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20

60

25

60

60

60

(5)

Gitte

1947

(12)

6

6

61

67

. 50

John Waterhouse et al, UKAEA 14th IAEA CODAC TM, San Paulo, Brazil, 15 - 18 July 2024



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## Contents

### Overview of CODAS

- Online system
- Data Warehouse
- Offline

#### Enhancements

- Diagnostic enhancement for DT operations
- Real time enhancements
- Tritium management
- Infrastructure

**COVID** mitigations

#### **Recent Operations**

- DTE2 and DTE3
- Desorption experiments
- Long pulse experiments Beyond Operations



## **JET CODAS - Overview**

Hardware and data acquisition/control management

Continuous and pulse-based acquisition

### Technologies

- Solaris sub-systems,
- CAMAC
- LSD Line scan devices: bespoke hardware to provide control lines and monitor state signals (generally bit orientated)
- PC's/Black Box protocols
- Siemens PLC interface hydra link
- VME
- EPICS

### Infrastructure

- Solaris Servers
- Network infrastructure
- Linux Clusters
- Workstations

### Hierarchy

- Level-3 low level direct plant interfaces etc
- Level-2 Sub-system
- Level-1 High level collective interface & pulse management
- Data warehouse
- Data access, Analysis and Visualisation

### Real time networks

- Traditional RTDN ATM
- ITER SDN/Ethernet & MARTe

### Control and protection

- CISS
- Plasma control
- PTN & RTPS etc
- Local Managers

### Configuration Extend Configuration Management

- *full stacked history*
- Custo positic include full signal path from sensor to analyzed data set
  - drive data acquisition/control configuration
  - S drive offline data processing
    - data provenance

## **JET CODAS Network Architecture**





Warehouse

NAS

Gen-Pub

Approximately 2000 devices on the operational networks



THAJA

TERFACE!

UNITS

ONLINE

COMPUTERS

(CORE SERVICES)

CONTROL

ROOM

e.g CRYOnet, Tritium plant network & other smaller plant networks



#### J. Waterhouse et al. JET CODAS - the Final Status

large flat networks

#### Real-time networks

JET Ops

DATAnet

CONTROLnet

**CONTROL**net

ATM and dedicated Ethernet

DATAnet & JET Ops network

#### Timing

star network of dedicated FO

#### CAMAC Loops

dedicated FO

### Private networks

## **JET CODAS Sub-System Level-2**

Pulse execution and data acquisition

• Included in JET Pulse or excluded,

#### Supervisor

- Ensure things in the right state
- Setup hardware for pulse
- Collect data after pulse

#### GAP – General Acquisition Program

Pulse timing system

- No actuator mode
- Central or local timing
- CAMAC timers and clocks
- Bespoke VME module
- Clock train and events
- VME reset
- PC version

#### Data archive

• QPF, JPF, LPF



Continuous control and acquisition

Process variables

- many formats
- scaled and unscaled
- saved state or plant state
- transport to other sub-systems and processes (Solaris) on-line and off-line (read only)
- Black Box and PLC interface
- EPICS interface

#### Data archive

- CGRT data
- Several trend viewer on Solaris and Linux

#### Mimics and touch panels

- bespoke language
- role based access control
- user action logging

Tasks and scripts

bespoke language

#### **Events and Alarms**

- Conditioning
- Startup and shutdown

#### Process status and monitoring

#### Sounds Familiar

- pre-dates EPICS
- perhaps if JET developments had been more open it could have become the standard

#### 24 sub-systems on JET

- 1 sub-system on Neutral Beam testbed
- 1 sub-system for Network management and monitoring
- Several development sub-systems

5

## Uniform interfacing to e.g. diagnostics via network

Implemented on Linux, Windows and Labview

- Layered on top of HTTP (widely supported)
- Diagnostic implements one or more facets:
  - Pulse initialisation / data collection
  - Monitoring of state-variables
  - Monitoring of operational status
    - Hierarchical set of reasons why system is not ready
  - Setting of parameters
  - $\circ$  Error logging
- Unlike ITER, not self-describing (so CODAS and diagnostic need to agree on names used)
- Protocol adapter for interfacing with PLCs
  - Hydra link



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## **JET CODAS - Black Box Interface**

## **JET CODAS - Level-1**

#### Collective view of the JET Plant

- Implements the JET Operating Instructions
- Captures and implements a great deal Knowledge of how things work together

#### Session Leader

• Prepare details of next pulse

#### Engineer in Charge

- Pre-pulse checks
  - Force state
    - override issues
- Load plant
- Post pulse checks

#### Heating system pilots/operators

Setup plant

#### Diagnosticians

Setup plant

#### CODAS

• Setup and run special modes

	6			EIC Col	ntrol	Panel			Fin	d [					SL/I	EIC Pages
Plant	Shifts	DryRuns	PIW	Gri	3	Post-Pulse	Ch	ecks	Uti	ilities	Se	ttings	Refer	rence 🔤		Title
WebPages																Main Pag
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Standard	d B (no gas)														T	2 + Gim1
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All Plant Ope	rators are rea	dy		Show Me	Ha	indling the	Experts	s ]							1	
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-			-			Control Pan									-	

Continuous Evolution New plant & mitigation of removal of old plant Experience gained Changes to operating regime, plant limits and budgets

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### User interface – xpsedit

- on-line with read/write access to the plant
- off-line read only
- Access controls

## Imports data from Operational tools

 Pulse, shift, programme, campaign planning tools

### Solaris application

Deamons run as processes on one of the sub-systems

### **Other Tools**

JETLogging

Hierarchical status display

Alarm Package

Real-time trend viewers

Real-time data viewers

 Video, key trends and realtime equilibrium

Data viewers

## **Control and Protection Systems**



	on Analysis for JE	PN 93212 on Fri Nov 2 14:29:52 201	
Systems			
 RF : 49.00 to	54.50		
Summary of stop	5		
51.000 RTPS Sec. 52.000 RTPS 3rd 53.000 RTPS 4th	- mary Stop : SLOV ondary Stop : FASJ Level Stop : DHS Level Stop : MC+I Level Stop : MhdF	r Dhs	
Plant Enable Wi	ndows		
Enable : 49 Disable : 53.00 Disable : 53.20		RFfast RFslow   RFslow RFfast 0040	
Enable : 49 Disable : 53.00 Disable : 53.20 RF was terminat BBI Trips 	40 ed by PEWS at 53.0	RFSlow RFfast	
Enable : 49 Disable : 53.00 Disable : 53.20 RF was terminat BBI Trips Hone detected Time	40 ed by PEWS at 53.0   System	RFSlow RFfast	Information
Enable : 49 Disable : 53.00 Disable : 53.20 RF was terminat BBI Trips 	40 ed by PEWS at 53.0   System     RTPS (in )	RFSlow RFfast	RTPS test 1 : IPCPS > 1e12 for 0 ms (44.0 to 60.0)   PTN (out) = SOFT>DA + SCE>CTS + STOP>RPC + STOP>DM3 + STOP>SPI + STOP>DM2 + STOP>TAE
Enable : 49 Disable : 53.00 Disable : 53.20 RF was terminat BBI Trips Mone detected Time 50.000	40 ed by PEWS at 53.0   System   RTPS (in )   RTPS->PTN 	RFSlow RFfast   Input/output   Rtpp : Rtpp.6 (assigned SLOW)	RTPS test 1 : IpCPS > 1e12 for 0 ms (44.0 to 60.0)   FTN (out) = SOTT>DA + SCB>CTS + STOP>RPC + STOP>DM3
Enable : 49 Disable : 53.00 Disable : 53.20 RF was terminated BITTIPS None detected Time 50.000 50.000	40 ed by PEWS at 53.0   System   RTPS (in )   RTPS->PTN 	RFSlow RFfast 0040   Input/Output   Rtpp : Rtpp.6 (assigned SLOW)   RTPS-RQ6 (USer)   Primary stop : SLOW   Rtpp : Rtpp.7 (assigned FAST)	RTPS test 1 : IpCPS > 1e12 for 0 ms (44.0 to 60.0)         PTN (out) = SOFT>DA + SCE>CTS + STOP>RPC + STOP>DM3 + STOP>RPT + STOP>TAE caused by SLOW(R)         Scenario = D12_C_SFE_LT:001 (was D12_C_SFE_LT:001)         RTPS test 2 : IpCPS > 1e12 for 0 ms (44.0 to 60.0)         PTN (out) = FAST>DA
Enable : 49 Disable : 53.00 Disable : 53.20 RF was terminat. BBI Trips None detected Time 50.000 50.000 51.000	40 ed by PEWS at 53.0   System   RTPS (in )   RTPS->PTN   RTPS (out)   RTPS (in )   RTPS (in )	RFSlow RFfast 0040   Input/Output   Rtpp : Rtpp.6 (assigned SLOW)   RTPS-RQ6 (USer)   Primary stop : SLOW   Rtpp : Rtpp.7 (assigned FAST)	<pre>RTPS test 1 : IPCPS &gt; 1e12 for 0 ms (44.0 to 60.0) PTN (out) = SOTT&gt;DA + SCB&gt;CTS + STOP&gt;RPC + STOP&gt;DM3 + STOP&gt;SPI + STOP&gt;DM2 + STOP&gt;TAE caused by SLOW(R) Scenario = D1Z_C_SFE_LT:001 (was D1Z_C_SFE_LT:001) RTPS test 2 : IPCPS &gt; 1e12 for 0 ms (44.0 to 60.0)</pre>

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## **Central Interlock and Safety System**

- Network of ten JET pulse-oriented PLCs
- Monitors plant/actuator state per subsystem
- Ensures that all require plant sub-systems are in the correct state to allow pulsing.
- Site on top of Personal Safety & Access Control System (key exchange & two complementary hard-wired interlocks)





- Built as a finite state machine with combinatorial input logic.
- Strong administrative controls for overrides.
- Sub-systems can be in or out of the overall CISS systems



## **Pulse Termination Network**

-		-	s <mark>PIW Grid</mark> PostPulse <mark>Checks Utilities <mark>Settings</mark> Reference WebPages</mark> Pages	He
in Gas PNV	Heat Pro 🖤 Tran	PTN P	TTPS VIM RTPP PEWS RTSP DWV Basic Machine Protection (PTN)	
	p. Good chance o	f soft la		
put	Trigger Time Ac	t InOvr	PTN Output StopType	
ape Control	PTN 0		1111-11-11 11-1111 Slow	
w Failure	PTN 0		1111-1111 11-1111 Slow	
dium Failure	PTN 0		1111-1111 11-1111 Slow	
h Failure	PTN 0		1111-1111 11-1111   Slow	
LM Failure	OVR	Yes	Heating System Excluded or Override selected by user	
LM Failure	OVR	Yes	Heating System Excluded or Override selected by user	
LM Failure	OVR	Yes	Heating System Excluded or Override selected by user	
S	PTN 0		111-1111 11-1111 Slow	
Button	PTN 0			
FA 1 Trip	PTN			
3 Fault	PTN 0			
= Fault	PTN			
PS Ipmax	PTN 0		1111-1111 II11 Slow IpMax 2.50 M A Set suggested PFPS settings	
PS Iperror	PTN 0		1111-1	
Error	OVR	Yes	TF is excluded or system not in use MaxDiff 4982.9 A	
	-			
ut	op. Some damage Trigger Time Ac		. PTN Output StopType	
pe Control	PTN 0		-1111111	
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S-ES	PTN 0		-1111111-11-11-11 11-1111 Fast	
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ut	Trigger Time Ac	t InOvr	PTN Output StopType	
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uption	and a second sec		-111111-11 11-1111 Nsb Minip 800.00 K A Tstart 42.0 s	
	PTN 0			
ruption 3 it	PTN 0	Yes	Override selected by user	

- Call - L - L	PCD: 70. 5(P) RTP	000s S			TECTI 93212	ON SYS	TEM RTPS Log Control vi		XG logs PTN logs View Plog Print Plog
	PTN	INPUT TF	IP T	IMES		PTN O	UTPUT	TRIP	TIMES
PFPS/PTN T	rips	RTPS Tri		Ext. Syst	ems Trips	Output	Bank 1	Output	Bank 2
PFP-DSRPT PFP-IPERR PFP-IPMAX PFP-MLOCK PFP-MLOCK PFP-MLOCK PFP-MSB BUT-COP1 BUT-COP1 BUT-COP1 BUT-SL2 LOW-FAIL UN-FAIL VM-FAIL LHLM-FAIL 0/R PTN-TEST VR-PTN-EFF CTS-PCD	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000		0.000 0.000 0.000 49.999 50.999 0.000 51.999 52.999 53.199 0.000 0.000 0.000	CIS-ES DMS-FAST DTF-FAIL KY3-FAIL SC-SOFT SC-FAST MED-FAIL BUT-SL BUT-SL BUT-ELC CPS-SOFT CPS-FAST RFA-SNGL RFA-TRIP PDF-FAIL	0.000 0.000 56.565 0.000 54.817 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	HARD>DA FAST>DA SOFT>DA SCB>CTS GIM>PDF FAST>PEW SLOW>PEW HARD>SC FAST>SC SLOW>SC STOP>HV TRIG>DM3 SLOW>TF STOP>RPC	0.000 50.999 49.999 54.818 54.818 0.000 0.000 54.818 0.000 54.818 0.000 0.000 54.818 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000	STOP>DM3 STOP>PRC TRIG>SPI STOP>XZ3 STOP>SPI FAST>NB SLOW>NB FAST>LH FAST>CH FAST>LH FAST>RF SLOW>RF STOP>PEL SLOW>LH TRIG>DM2 STOP>DM2 STOP>TAE	49.99 49.99 49.99 49.99 0.00 0.00 0.00 53.19 52.99 0.00 0.00 0.00 49.99 49.99
PTN: RUNNING	CAC OK	PFPS&U	00.000 NO. 100	AC OK	■ PEWS RUNNI State: STAN			2: Host I/I	RUNNING
Watchdg(CISS)	: OK	=Watchdg		ок	=Watchdg(PT		∎Wato		OK rt

Simple mapping from inputs to outputs.

Mapping set when pulse is loaded and remains constant throughout the pulse. Hardwired inputs and outputs implemented using pulse trains over fibre optics. Output enable/disable timers & time stamping.

Build on CAMAC CAC technology

## **Pulse Enable Window System**

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Provides enable windows (pulse trains over FO links) to heating systems plant based on time and basic plasma conditions.

## PEWS

• CAMAC CAC based control

## PEWS2

- VME/PowerPC based control
- Enhanced neutral beam shinethrough calculations
  - PINI by PINI
  - Warns neutral beams local manager

Algorithm	Parameter	Value	Algorithm	Parameter	Value	Output Signal	Override
NB Shutter	Min  lp	500.00 k A	Radio Frequency:	Min [Ip]	500.00 k A	Enable NB shutter	No
NB Slow:	7		Radio Frequency:	Notch Min [Ip]	500.00 k A	Enable tangential bean	ns No
Idiv Disabled			Radio Frequency:	Notch Tstart	40 s	Enable normal beams	NO
limb Enabled		Max limb/ lp  0.002	Radio Frequency:	Notch Width	0.5 s	Enable beams (slow st	
	Min limb/[lp]	F0.004	Lower Hybrid:	Min []p]	500.00 K A	Enable RF (fast stop)	NO
sha Disabled			Lower Hybrid:	Min Ne	15 E18/m2	Enable RF (slow stop)	NO
			Pellet Gun:	Min [lp]	1.00 M A	Enable LH (fast stop)	
pfx Disabled						;	No
	-		SPI:	Min [Ip]	100.00 k A	Enable LH (slow stop)	No
le Disabled						Enable pellet gun Enable Pellet PLC	NO
B Tang/Norm:	Slow ranges plus	10 %	Ip  Limits:	Hysteresis	30.00 K A		
3	Notch duration	0.5 s	Ne Limits:	Hysteresis	3 E18/m2	Enable SPI	No
B Tangential:	Min [lp]	750.00 K A	Idiv/Ip  Limits:	Hysteresis	0.01	PEWS Signals	
	Min Ne	75 E18/m2	limb/[Ip] Limits:	Hysteresis	0.0003	V	
	Notch Min Ne	22 E18/m2	Ishape/Ip  Limits:	Hysteresis	0.001	lpfx/lp  with limits	[Ishp/Ip] with limits
	Notch Tstart	0 s	lpfx/lp  Limits:	Hysteresis	0.001	limb/ lp  with limits	Idiv/Ip  with limits
B Normal:	Min [Ip]	750.00 K A				limb Ishp Ipfx	IpKC1 IpCPS
	Min Ne	75 E18/m2	Min	Max	Lim Hysteresis	Ip Ne Idiv	Excellente Partie
	Notch Min Ne	22 E18/m2	LH BOLO -1e+00 LH Fe23 -2e+00		100000 40000 7e+06 200000	BOLO with limits Beam Ali	Fe23 with limits gnment (Plant)
	Notch Tstart	0 S	LH FeLH	1.5e+07	7e+06 200000	AH	excluded
B Shine-throug	h:Max energy density	3.6e+07 J/m2	Enreen	1.00107		YC	excluded
	PEWS2 Warning Fraction	0.9	Min	C1 C2	C3 C4	10	excluded

## **Protection of the ITER like Wall**

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VME/Power PC ATM networks Data logging – XG Data viewer Data replay through individual components





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# **Real-time Protection Sequencer**

- Aware of plant inputs to PTN
- Can drive plant stops through PTN
- Real time network connections to other event detectors, RTGS, PPCC, and heating systems local managers
- Can initiate 'Jump to Termination'
  - intended for protection but sometime 'miss-used' as experimental feature
- Hierarchical application of stops
- Can take over control of pdlm and nblm etc



52

54

56

58

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Otherwise gets confusing

# **Other Protection Systems**

### **Vessel Thermal Map**

- Takes thermal diagnostics (cameras and bolometers) as inputs.
- Implements thermal models
- Protection against NBI and RF induced hot spots is done by setting a lower temperature limit in VTM for Regions of Interest where these may occur. If this is reached
  - the offending heating systems (individual PINI, RF antenna etc is stopped by the local manager
- If temperature in the Region of Interest continues to rise a global stop is requested when the next higher temperature limit is reach:
  - Main changer hot spot
  - Divertor hot stop
  - Both

### Protection aspects of Real-time networks

- RTPP
- PDV
- RTSS(P)







### **APODIS & RAPTOR**

Disruption predictor

### PETRA

- Dud detection
- Disruption avoidance
- Disruption mitigation

Alarms go to Realtime Networks & RTPS to be actioned

### WALLS

### Inputs from

- Magnetics diagnostics
- Plasma control system
- Heating system local managers

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- PDV
- Bolometry
- Thermocouples

Model based algorithm computing plasma wall loading

- The position of the strike points of the plasma in tiles
- The penetration of the plasma between tiles
- The angle of incidence of power on tiles
- The plasma power load on tiles
- The bulk and surface temperature of tiles due to plasma power loads

WALLS alarms go to RTPS to be actioned

This provides a backup when cameras in VTM are blind



## **JET Data Warehouse**

- Oracle Solaris based system using ZFS
- Several upgrades
  - Hardware
  - Operating system
- 40 years of data can still read
- the early data with the standard tools
- Keep all data on-line and 3 copies of data offline inc. cloud storage



## **JET Data Automated Analysis**



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Generates PPF data stored on the data warehouse

# **JET CODAS Enhancements**

Norsk Data -> Solaris VME Protection of the ITER like wall Black Box protocol & PLC interface Virtualisation of Solaris sub-systems & split CAMAC access layer Adoption of ITER relevant technologies • EPICS, SDN, MARTe V2 DT enhancements • Tritium introduction • Tritium tracking • PSACS Key monitoring and interlocks Disruption Mitigation • DMV's & SPI
Disruption Mitigation
• DMV S & SPI Real-time Control
Covid driven enhancement

### **EURO***fusion* enhancements for **DT – CODAS** integration

Gamma ray camera	Gamma ray spectrometer
Vertical compact neutron spectrometer NE213	Vertical compact neutron spectrometer CVD
Correlation reflectometer	Charge Exchange diagnostic upgrade
Time of Flight upgrade	Neutron camera upgrade
Single diamond spectrome	ter Viewing systems upgrades

Driven by technology obsolescence/refresh and new requirements/enhancements



Adoption of ITER relevant technologies EPICS

Introduce EPICS to augment our traditional system

- Access to a vast body of well supported (open source) software
- Cross platform support (Windows and Linux)
- ITER compatible
- Introduce some compatibility with MAST
- Contribute back to the community

Target applications

- Filter wheel controller for cameras/spectroscopy
- Turbopump controllers
- Radiation Protection Instrumentation

One of my software/control engineers said "its great, I have integrated this device into CODAS without writing a single line of code"



XX

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18

## **Adoption of ITER relevant technologies** SDN ATM system

- JET real-time network/ATM ITER CODAC • Ethernet/SDN bridge
- MARTe application ۲
- Initially unidirectional ۲
  - Real-time Flux surface reconstruction and real-time display based on Mantid
- Extended to bidirectional
  - Loopback through the existing real time signal server
  - Real time High Resolution Thomson scattering (HRTS) reconstruction (KE11), a MARTe V2 application
  - Real time ECE Michelson interferometer (KK1)
  - RTCC2 •
  - Release spares for real-time protection system
- Were JET to have run for a few more years
  - Move local actuator managers & other control/protection systems to Ethernet/SDN



SDN Bridge

application

ATM

interface

SDN

interface

ATM system

ATM system

ATM

switch



HRTS

Acquisition

Mantid RT display

tool

HRTS

control PC

Ethernet

switch

## **Neutron Tolerance**

Bit errors, noise, latch-up, FO darkening

Some viewing systems moved out of Torus Hall and some left in Heated jackets on fibre optics for several diagnostics Remote controllable power switches to mitigate for thyristor latchup

Rad-hardened passive vacuum gauges, RGA electronics on extra long cables, turbomolecular pumps adapted for high radiation environments & shieled

Si diode detectors lost sensitivity, higher leakage current with hall effect characteristic.

- neutron rate of order  $3 \times 10^{11}$  /cm2/s in DTE2 pulses Digitiser issues on top of the machine
  - able to reset whilst network connection remained live
  - then network connection died

1 n/cm2/s limit for modern high-density electronics and people

Mid-plane protection camera removed for DTE2 so run 'blind' replaced after DTE2 but 1 year on residual Tritium 0.3%  $30 \times 10^{15}$  n in a pulse ->  $1.6 \times 10^9$  n/cm<sup>2</sup>/s and still noisy

## Pellet injector camera on top of the machine



- shieled with 20 mm polyethylene – hard errors
- Normally changed every 2 years



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## **DT enhancements Neutron and gamma diagnostics**

# Two groups of 20 single board TSB7053 PCs

Most cases support four PCs

Not standard CODAS PCs so custom Embedded Windows OS support to include device drivers n YN3/ECU1/0003 UNIT/ENVICE - To KWH & Hand To KWH & Handlor

#### Set good technical standards

One of the Neutron diagnostic enhancements came with several chassis each containing 4 vertically mounted PC's It overheated and had to be replaced with several of our standard rack mount diagnostic PC's Spares and maintainability

## DT enhancements Viewing systems and Protection

Relocation of camera systems outside the Torus Hall

Cameras named "KLDT-xxxx" installed for DTE2/3 as part of CDT2 project.

All other cameras were removed.

New high resolution operational camera, KLDT-05WB.

Using a cooled ZWO astronomy imaging camera. An IR protection camera with the same view Protection and Scientific IR cameras: Divertor









## **DT enhancements - Spectroscopy**

Development of real-time software for H/D/T ratio measurement for use in experiment.

Fit four or six Gaussian functions to the data.

4 if only D and H present

6 if T also present.

The relationship between some of the parameters of the fit are constrained.

A Levenberg-Marquadt solution is carried out to evaluate the free parameters defining the Gaussian functions. At each stage of the iteration the full set of Gaussian parameters are calculated based on the current best fit of the free parameters. These parameters are used to generate an estimate of the source spectra, and the derivatives with respect to intensity, position and width in order to guide the solution. UK Atomic Energy Authority

Running at reliable 40ms cycle time

# **DT enhancements Real time systems**

KE11RT is a MARTe V2 application running on lin-ke11-rt

- Reads in data from KE11DAQ each time the HRTS laser fires
- Produces real-time estimates of the Te and ne profiles.
- The laser <~20Hz
- The KE11RT output package is sent on the SDN/Ethernet at 2ms cycle with the data in the body of the packet only updating after each new laser pulse has been processed
- The temperatures and densities are used by PETRA, which tries to fill in any gaps where certain groups weren't available or had bad data.
- This is currently then stored as XG data points



## **DT enhancements**

## **Tritium Management, Introduction and Tracking**

5 new TIMS in addition to the 12 existing GIMS Neutral Beam PINI grid gas  $D_2$  or  $T_2$ 

### PDLM duplicated for the TIMS

- Density feedback control
- Valve opening
- Flow control

### Gas inventory and tritium tracking

### Level-1 controls

- Communication with Tritium Plant
- Configuration
- Budget management

### TIM Level 2 controls and communication





J. Waterhouse et al. JET CODAS – the Final Status





## **Real-time Control Enhancements**

File View Schedule Pulsetype Plant Pages Reference RTCC Networks Copy Swap RTCC – VME/Power PC running Network 4 EFCC compensation lines 6-21 Output is on ss1 make sure to remove the ss1 Delayed DMV triggering lines 101-143 Clear Print Test JPN: EFCC compensatio and delayed DMV trig This one is identical to the one in Network output being delayed by 4ms and put on pp2 Delayed IpSpike/RR voltages only lines 145-1 SS: Enabled PP: Enabled NB: Disabled RF: Disabled VXWorks with RTDN over ATM build on ink to: LH: Disabled TAE: Disabled PDF: Disabled GIM: Disabled JTT Disabled his one only uses the VLRRL\*VLRRU and same educed levels, delayed by 4ms and put on pp ontroller 4 Load Reset Load Status: OK Edit Settings Copy View subnets Network 1 Network 2 Network 3 love to : MARTe Declare PDO 1 timeCtrl/On(40.00) Off(80.00) Level-1 configuration editor 2 logCtrl/Ctrl(Ton)\_InvCtrl(No) 3 timeCtrl/On(40.00) Off(70.00 4 unused/unused unused/unused signal/Sig(Loca)\_SimJPN(0 Loca: Measured Locked Mode Sign signal/Sig(KC1ISAL)\_SimJPN( sal: Measured EFCC current unused/unu ) unused/unused signal/Sig(KC1ISBL)\_SimJPN(0 ad to Plant Reset Plant Display Plant Comments Graph View func/Sig(sal) En(0) InvEn(No) Func(power) A(2) Gain(1) Offset( rtcc1 functions 3 func/Sig(sbl)\_En(0)\_InvEn(No)\_Func(power)\_A(2)\_Gain(1)\_Offset(0 and constant cts I sum/lp1(sal2) Gain1(1) lp2(sbl2) Gain2(1) lp3(0) Gain3(0) lp4(0) Gain4( delay fdev func 5 func/Sig(sl2)\_En(0)\_InvEn(No)\_Func(power)\_A(0.5)\_Gain(1)\_Offset(0) 6 tr1/Sig(sl)\_En(Ton)\_InvEn(No)\_b0(0)\_b1(32)\_a1(32) unused/unused unused/unused 9 gain/Sig(LocaE)\_Gain(3.12e-06 0 sum/lp1(Loca)\_Gain1(1)\_lp2(LocaP)\_Gain2(-1)\_lp3(0)\_Gain3(0)\_lp4(0)\_Gain4( ss/SigIdx(1)\_Sig(LocaC)\_Status( unused/unused testSe 3 unused/unused timeCtr 4 unused/unused timer varLimi 5 unused/unused 6 unused/unused Trip Input Trip Statu tec2 function unused/unused vecsignal fromstruct slice average findpeal vecinterp pi e Actively used during **Detachment Control and Disruption Avoidance** - X-point radiator

RTCC2 – Linux PC with ITER/SND over Ethernet Built on MARTe V2 New graphical user interface

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Would like to have implemented statistical selection and derivation of control signals

> plasma density in PDV for gas feedback control

# **Disruption Mitigation Systems - DMV**

### **Disruption Mitigation Valve**

- Originally an ITER related experiment
- Later mandatory protection for high current/energy pulses
- Poses risks to plasma facing systems
- Neutral beam interactions catastrophic
- Timing/Trigger system using PTN with fail-safe interlocks to additional heating systems
- Automation of routine operation
- Level-1 interface
- Expert user required for special cases
- PLC data extracted over ethernet for logging and display in JET control room
- Integrated into Gas Inventory

Each DMV system is controlled by its PLC to mix the appropriate gas species and pressurise the injection volume. The trigger originates from the Pulse Termination Network, either in response to a disruption, or predicted disruption, or as part of an experiment. A large volume of gas is injected when triggered

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# **Disruption Mitigation Systems - SPI**



#### Shattered Pellet Injector

- Shared gas supply with DMVs
- Integrated into DMS interlocks
- Gas species frozen to form pellets
- Cold head cooled to 10K
- Propellent gas typically D at 60bar
- Partial automation to support export users
- An ITER related experiment
  - NOT a protection system
  - but also used for runaway experiments
- Possible damage to inner wall if no plasma
- Failure modes: no fire, premature injection
- Integrated into Gas Inventory
- Trigger via PTN with interlocks





The pellet shards penetrate the plasma more rapidly than a DMV gas puff, and SPI technology will be used on ITER.

# **Developments to mitigate for COVID**



Web browser access to JET Mimics Improved remote access to operational systems Video stream intercept and serve in real time through the web

- Colour Operations Cameras only
- Re-use control room live software, running on a dedicated PC, to generate the live/rolling replay views for remote users
- The Staging PC grabs the monitor output and presents it to a WebRTC server



• Few people on site and in Control Room

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- How do you manage remote access
  - Monitoring & Plant Control



# **Deuterium Tritium Results**



- T-rich hybrid scenario experiments revisited:
  - repeat the highest performance pulse
  - with improved resilience to high-Z impurity accumulation, achieved via higher P<sub>ICRH</sub>
  - Higher power, optimised gas



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## **Very long heated pulse** A CODAS challenge 1.5

### Traditional JET pulse

- 80 s of TF
- 40 s of plasma
- 10 s NBI heating 30 MW

### Plant limits

- Central solenoid Vs
- Power supply limits
- Thermal limits

### **CODAS Limits:**

- Explicit timing settings ٠
  - Plant enable windows
  - Protection limits
- Implicit assumptions
  - Timeouts
  - Sampling rates/number of samples

### Long Pulse

٠

- 110s TF
- 60 s of plasma at 1.4 MA
- 60 s of NBI heating at 4 6 MW
- 40 s of RF power at 2 MW .

Be aware of your explicitly and implicit limits

ΜM



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## **LID-QMS**

## **Laser Induced Desorption Quadrupole Mass Spectrometry**

Usual key exchange and primary safety circuit

- To ensure no one is in controlled areas Torus Hall
- Special CODAS Pulse Mode:
  - No checks on Central Interlock and Safety System
  - Limited subsystems enabled to speed up readout
- Enhancements required:
  - Repurposing Cameras to view tile being used
  - Laser control/triggering system
  - Articulated mirrors to steer incident point
  - High level (Level-1) controls
  - Mode setup and return to normal scripts in Level-1
- Operating mode
  - Initially in pauses in operations meal breaks
  - Later whole shifts inc. Saturdays





### Laser scan on tile

## Last Ever JET Pulse.....105929 LID-QMS pulse with JET pulse announcement message



## **JET Data Centre**

### Politics

- BREXIT
- Who owns the JET Data
- Are we a member of
- Who has access to the data
- Who is funding
- Proposal to lift and shift the JET Data Centre
  - Separation of operational systems from the data warehouse
  - Local caching for data new data and visualisation/analysis and local resilience
  - Very high bandwidth connection
  - Failed so stays local

### Future access to JET data by others (DTT, CFS and other)?

- Data mining
- IMAS interface
- Virtual-JET to develop and test future control and protection systems

JET data volumes per pulse Total non-video synchronous pulse data in GB



JET pulse number





# **Beyond Operations**

Plasma operations ceased at the end of 2023

- Much of the plant is still running:
  - Vacuum pumping and plant monitoring
  - Environment monitoring
  - Radiation protection instrumentation
  - Access Controls

#### Forthcoming activities:

- Power down to reduce electricity bill
- Diagnostic calibrations
- In-vessel sample retrieval
- Detritiation
- Decommissioning and repurposing
- CODAS Sub-systems powered down when associated plant it turned off
  - Greyed out and marked Decom
- Parts of CODAS will have to remain operational for several years until functionality replaced
- Maintain Configuration Control & Documentation
  - Decommissioning
  - De-planting

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## Conclusions

JET Control and Data Acquisition has stood the test of time and supported a very successful programmes on JET.

- Much of the architecture from 40 years ago still in use
- Evolution to meet experimental needs and changing technology
- Much technology development in the early period as components were not commercially available and continues at a diminishing rate right through to the end
- High standard, administrative controls, documentation JET is a research machine
- Adoption of new technologies as appropriate
- Maintenance of old technologies where appropriate (e) Data to Solaris computers)
- Supply in-kind and interfacing to CODAS some intered

### Aspects of JET CODAS live on

- JET Data Centre continues to provide access to all ( >4 data
- Support for diagnostic calibration
- Support for plant & environment monitoring, radiation protection instrumentation and access controls
- Possible support for detritiation
- CODAS plant facing system are being shut down when no longer required
- De-planting and Repurposing to follow

Very flexible

Future large machines will be different

Commissioning will be more like a research machine

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- Then repetition of pulses to build up statistic
- Reliability & Maintainability
- Technology refresh

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