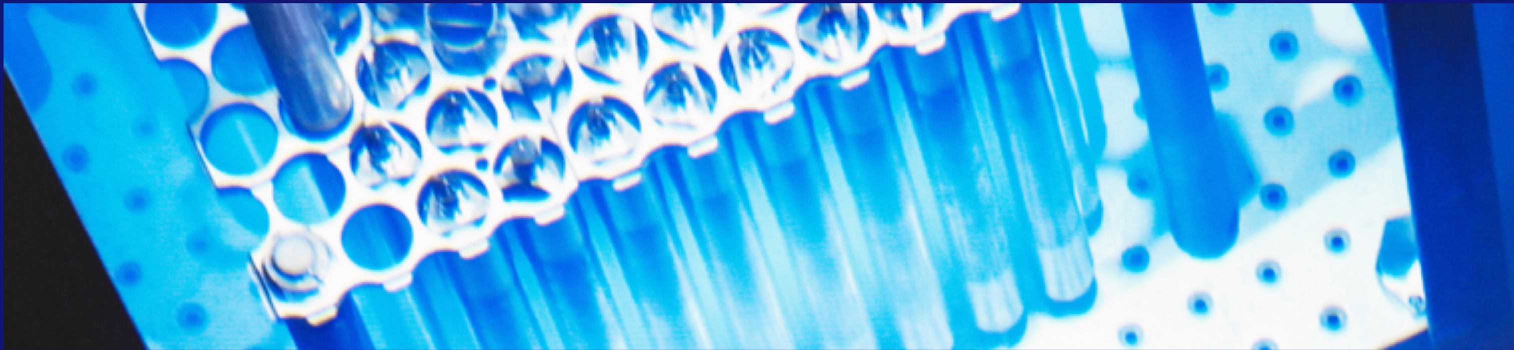

65 1955-2020 BREAZEALE Nuclear Reactor

Implementation of a New Digital Console at the PSU Breazeale Reactor

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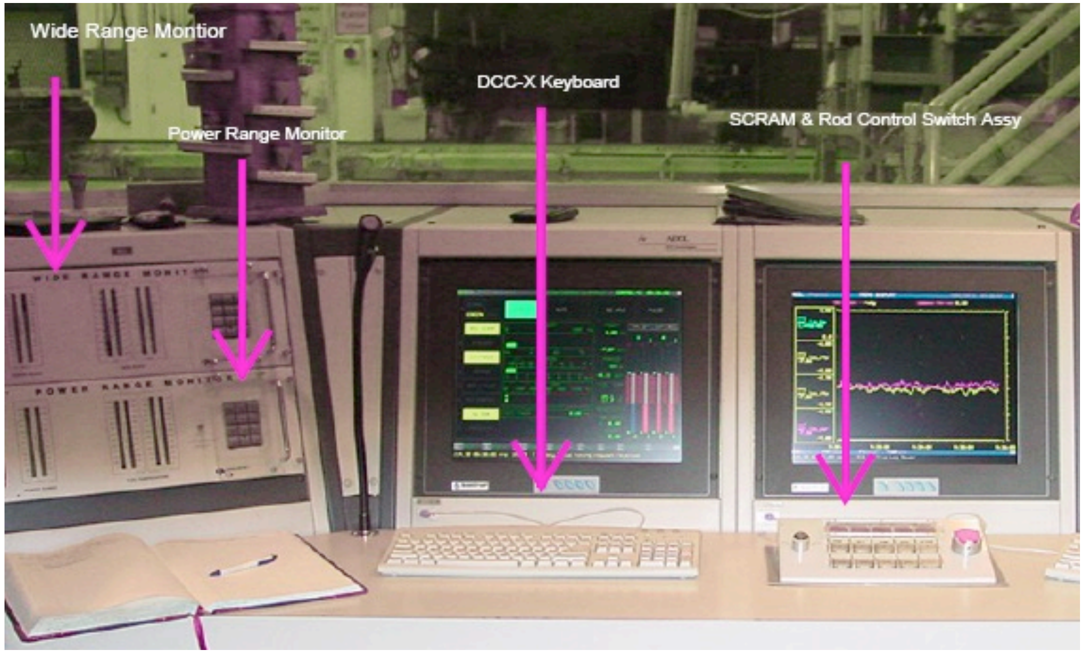
Adams Tong
Research and Development Engineer

Introduction

- The replacement of the PSU analog/digital hybrid console was funded with a $1.1 M DOE NEUP grant in 2017 (DE-NE-0008658)
- The replacement of the digital console was completed in 2021.
  - Not credited in safety analysis or TS
  - Replaced under 50.59
- PSU RSEC has been reluctant to share details of 50.59 review while NRC review was still pending.
- Previous TRTR presentations have covered the reactor console design and installation planning.
- This presentation will discuss:
  - 50.59 evaluation
  - Software V&V and documentation
  - Testing
  - Plans to replace reactor safety system

Foxboro vs. AECL Console

- The AECL digital control console (DCC) was installed ca. 1992
- Console functions were executed in seven "loops."
  - RRS – Reactor Regulating System
  - SSS – Safety Support Slow
  - SSF – Safety Support Fast
  - FAC – Facility Control
  - OPR – Operator Control
  - DSP – Operator Display
  - PULS – Pulse Control / Data
- Each time the console executed a loop, a signal would be sent to the watchdog relay to reset a timer. If the relay was not reset within 2 seconds → SCRAM.
- The newer Foxboro system was designed to replicate the AECL software design to the maximum extent possible. However, the digital console is now a distributed control system (DCS), with inputs processed by field bus modules (FBMs) controlled by a field control processor. The operator's screen is a GUI run by software.
- To a large extent, the operator interacts with the DCS in the same way as the DCC, with some minor differences.


Wide Range Montior
Power Range Monitor
DCC-X Keyboard
SCRAM & Rod Control Switch Assy
WIDE RANGE MONITOR
POWER RANGE MONITOR


EVACUATE BUILDING
WIDE RANGE MONITOR
POWER RANGE MONITOR
AECL
MANUAL
AUTO
SQ WAVE
PULSE
Reactor Key

50.59 Evaluation

- The 50.59 evaluation is captured in PSU RSEC procedure AP-12, which also includes ALARA, PSP, and EP reviews for changes at the facility.
- License-basis safety functions, including all required SCRAMs and interlocks, are performed by the analog RSS. (The RSS watchdog relay is reset by the DCC / DCS).
- The digital console has no effect on most of SAR Ch. 13:
  - MHA: fuel element cladding rupture during handling;
  - Evaluation of maximum fuel temperature (limited by RSS SCRAM);
  - Pulse from full reactor power (prevented by RSS interlock).

Water Loss Accident Scenario

- The only scenario in the SAR which includes operator action is a rapid water loss through the two reactor pool drain pipes. This can be affected by a malfunction / freezing of the DCS operator interface (GUI).
- The reactor operator is assumed to immediately receive a low water message on the console and SCRAM.
- Maximum fuel temperature = 860 C, set by time for water to drain to fuel level.
- The new console display is software-based. What if the software freezes and the operator does not notice?
  - Watchdog scram from frozen interface may take much more than 2 sec.
  - A one-minute delay in response would increase maximum temperature to 870 C. (Limit is 950 C).
  - The operator would need to ignore or misinterpret an audible alarm in the control room and not notice the change in pool level.
- In order to mitigate this potential problem, a heartbeat (blinking light) was added to the screen, and the "Primary water low" message is now accompanied by a SCRAM.

50.59 Screening

X Change to an SSC that adversely affects design function as described in SAR?

Watchdog scram reset method is changed, GUI may freeze for > 2 sec without watchdog scram

✓ Change to a procedure that adversely affects how an SSC design function is performed, controlled, or tested?

✓ Revise / replace SAR evaluation methodology?

✓ Test or experiment not described in SAR where SSC is used / controlled outside the reference bounds in SAR or inconsistent with analyses or descriptions in SAR?

50.59 Review

- More than minimal increase in:
  - Frequency of SAR accident?
  - Consequences of a SAR accident?
  - Likelihood of SSC malfunction as evaluated in SAR?
  - Consequences of SSC malfunction as evaluate in SAR?
- Create a possibility of:
  - Accident different from those in SAR?
  - Malfunction of SSC with result previously evaluated in SAR?
- Change in design basis limit or assumption in SAR accident analysis?
- Change in method of analysis?

50.59 Review

- Closest “hit” was on sudden loss of pool water scenario.
  - Does the increase in time before scram significantly affect maximum temperature?
- Even with same evaluation methodology, increase in maximum fuel temperature only increased minimally (10 C).
- Most 50.59 review questions were obviated by robustness of TRIGA fuel and the lack of SSCs in the digital console

Software V & V

- **Front End**
  - Visual elements such as buttons, textbox, graphics, and text messages that enables users to interact with the application.
  - Programmed and run on client workstations.

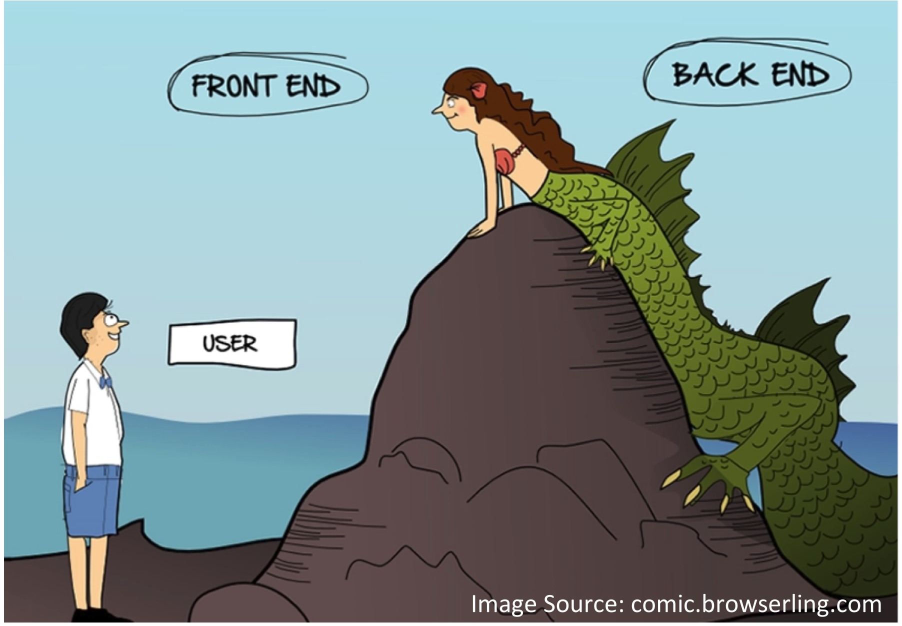
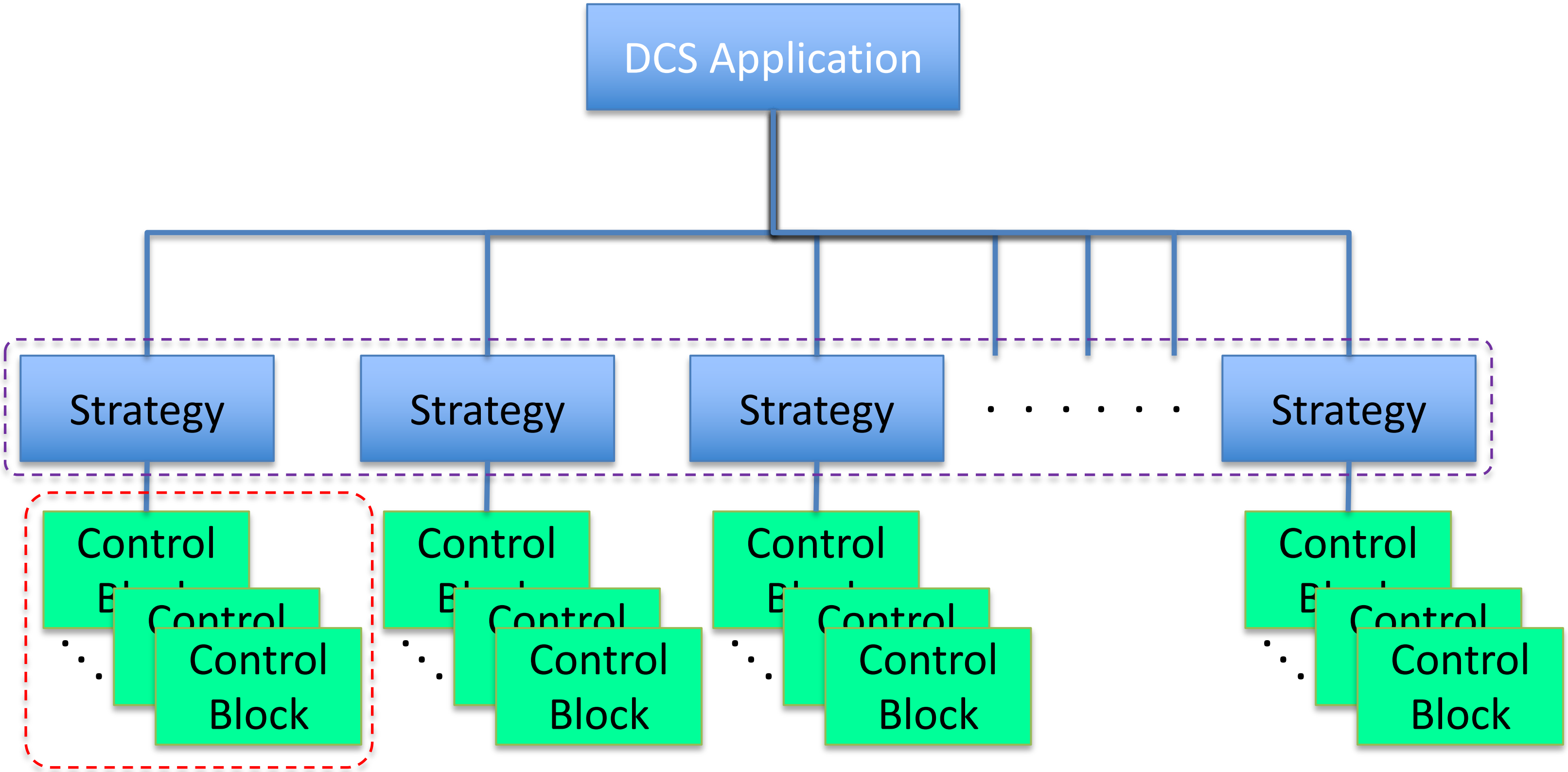


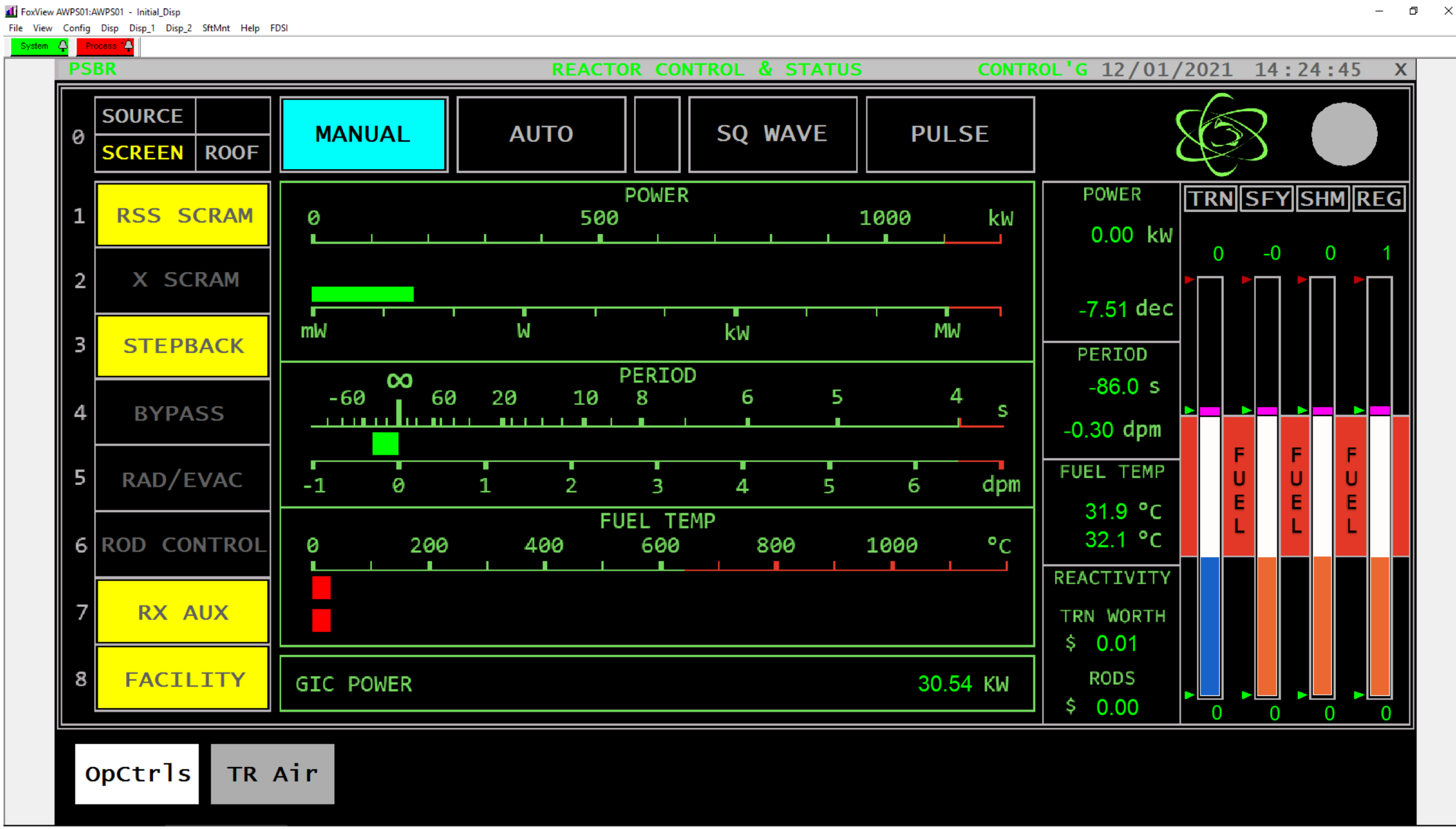
Image Source: comic.browserling.com

- **Back End**
  - Data and infrastructure that accept inputs from user and field devices and make the application work.
  - Programmed on server but run on Field Control Processor (FCP).

Backend V&V


DCS Application
Strategy
Strategy
Strategy
Strategy
Control Block
Control Block
Control Block
Control Block

Frontend V&V


FoxView AWPS01:AWPS01 - Initial_Disp
File View Config Disp Disp_1 Disp_2 SftMnt Help FDSI
System
Process
PSBR
REACTOR CONTROL & STATUS
CONTROL'G 12/01/2021 14:24:45
X
0
SOURCE
SCREEN
ROOF
MANUAL
AUTO
SQ WAVE
PULSE
1 RSS SCRAM
2 X SCRAM
3 STEPBACK
4 BYPASS
5 RAD/EVAC
6 ROD CONTROL
7 RX AUX
8 FACILITY
POWER
0 500 1000 kW
mW W kW MW
PERIOD
-60 ∞ 60 20 10 8 6 5 4 s
-1 0 1 2 3 4 5 6 dpm
FUEL TEMP
0 200 400 600 800 1000 °C
GIC POWER
30.54 KW
POWER
0.00 kW
-7.51 dec
PERIOD
-86.0 s
-0.30 dpm
FUEL TEMP
31.9 °C
32.1 °C
REACTIVITY
TRN WORTH
$ 0.01
RODS
$ 0.00
TRN SFY SHM REG
0 -0 0 1
FUEL
FUEL
FUEL
0 0 0 0
OpCtrls
TR Air

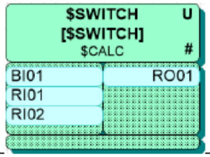
Software Documentation

- DCS Design Manual – Overview of all strategies and user interfaces.
- DCS Control Logic Diagram – Graphical representation of every strategy.
- Control Block Manual – Functional description of control blocks.
- Control Block DVT – Design Verification Report (including test method and test data) for the control blocks.
- Control Block Code – RPN and graphical representation of control blocks.
- Electronic Tuning Log – Parameters for the control blocks deployed in DCS.
- Physical IO Connection List – Mapping of DCS IO connection and field devices.
- Control Rod Drive Motor & Controller Upgrade – Supplement design manual for the upgraded control rod drive controller and motor.
- Pulse Tracing Computer – Supplement design manual for the pulse tracing computer.

Control Block Manual (Example)

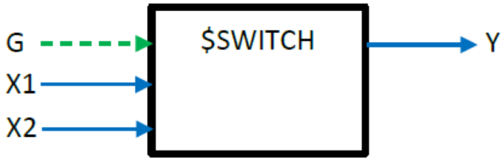
LIII.$SWITCH

Block Symbol:



Derived From: $CALC

Functional Description:



The Switch block ($SWITCH) selects one of the two analog inputs as output depending on the value of a boolean gating signal. The first input is selected if the boolean input is TRUE else the second input is selected.

I/O Mapping:

- BI01 – G
- RI01 – X1
- RI02 – X2
- RO01 – Y

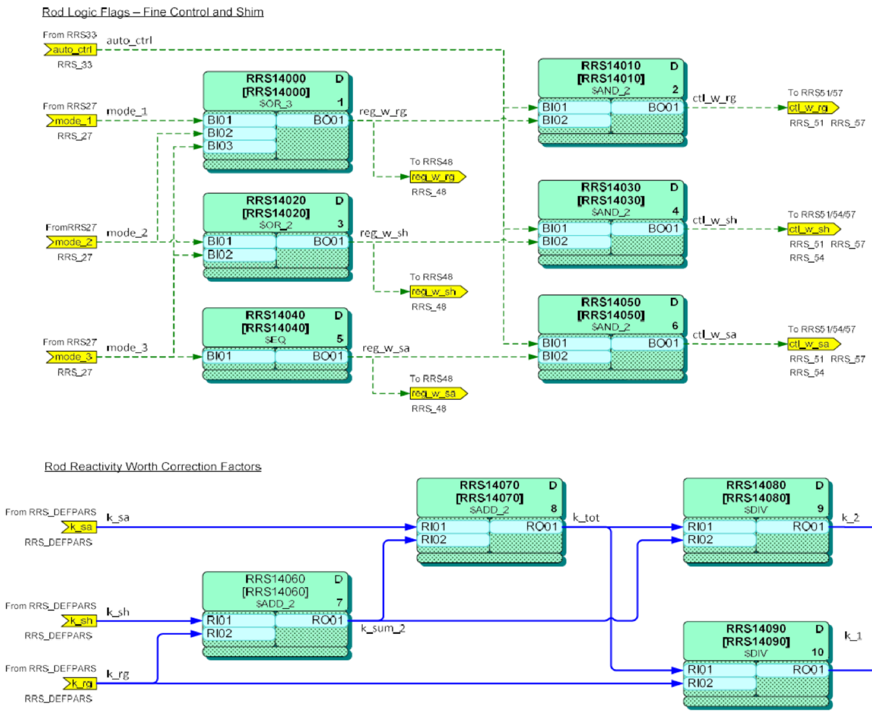
Essential Block Parameters:

- PERIOD – block sampling time, *user-defined*
- HSCO1 – high scale output 1, *user-defined*
- LSCO1 – low scale output 1, *user-defined*

Note: None

DCS Control Logic Diagram & DCS Design Manual 1 (Example)

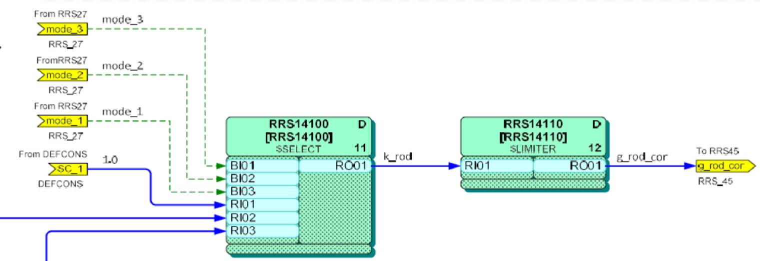
DCS Design Manual



F.2.13 RRS_042 – Control Mode Factors and Flags

This sheet generates a number of flags based on the rod control mode to determine if a rod is being used for automatic fine control in one of the three-rod-bank configurations. A correction gain factor is also computed to adjust overall controller gain for the different reactivity sensitivities of the rod banks.

The rod bank correction gain factor has a value of one if a three-rod-bank is selected for control. The gain is increased for two and one rod banks according to the banks relative reactivity sensitivity with position. This gain correction is computed from the individual rod sensitivities assuming the rod reactivity sensitivities are additive, to obtain the bank reactivity sensitivity. The individual rod reactivity sensitivities (**k_sa, k_sh & k_rg**) are defined in RRS_DEFPARs and can only be changed with ArchestrA Control Editors. Values for the mid-range of travel of the rods should be used.



RRS_42	Galaxy: PSU_Galaxy
	Report: Diagram
	Page: 1 of 1
	Date: Monday, July 25, 2022
	User: Engineer

DCS Design Manual 2 (Example)

G.2.2 Screen 2-1 MANUAL mode Menu (DCS-X only)

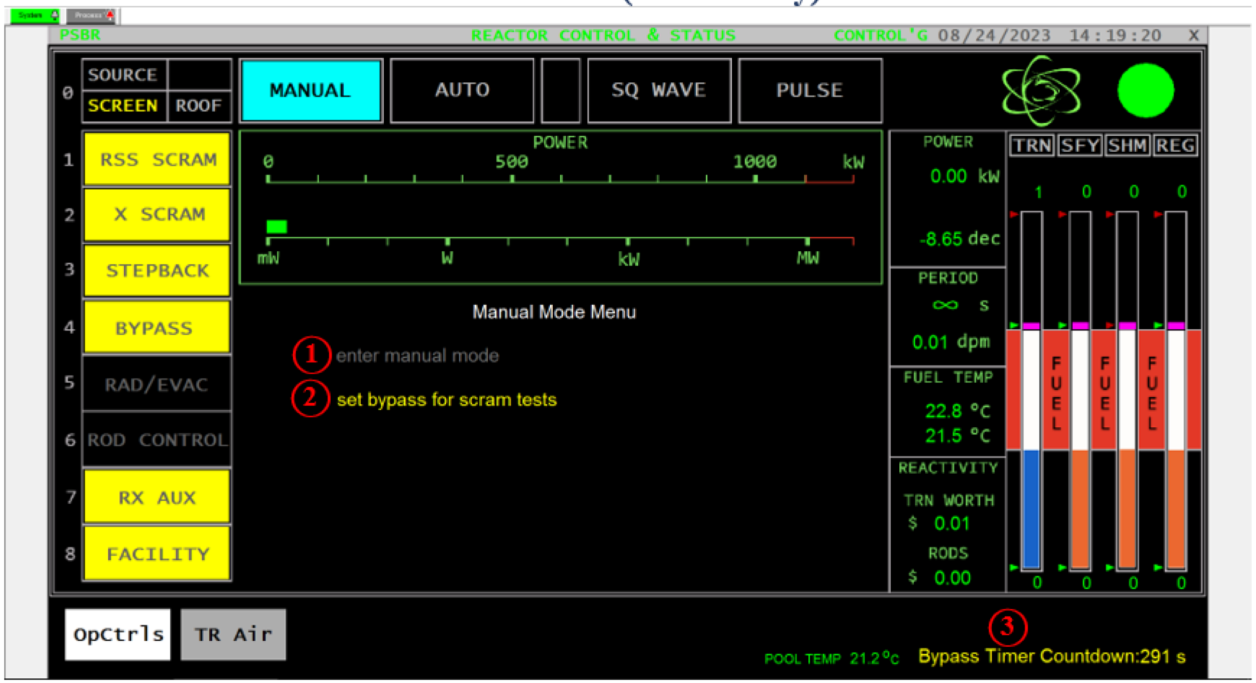


Figure 2. Screen 2-1 Manul Mode Menu (DCS-X only)

1. Enter Manual Mode Button
2. Set Bypass for SCRAM Tests Button
3. Countdown Timer for Bypass for SCRAM Tests

#	Update	Action
1	Text Color – OPR1020.CIN	(MomContact – OPR1020.IN
2	Text Color – OPR1015.BO01	DM Command – toggle OPR1000.IN
3	Visibility – OPR1015.BO01 Text Contents – OPR1010.RO02	-- (None) --

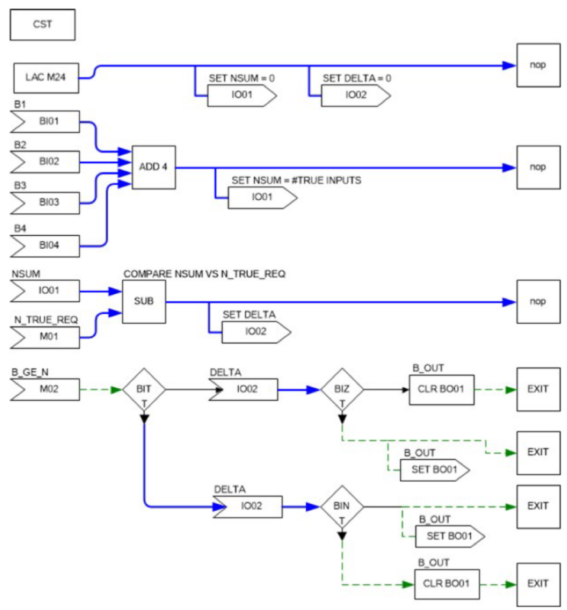
Function Block Code (Example)

RPN Codes

PSBR-DCS-009 Rev. 0

RELEASED

[$N_GATE] Steps	
Step	Value
STEP01	CST
STEP02	LAC M24
STEP03	OUT IO01 ;SET NSUM = 0
STEP04	OUT IO02 ;SET DELTA = 0
STEP05	
STEP06	IN BI01 ; B1
STEP07	IN BI02 ; B2
STEP08	IN BI03 ; B3
STEP09	IN BI04 ; B4
STEP10	ADD 4
STEP11	OUT IO01 ; SET NSUM = #TRUE INPUTS
STEP12	
STEP13	IN IO01 ;NSUM
STEP14	IN M01 ; N_TRUE_REQ
STEP15	SUB ;COMPARE NSUM VS N_TRUE_REQ
STEP16	OUT IO02 ;SET DELTA
STEP17	
STEP18	IN M02 ;B_GE_N
STEP19	BIT 26
STEP20	IN IO02 ;DELTA
STEP21	BIZ 24
STEP22	CLR BO01 ; B_OUT
STEP23	EXIT
STEP24	SET BO01 ; B_OUT
STEP25	EXIT
STEP26	IN IO02 ;DELTA
STEP27	BIN 30
STEP28	SET BO01 ; B_OUT
STEP29	EXIT
STEP30	CLR BO01 ; B_OUT
STEP31	EXIT
STEP32	
STEP33	
STEP34	
STEP35	
STEP36	
STEP37	
STEP38	
STEP39	
STEP40	
STEP41	
STEP42	
STEP43	
STEP44	
STEP45	
STEP46	
STEP47	
STEP48	
STEP49	
STEP50	



Graphical Representation

$N_GATE

30

Galaxy: PSU_Galaxy
Report: Steps Table
Page: 2 of 3
Date: Thursday, July 20, 2023
User: Engineer

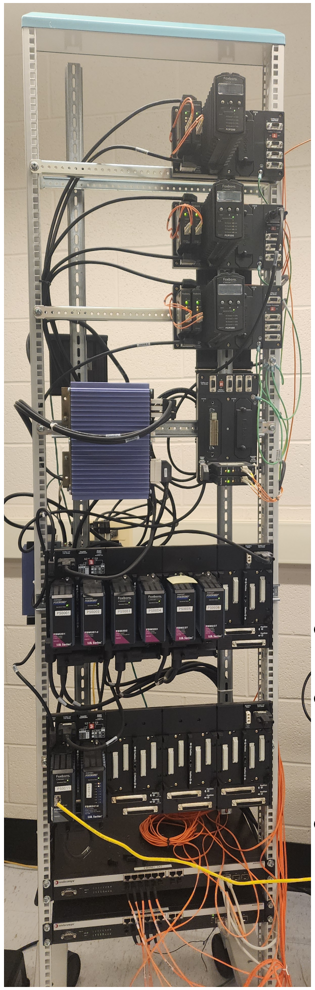
Physical IO Connection List (Example)

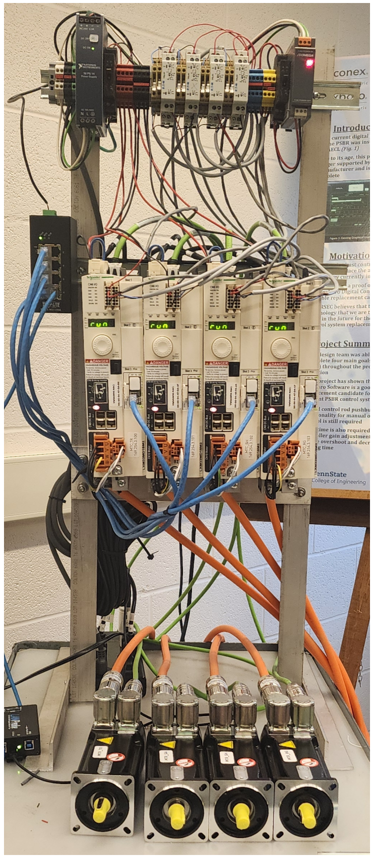
I/O Type	Tagname	Description	Where used (Strategy:BlockID)	IOM_ID	I/O Module	PNT_NO
AI	FC_SQRT_PWR	Fission Chamber Power SQRT	RRS_9.RRS3030 & SSF_218.SSF6000	CPPS01_ECB:PSU002	FBM201D	1
AI	FC_LOG_PWR	Fission Chamber Power Log	RRS_9.RRS3000 & SSF_203.SSF1000	CPPS01_ECB:PSU002	FBM201D	2
AI	FC_LOG_RATE	Fission Chamber Log-Rate	RRS_9.RRS3110 & SSF_209.SSF3000	CPPS01_ECB:PSU002	FBM201D	3
AI	F_TEMP_1	Fuel Temperature #1	RRS_15.RRS5305, SSF_203.SSF1100 & SSS_109.SSS4000	CPPS01_ECB:PSU002	FBM201D	4
AI	POOL_TEMP	Reactor Pool Bulk Temp	FAC_312.FAC4200	CPPS01_ECB:PSU002	FBM201D	5
AI	E_B_RAD_AI	East Bay Monitor Signal	SSS_112a.SSS5000	CPPS01_ECB:PSU002	FBM201D	6
AI	GIC_PWR_WIDE	Gamma Ion Chamber Wide Range	PULS_100.PULS30, PULS_100.PULS100 & PULS_100.PULS101	CPPS01_ECB:PSU002	FBM201D	7
AI	BEAM_RAD_AI	NBL Rad Monitor Signal	SSS_115.SSS6000	CPPS01_ECB:PSU002	FBM201D	8
AI	GIC_PWR	Gamma Ion Chamber Power	RRS_14.RRS5000 & SSF_218.SSF6005	CPPS01_ECB:PSU003	FBM201D	1
AI	F_TEMP_2	Fuel Temperature #2	RRS_15.RRS5400, SSF_203.SSF1200 & SSS_109.SSS4005	CPPS01_ECB:PSU003	FBM201D	2
AI	W_B_RAD_AI	West Bay Monitor Signal	SSS_112a.SSS5010	CPPS01_ECB:PSU003	FBM201D	3
AI	S_B_RAD_AI	South Bay Monitor Signal	SSS_112a.SSS5040	CPPS01_ECB:PSU003	FBM201D	4
AI	CO60_RAD_AI	Co-60 Monitor Signal	SSS_115.SSS6010	CPPS01_ECB:PSU003	FBM201D	5
AI	HX_DIFF_P	HX Inlet-Outlet Diff. Press	FAC_315.FAC5300	CPPS01_ECB:PSU003	FBM201D	6
AI	SPR_LOG_PWR	Spare FC Power Log	SSF_206.SSF2700	CPPS01_ECB:PSU003	FBM201D	7
AI	SPR_SQRT_PWR	Spare FC Power SQRT	SSF_206.SSF2800	CPPS01_ECB:PSU003	FBM201D	8

ID	DerivedFr	PERIOD	DESCRP	HSCO1	LSCO1
DSP_110.DSP2025	$SWITCH	0	SWITCH	4.0	0.0
DSP_110.DSP2035	$SWITCH	0	SWITCH	4.0	0.0
DSP_110.DSP2045	$SWITCH	0	SWITCH	4.0	0.0
DSP_110.DSP2090	$SWITCH	0	SWITCH	4.0	0.0
DSP_120.DSP3080	$SWITCH	0	RG_ROD_POS	16.0	-1.0
DSP_120.DSP3180	$SWITCH	0	SH_ROD_POS	16.0	-1.0
DSP_120.DSP3280	$SWITCH	0	SA_ROD_POS	16.0	-1.0
DSP_120.DSP3380	$SWITCH	0	TR_ROD_POS	16.0	-1.0
FAC_312.FAC4400	$SWITCH	0	SWITCH	1	0
FAC_318.FAC6420	$SWITCH	0	SWITCH	1	0

Electronic Tuning Log (Example)

Bench Testing





- Isolated test system for bench testing of all V & V.
- Accept real and simulated inputs – testing system behavior and operational boundaries
- Also used for troubleshooting, improvement & development of new console features.

Control Block DVT (Example)

XIV. $DIV

A. Test Method:

1. Create a new instance of $DIV block in the $BTest_strategy
2. From FoxSelect, open the $DIV block from $BTest_strategy.
3. Change RI01 & RI02, observe and record RO01

B. Test Result:

RI01	RI02	RO01	Pass / Fail?	RI01	RI02	RO01	Pass / Fail?
0	0	0	Pass	1	0	0	Pass
0	1	0	Pass	1	0	0	Pass
1	1	1	Pass	1	0.1	10	Pass
1	2	0.5	Pass	1	0.2	5	Pass
1	3	0.333	Pass	1	0.3	3.333	Pass
10	3	3.333	Pass	10	0.3	33.33	Pass
100	3	33.333	Pass	10	0.03	100	Fail
100	5	20	Pass	10	0.03	333.333	*Pass

*Retested with HSCO01 increased from 100 (default) to 1000.

C. Conclusion:

PASSED W/ CONDITION – since the $DIV block is $CALC based, programmer shall take into the consideration of the high scale output (HSCO1) and the low scale output (LSCO1) parameters when deploying the $DIV block in the control program to prevent unintentional clamping of the output. As shown in the last test with 100/0.03, the output is clamped at the 100 unless the HSCO1 value is increased.

Challenges

Engineering & Design:

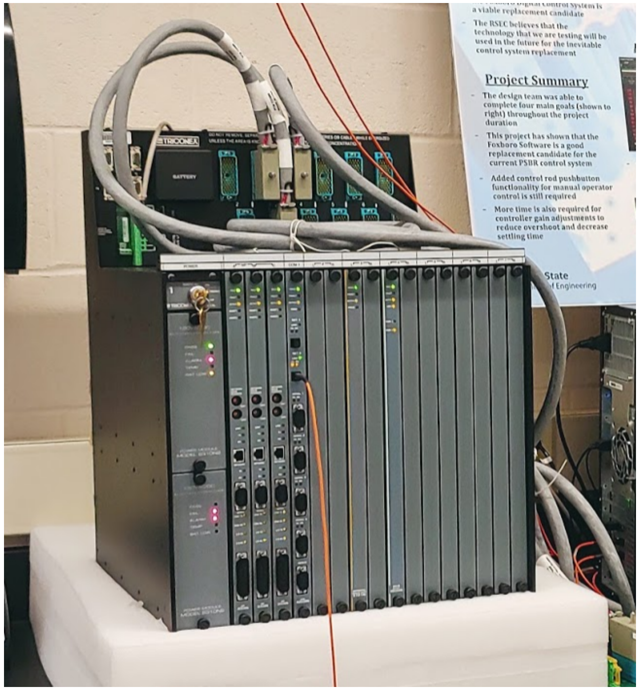
- Recreate most control blocks solely based on their functional description.
- Recreate OPR and DSP compounds (backend for User Interface) based on operator experience.
- Control Rod Motor Controller & Pulse Tracing Computer.

Documentation:

- Amount of documentation required.
- Upkeep of documentation following changes / improvements.

Next Steps

- TRICONEX digital reactor safety system is planned for use in place of analog RSS
- RSEC engineers will program the TRICONEX system
- The analog RSS performs all of the safety functions (scrams, interlocks, etc.) credited in the license and Tech Specs

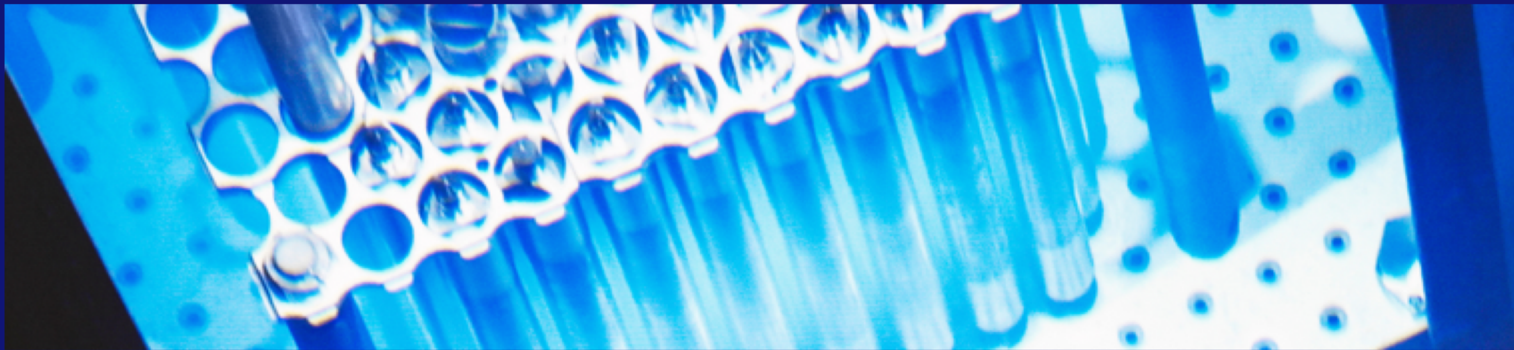


Next Steps

- RSEC has had the hardware to perform the TRICONEX upgrade since 2017.
- Other priorities, such as the beam hall expansion and the installation of the non-safety related digital control console equipment, have diverted staff resources.
- A pre-submittal (aka phase zero) meeting is planned for November 2024 to begin moving forward with the license amendment for the digital RSS.

Conclusion

- AECL digital console was replaced with a new Foxboro DCS programmed by RSEC staff after 31 years of service.
- The new console was approved via 50.59; this was reviewed by NRC as part of the 2023 reactor safety inspection.
- This effort required significant staff resources to perform adequate testing, documentation, and V&V.
- In November 2024, PSU RSEC will begin to engage NRC and work towards licensing the digital reactor safety system.



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1955-2020
BREAZEALE
Nuclear Reactor

Implementation of a New Digital Console at the PSU Breazeale Reactor

Jeffrey Geuther
Associate Director for Operations

Adams Tong
Research and Development Engineer