UK Atomic Energy Authority

Use of MARTe2 to enhance the JET Real-Time Central Controller.

Chris I. Stuart 5th July 2021

IAEA 13th Technical Meeting on Plasma Control Systems, Data Management and Remote Experiments in Fusion Research

European Commission

Research Councils UK Energy For a Low Carbon Future

Contract for the Operation of the JET Facilities Co-Funded by Euratom
This work was funded by the RCUK Energy Programme [Grant number EP/T012250/1]

CCFE CULHAM CENTRE FOR FUSION ENERGY

Talk Outline

- Context (briefly)
  - Many of us are working on the same problems, with variations.
  - The abstractions are common, with minor vocabulary differences.
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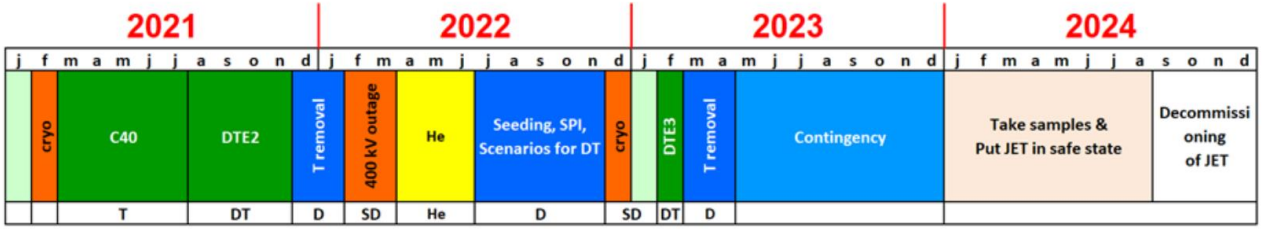
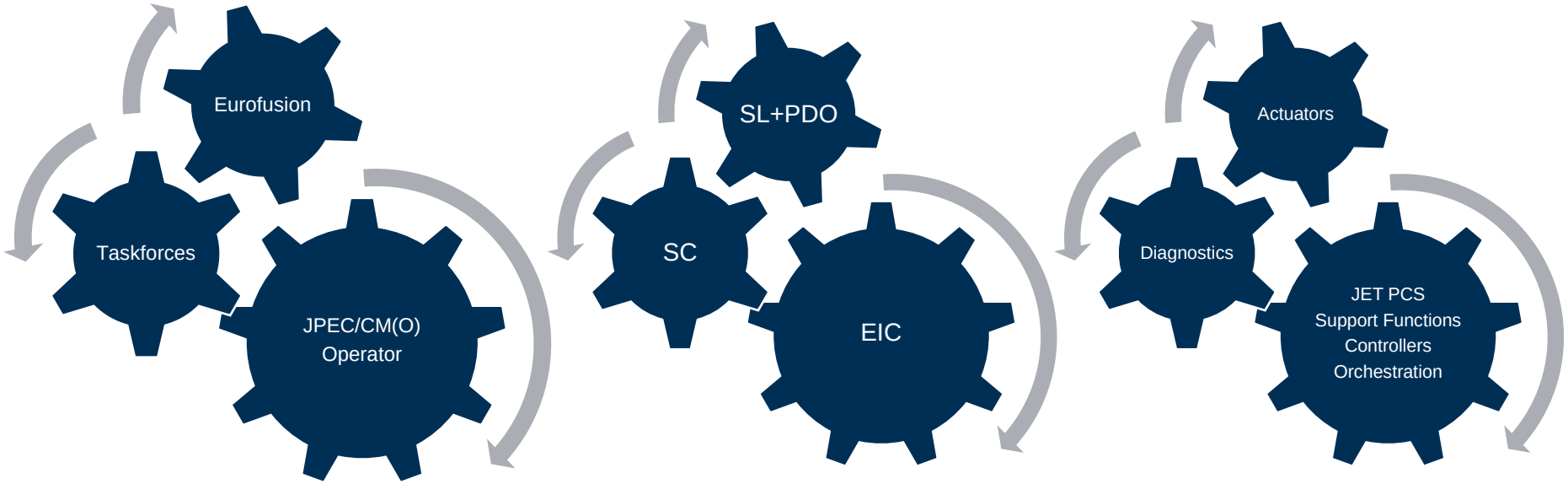
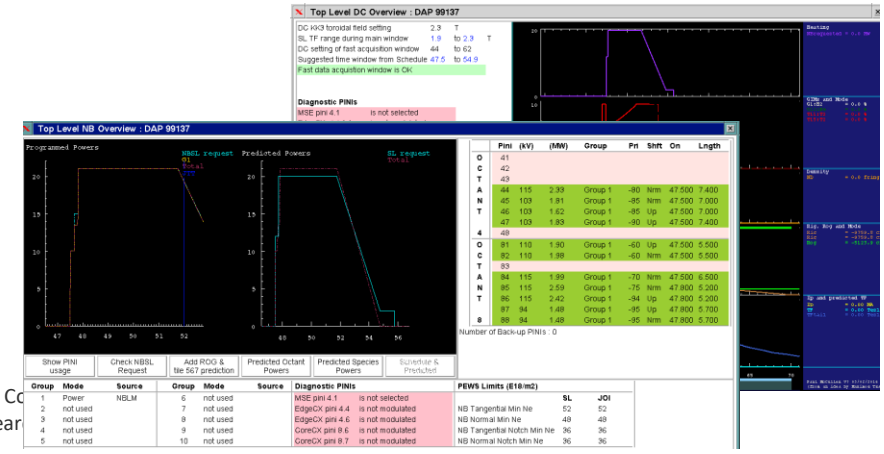
Big Picture: JET Operations Workflow

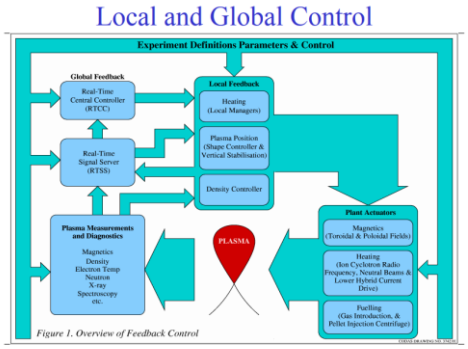




C40 Scientific goals, PTs approval schedule & Timeline

- T pulses (C39/T, C40) approval schedule (deadlines for PTs submission and JPEC approval)
- C40 Scientific goals, with number of allocated pulses, T-consumption, T-gas used (update: 11/April/2021)
- C40A timeline cycles 5 & 6 (update: 18/June/2021)





Plasma Control Systems

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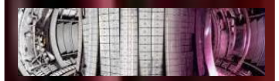






Actuators	Local Managers MARTe VS + SC	Actuator Controls	Actuator Controls	Actuator Controls	Actuator Controls
Arbitration	PTN, RTPS	PCS / APS	DCS	MARTe2	GA PCS
Controllers	RTCC, RTPP	PCS / APS	DCS	MARTe2	GA PCS / RTF
References	Level-1	PCS / APS	DCS	MARTe2	GA PCS
Support Functions	WALLS, VTM, BetaLi, …	PCS / APS	DCS	MARTe2	GA PCS
Diagnostics	KC1D, KG1RT, KN1RT,…(80+)	Diagnostics	Diagnostics	Diagnostics	Diagnostics

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RTCC in production

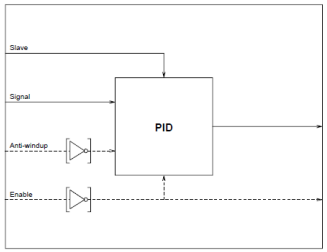
1.18 pid

Proportional-Integral-Derivative Controller

INPUTS		
Label	*Type*	*Status*
Signal input	Analogue	Essential
Slave input	Analogue	Optional
Enable input	Digital	Optional
Anti-Windup input	Digital	Optional

OUTPUTS
Analogue and Digital.

PARAMETERS		
Label	*Type*	*Template*
Invert enable	Integer	YesNo
Invert anti-windup	Integer	YesNo
Proportional gain	Real	Real
Integration Ti	Real	Real
Derivative Td	Real	Real
Derivative range	Real	Real



This algorithm implements an advanced PID controller transfer function:

$$G_{pid}(s) = Gain\left(1 + \frac{1}{sT_i} + \frac{sT_d}{1 + \frac{sT_d}{D_{range}}}\right) \quad (1.6)$$

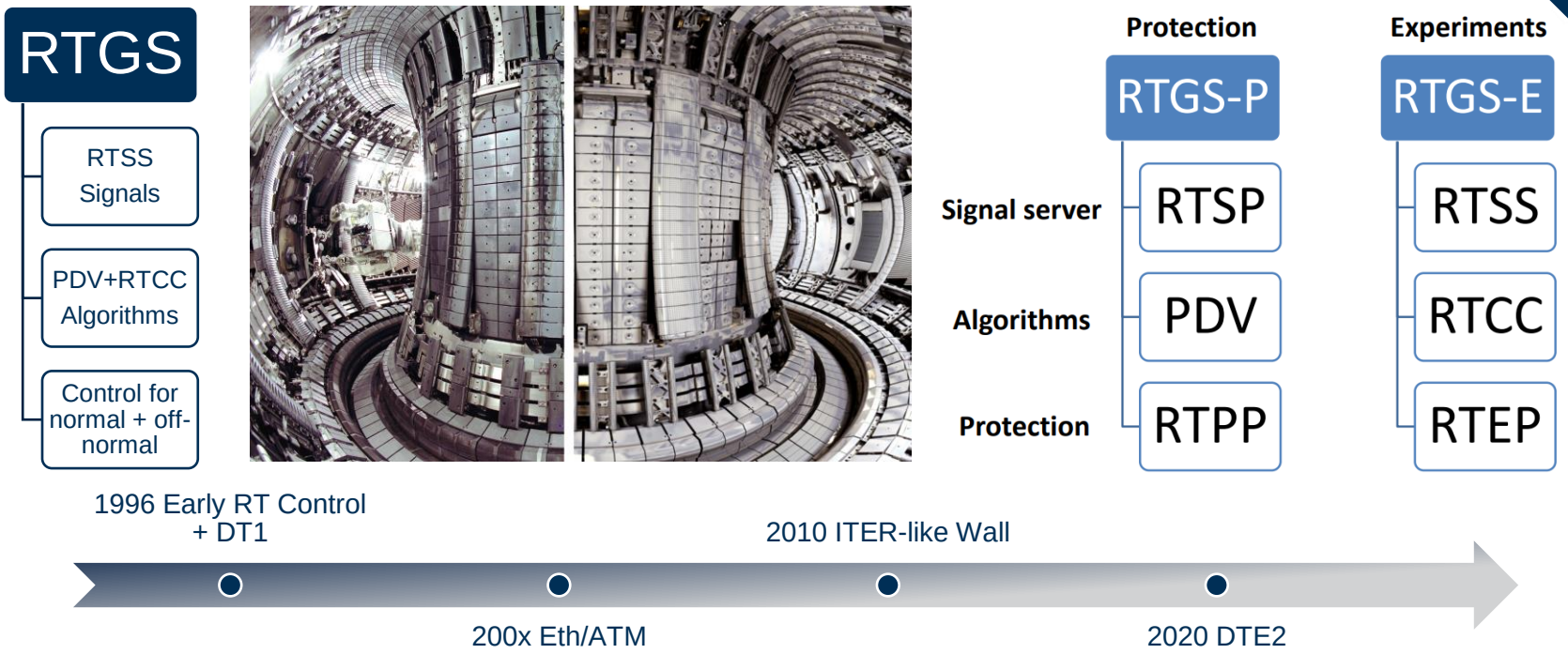
RTCC System Technology

- 1996-2020 Bespoke C application
- VME/PPC single core embedded
- Incremental changes/optimisations
- Essential operations system

RTCC Operator Support

- Network editor / rapid test facility
- Database of algorithms/signals
- Specialist training required
- Expert with physics/control skills

RTCC in production



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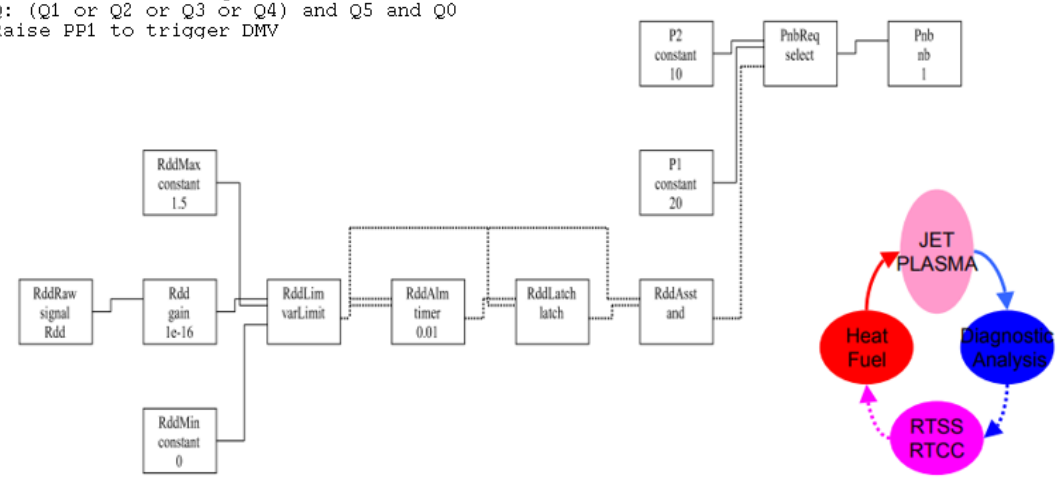
```
JOI 1.1a Trigger DMV when
Q0: Ipla > 0.25 MA
Q1: Loca > 2e-3 T <86306 0.0003>
Q2: Loca/Ipabs > 400e-12 T/A
Q3: VLu * VLl > 500 V^2 <86306 200>
Q4: VLu*Vll/(Ipabs*Ipabs) > 5e-11 V^2/A^2
Q5: Wtot,filtered equiv ~ 20ms asertion > 5 MJ
Q: (Q1 or Q2 or Q3 or Q4) and Q5 and Q0
Raise PP1 to trigger DMV
```



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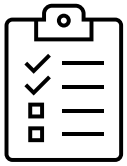

PDO example control tasks

- Gas modulation (M13-24, M15-16)
- ICWC pressure control
- Sawtooth control with ICRH
- ELM frequency control with pacing pellets
- Radiation fraction/seeding species concentration control with impurity GIM
- Combined H factor and radiation control
- Neutron rate monitoring
- Alpha particle heating simulation
- ITB controls
- Total energy protection (JOI 1.1a)
- Radiation peaking monitoring using the bolometer
- BetaN control with NBI
- ELM frequency as a safety net for pellets with gas (M15-01)
- ELM frequency control with gas (M15-02)
- Detachment control using Langmuir probes with N2
- He3 concentration control with gas

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RTCC in production

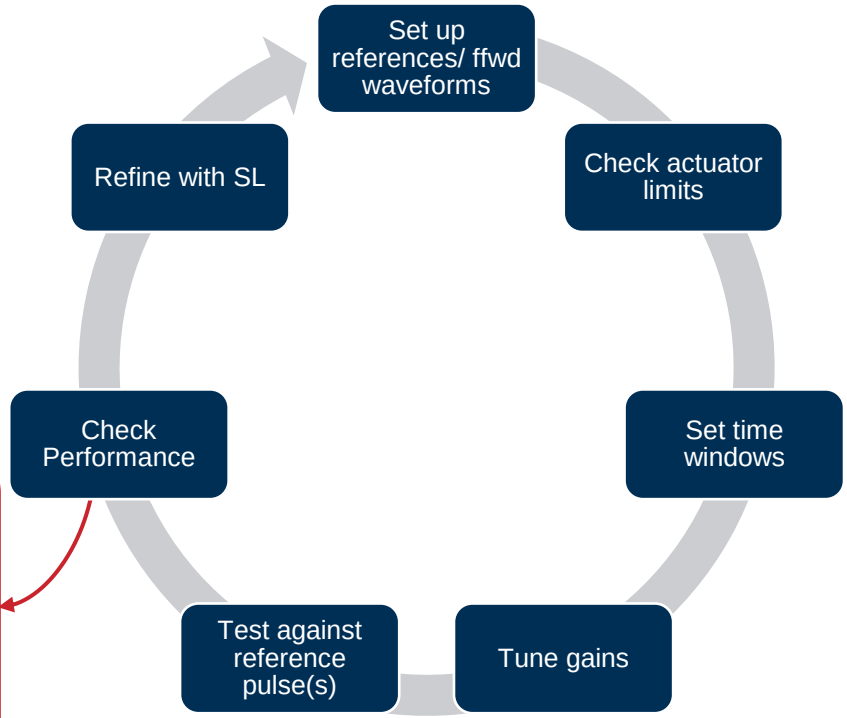
14 fully qualified PDOs

11 trainees

Training program

Roster

Continuous improvement cycle



Recent issues:

- *Missed real-time cycles*
- *Incomplete data collection*

Problem: CPU and RAM

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RTCC++

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CPU upgrade : from 1GHz single core PPC -> 4 Core 2.4GHz i7
Memory upgrade : from 500MB to 32GB
Connectivity : 100Mbps ethernet + 155 Mbps ATM to Dual Gbps ethernet/SDN
OS : VxWorks 5.x running in kernel mode to Linux 5.x using core isolation
RT tuning : RT PREEMPT patches within Centos or Rocky or Custom Yocto
Compiler : from gcc 3.4.3 to gcc 4.8.5 (Centos7 – possibly above TBA)
Software stack : From bespoke C to MARTe 2.0
DevOps : from none to git + CI + unit tests + MARTe 2 QA + SonarQube

System Upgrade Requirements

- Capacity++ : modern hardware
- Multicore PC, RT Linux, C++
- Feasible implementation time/cost
- Leave future exploitation open

Operator Requirements

- QA to modern standards/DevOps
- Backwards compatibility
- Better usability
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RTCC++

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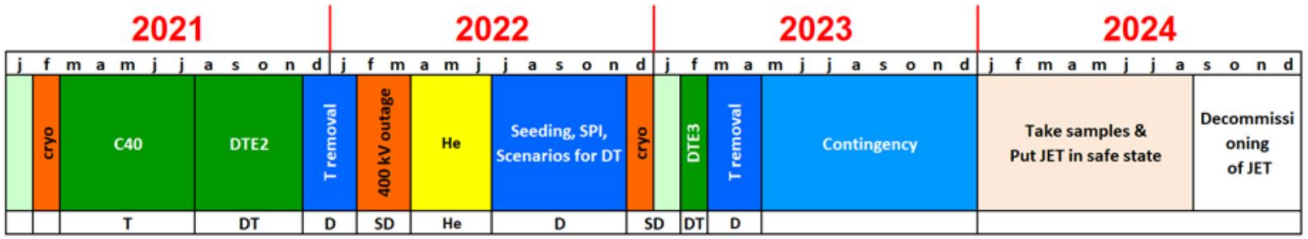

OXFORD BROOKES UNIVERSITY

Software Sustainability Institute

CODAS & IT

BETTER SOFTWARE BETTER RESEARCH

UNIVERSITY OF BATH

RSE

MARTe2

FUSION FOR ENERGY

iter

MARTe2

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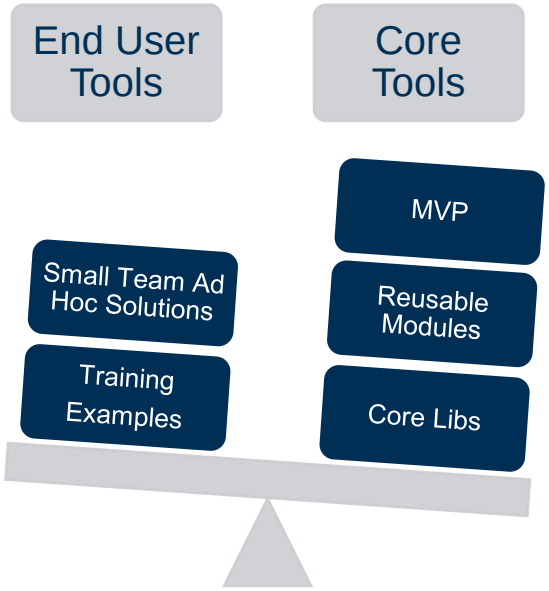

consensus: “just” need nice powerful tools

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Tools : Surely just MATLAB/Simulink ?

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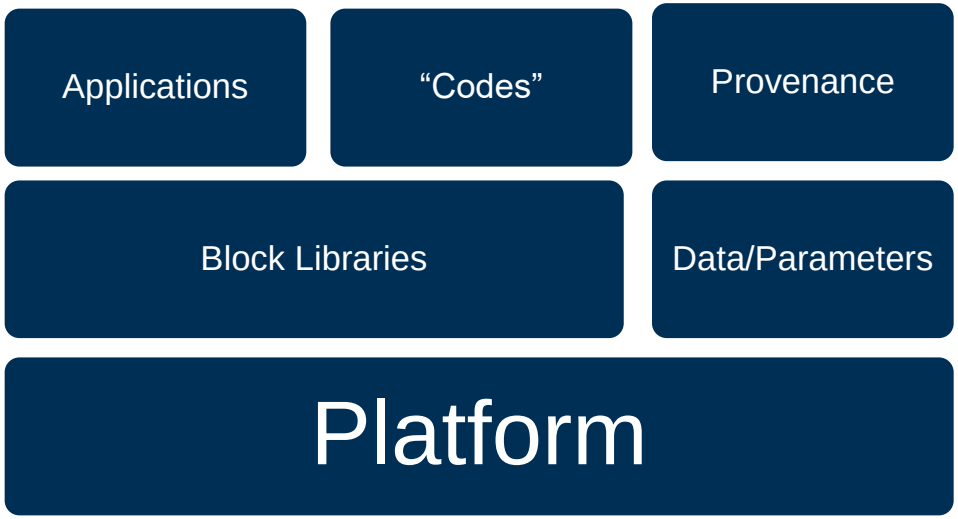

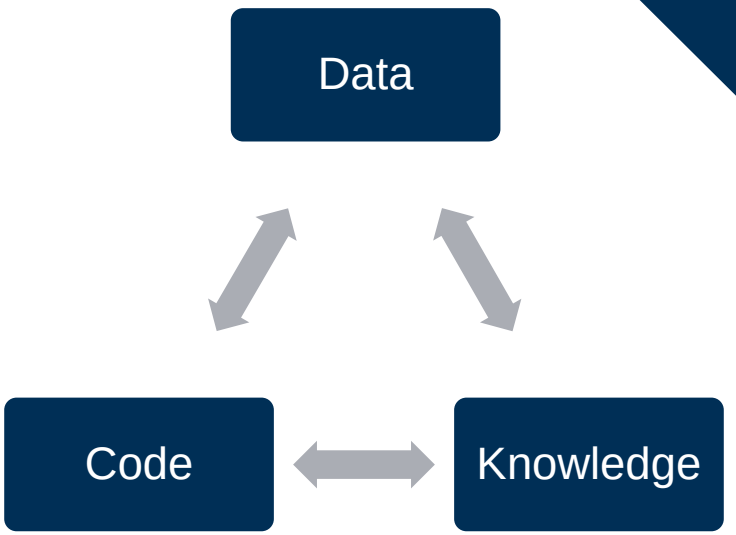

Mono-culture risks

- Fully open source / Fully proprietary : all extremes have problems.
- What is capital expenditure? What is a consumable ?
- What is the total cost and risk of ownership ?
- Mitigate with good architectures and inter-operability.
- Design for high levels of parallelism and AI in the loop (Google/TAE).
- IP Management.

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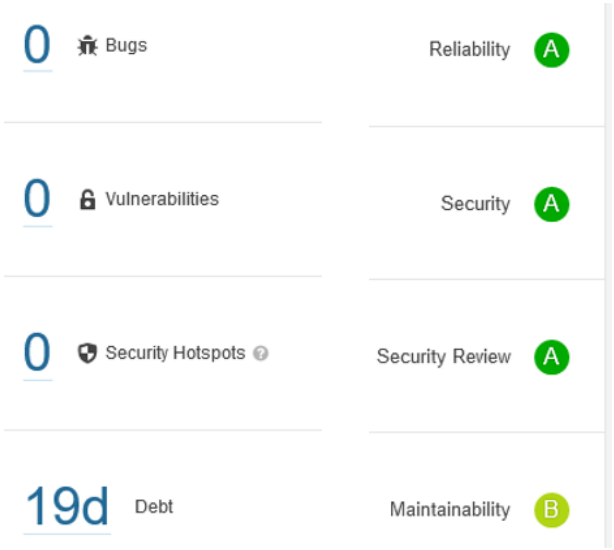
passed **Pipeline #59709** triggered 1 month ago by Fox, Peter

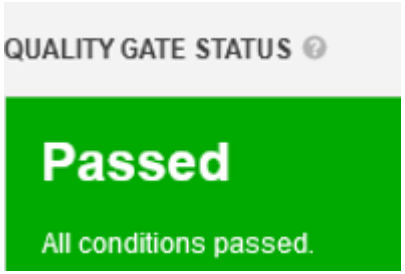
Merge branch '9-add-coverage-check' into 'develop'

```
Resolve "RTCC2 QA pipeline"

See merge request !10
```

4 jobs for develop in 2 minutes and 35 seconds (queued for 3 seconds)





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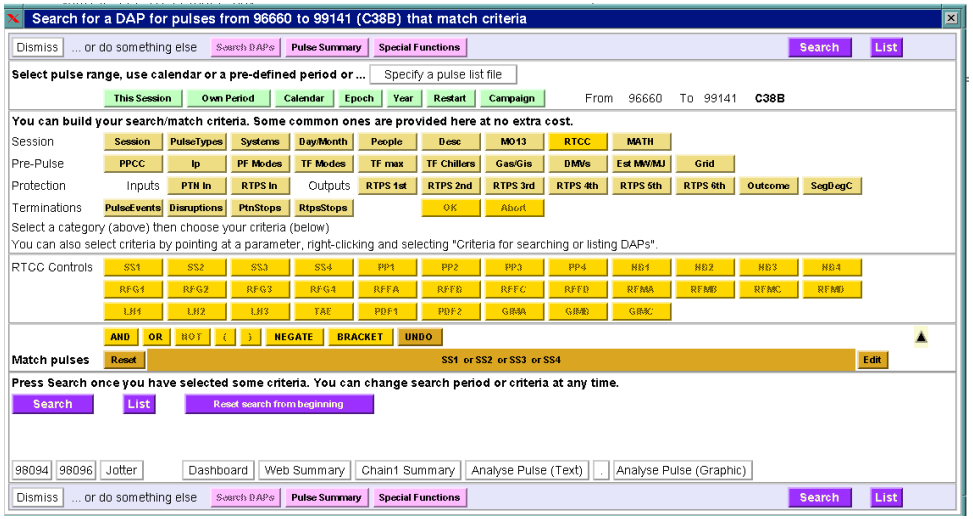
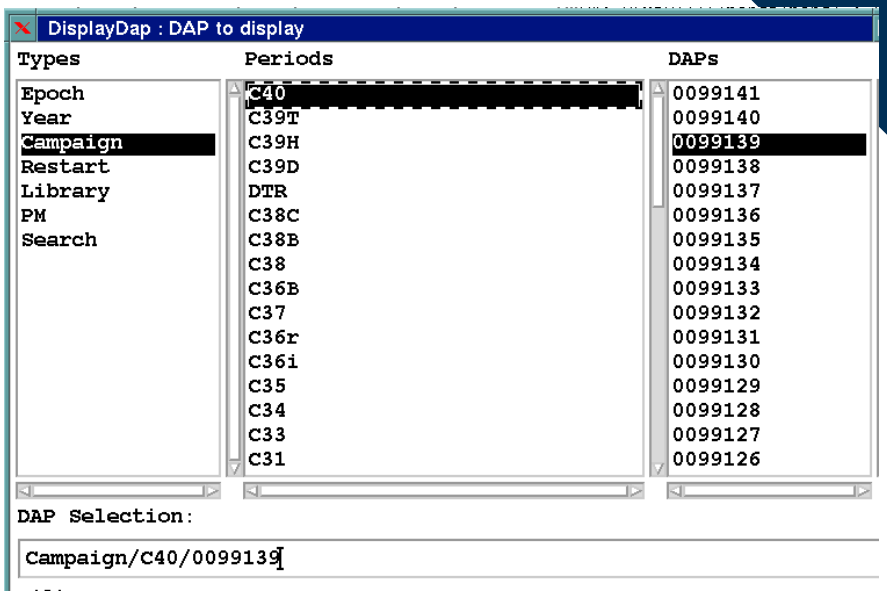
Reuse : Ability to replay successful configurations from ~100k pulses





576 pulses in C38 (out of 2481)

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New Generation Tools

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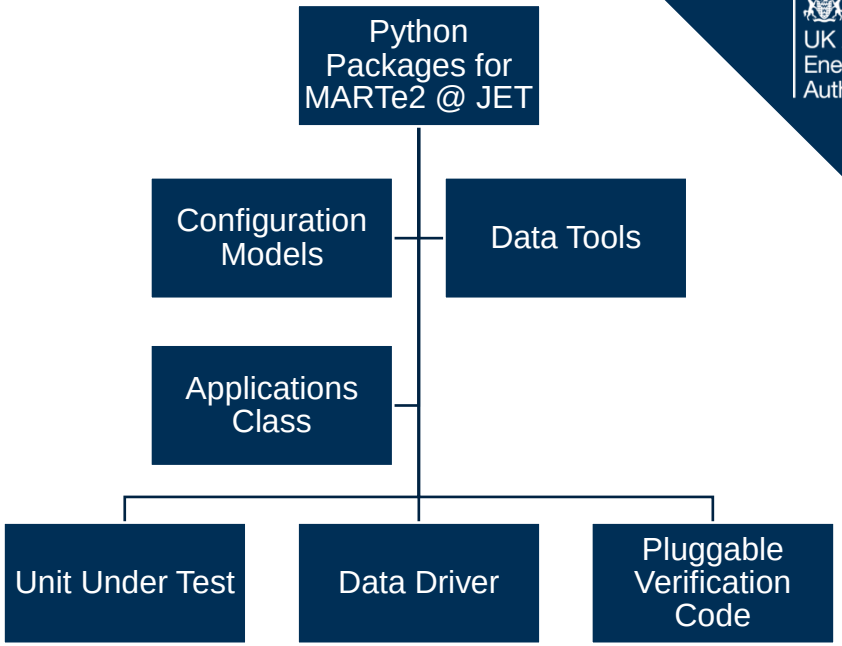
rtcc2lib
- better usability
- maintain performance

```
rtcc2::Matrix<int> a(2, 2);
rtcc2::Matrix<int> b(2, 2);

auto c = a * b;
```



better expressivity whether in C++ or configuration DSL

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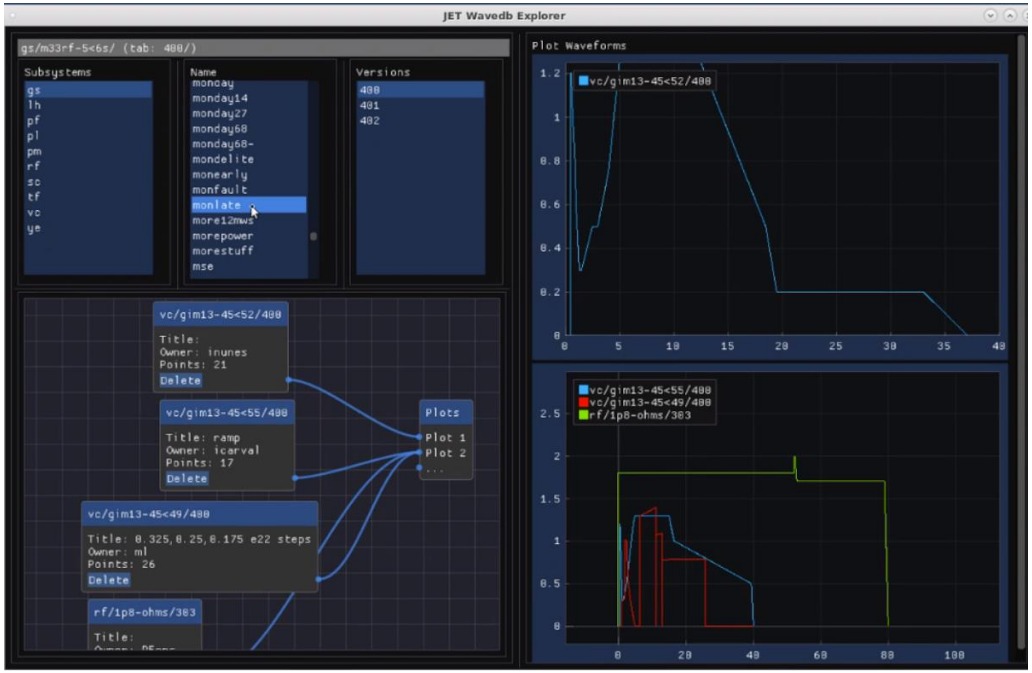

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RTCC2

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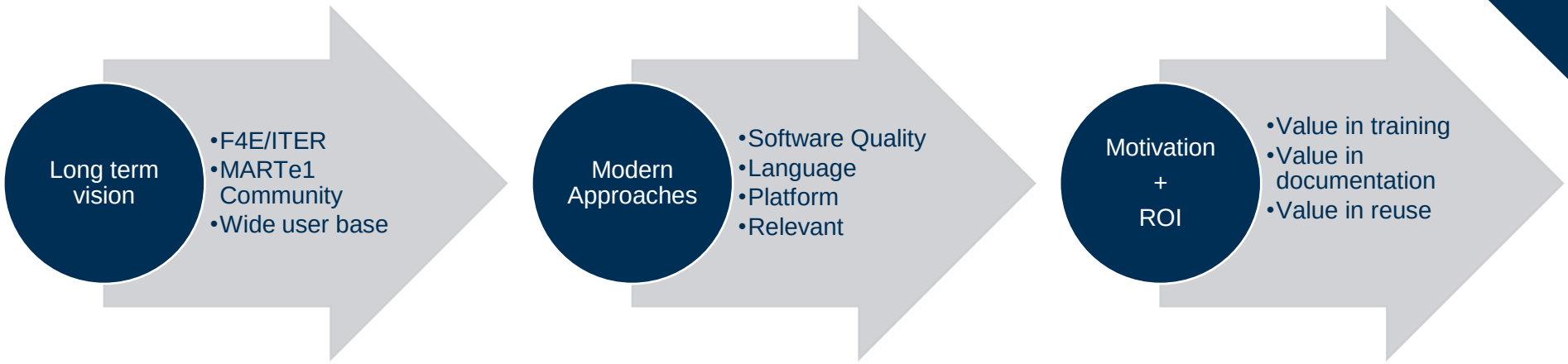

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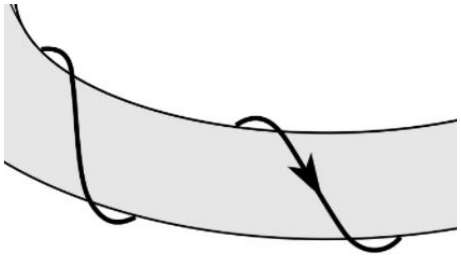
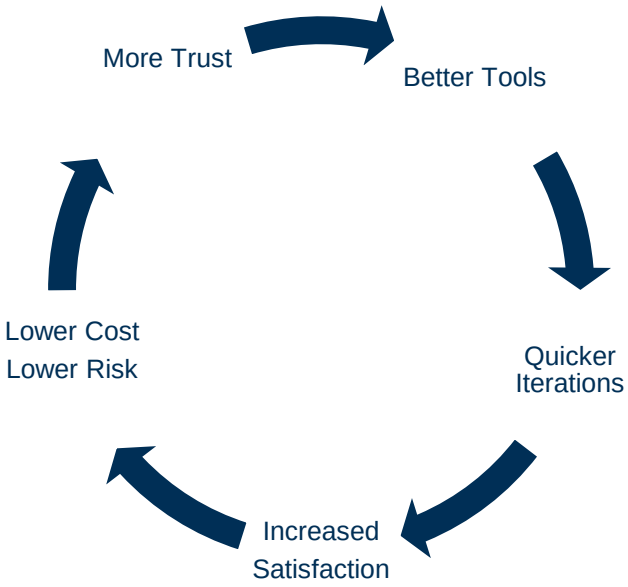
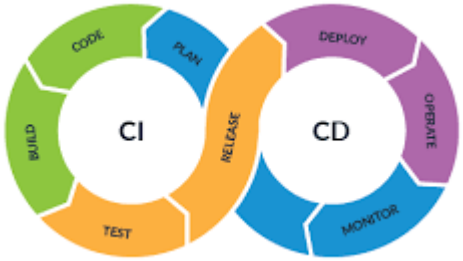
Virtuous Spiral : once bootstrapped







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Project Roadmap

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OXFORD BROOKES UNIVERSITY

MSc Dissertation

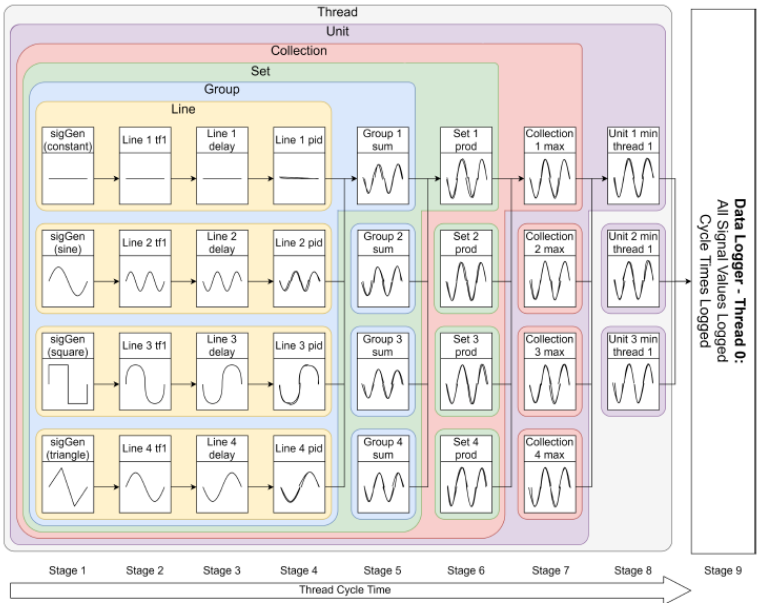
Mark Anderton

15080740

Supervised by Prof. Hong Zhu

School of Engineering, Computing and Mathematics

Oxford Brookes University



Phase 1: **Feasibility : (a) Proof Of Concept** (b) Prototype

Phase 2: Deploy dual servers operating parasitically but not controlling

Phase 3: Switch to RTCC2 for routine operations (increased capacity)

Phase 4: Iteratively add more functionality, staged on the live test server.

Project Roadmap

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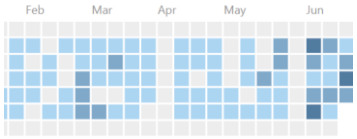
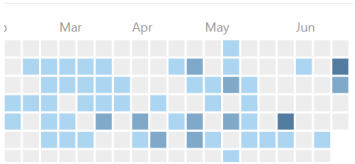
R **RealTimeEngine**
Project ID: 5337

R **RTCC2-lib**
Project ID: 5000



R **RTCC2 Configuration Manager**
Project ID: 5333



D **datagramtest**
Project ID: 4384

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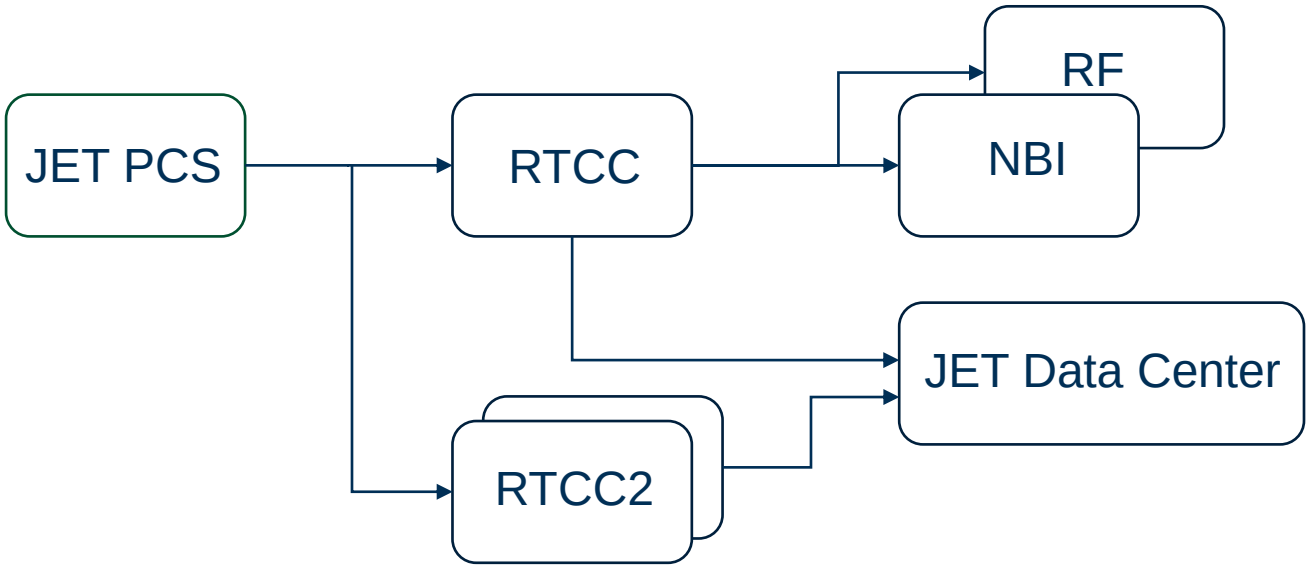

RTCC2 cluster : live / live test

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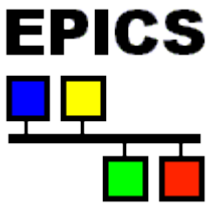
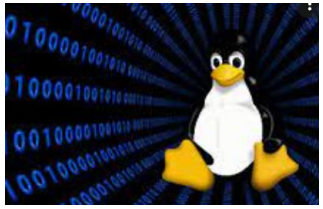
Project Roadmap





Phase 1: Feasibility : (a) Proof Of Concept (b) Prototype

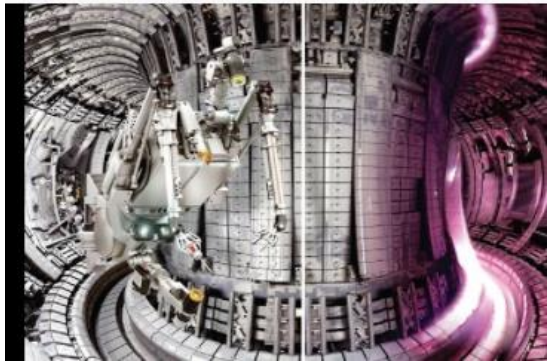
Phase 2: Deploy dual servers operating parasitically but not controlling

Phase 3: Switch to RTCC2 for routine operations (increased capacity)

Phase 4: Iteratively add more functionality, staged on the live test server.

Project Roadmap: Future ?

UK Atomic Energy Authority



Phase 1: Feasibility : (a) Proof Of Concept (b) Prototype

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Conclusions & Future Work : TBA/WIP

UK Atomic Energy Authority

- We are upgrading a core JET PCS tool

- 4 Phases (like all successful projects)
- Using latest methods
- Aligning with community standard technologies.

- Optimistic of collectively removing barriers to better science in this area.
- Hoping to work more closely with old friends and new partners as the era of fusion delivery progresses.

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Thanks for Listening. Questions? Discussion (now and after please?)

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