMs and data
- The MCP enables access to relevant data when processing queries
- The IMAS Data Dictionary MCP server can:
 - List all IDS schemas
 - Serve an IDS schema
 - Serve documentation
- Copilot queries made without the IMAS MCP server rely on web searches, returning vague and inaccurate responses
- Copilot queries made using the IMAS MCP server:
 - Provide accurate responses in a clear format
 - Expose information hidden in the source files

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Example Copilot query with custom MCP context



Edit with Copilot

Agent Mode

Ask Copilot to edit your files in agent mode. Copilot will automatically use multiple requests to pick files to edit, run terminal commands, and iterate on errors.

Copilot is powered by AI, so mistakes are possible. Review output carefully before use.

I or type # to attach context



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Agent < Claude 3.7 Sonnet <

×

Use of a custom MCP server improves the quality and accuracy of the response – Copilot 'knows' about IMAS

Copilot >> What is the IMAS definition for ion temperature?

Example response without MCP server

Based on the search results, I can provide you with the IMAS (ITER Integrated Modelling & Analysis Suite) definition for ion temperature.

In the IMAS data structure, ion temperature is represented in several ways:

1. As a profile measurement in the plasma_profiles IDS (Interface Data Structure), where it's defined as:

• ...

2. As a volume-averaged quantity in the plasma_initiation IDS:

• ...

The ion temperature in IMAS represents the measure of the average kinetic energy of ions in a plasma, typically expressed in units of electronvolts (eV). It's a crucial parameter in fusion research and plasma physics experiments.

IMAS uses these temperature definitions as part of its standardized data model for fusion research, particularly for ITER and other fusion experiments.

Example response with MCP server

IMAS Definition for Ion Temperature

In the IMAS data model, ion temperature is defined in several locations with specific meanings and contexts:

1. Core Plasma Region

In the core_profiles IDS (Integrated Data Structure), ion temperature is defined as:

Primary Definitions:

• •••

2. Edge Plasma Region

In the edge_profiles IDS, which covers the edge and scrape-off layer regions:

Primary Definitions:

In all these definitions, ion temperature is consistently measured in electron volts (eV) and represents the thermal energy of the ions in the plasma. The IMAS data model provides a comprehensive framework for storing ion temperature data at different levels of detail (averaged, species-specific, charge-state-specific) and in different regions of the plasma (core, edge, scrape-off layer).

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Copilot AI agents can prepare and submit Standard Name proposals from Visual Studio Code

Create / edit

issue



- User asks a Copilot agent to define a new Standard Name for 'ion temperature'
- The IMAS Model Context Protocol includes the
 IMAS Data Dictionary XSD files as context
- Pre-prepared Copilot prompts instruct the Al agent, providing guidelines, standards and formats for the construction of new standard names
- As prompted, Copilot creates a standard name proposal and submits it as an issue to the linked GitHub repository



- The AI generated issue is checked by GitHub actions for compliance with the Standard Name ruleset
- Issues are edited by hand, if required, and labeled with 'approve' once ready
- A GitHub workflow automatically commits proposal and raises a Pull Request for expert review



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THE WORLDWIDE INDUSTRIAL FUSION NETWORK

25/04/2025 **53**

The issue is submitted to the IMAS-Standard-Names repository authored as the Visual Studio Code user

	Simon-Melatosh opened 6 minutes ago		
📫 🛛 Fusion Conv	ventions: Standard Names issue-17 -	Q Search	
Standard names			
Standard names	Standard names	Table of contents ion_temperature	
	<pre>ion_temperature</pre>		
	units: eVtags: temperature, ions, plasma, thermal_energy		
	The temperature of ions in a plasma, typically expressed as the average kinetic energy of the species.	e ion	
	Ion temperature is a fundamental plasma parameter that characterizes the thermal energy o ions. It is mathematically defined as:	f	
	$T_i=rac{2}{3}rac{E_{k,i}}{n_i}$		

Questions





TO BE PART OF THE WORLDWIDE FUSION NETWORK

