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SIMULATOR VALIDATION OF CALCULATION CODE IN REDNET UPGRADE SYSTEM

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ABSTRACT

The reactor data network (REDNET) is a computer-based data acquisition, display and archival system which acquires data from the National Research Universal (NRU) reactor's "fuelled sites", and several experimental loop facilities in support of CANDU technology development (e.g., fuel, fuel behaviour, and materials research programs). The system supports the processing of data collected for subsequent display at the respective experimental facilities, and in the NRU control room.

REDNET was installed in the 1980s based on the 1970s computer technology. The computer hardware is obsolete and spare parts are either extremely hard to find or are now unavailable. The Upgrade system is intended to replace the REDNET and eliminate the risk of losing the data acquisition of important experimental data needed in support of the CANDU Fuel Development Program. An important goal of the Upgrade system is to improve the accuracy in the measurement and calculation of thermal power.

Calculations in REDNET are performed in FORTRAN code with some in-house macros. The same calculations are re-implemented in the Upgrade system in structured-text and function-block languages. To ensure that there is no deviation or loss of accuracy in the calculations of the Upgrade system compared to those in REDNET, software validation is performed on calculation code in the Upgrade system.

The validation consists of a two-stage and three-point check (at ~0%, 50% and ~100% signal level) process for every data type and data point in the Upgrade system.

This paper presents the purpose, the major tools and process, and the results of the validation. It is concluded, based on the validation results, that the Upgrade system achieves at least the same, and in many cases better, accuracy in all the calculations.

1. INTRODUCTION

Software validation is performed on calculation code in the REDNET U1/U2 Upgrade system. The U1/U2 Upgrade system will replace the part of the REDNET that acquires, displays and archives experimental data from the U1 and U2 loops of the NRU reactor. The same calculations as those in REDNET are implemented in the Upgrade system which employs Siemens-Moore QUADLOG hardware and *ProcessSuite* software. These calculations play an important role in correctly and accurately interpreting the experimental results which are crucial to CANDU technology development (e.g., fuel, fuel behavior, and materials research programs). The purpose of the software validation is to ensure that no deviation or loss of accuracy will occur in the configured calculations in the Upgrade system as compared to those in REDNET.

This paper

- describes the tools and process of the validation,
- presents and explains the validation results,
- analyzes the results and explains the discrepancies observed during the validation,
- determines, based on the analysis, the accuracy of calculations in the Upgrade system as compared to those in REDNET, and
- determines if the discrepancies are acceptable.

2. VALIDATION TOOLS

The Siemens-Moore QUADLOG Simulator, the REDNET Scratch Pad, and MATLAB are the three major tools used in the validation. They are described below.

<u>QUADLOG Simulator</u>

The QUADLOG Simulator is a part of the Siemens-Moore *ProcessSuite SafetyMatrix* software package that provides a simulation environment [1]. The QUADLOG Simulator is used to run the configured calculations in the Upgrade system without the need of physically connecting the actual hardware (e.g., the controller modules and the I/O modules). The simulation is run on a stand-alone PC without affecting the operation of the actual Upgrade system being wired and commissioned. The ‘Online Real-Time Display’ and ‘Variable Control’ options of the simulator allow the user to set (or change) the input value(s) of a calculation, and observe the resulting output from the calculation.

<u>REDNET Scratch Pad</u>

REDNET Scratch Pad is a part of the REDNET utility that provides a similar simulation environment in REDNET. One can type in the input value(s) to a calculation in the Scratch Pad, and observe the resulting output from the calculation.

MATLAB

MATLAB is a popular, proven and accurate math software package [2] which is commercially available and is widely used by hundreds of thousands of scientists/engineers around the world. When performing the validation, the calculation results from the QUADLOG Simulator and the REDNET Scratch Pad are compared. If there are discrepancies between the two (in most cases they do), the discrepancies are further investigated in MATLAB. MATLAB is programmed to perform the same calculations, and the results from MATLAB are used as a standard for comparison with those from the QUADLOG Simulator and the REDNET Scratch Pad.

3. VALIDATION APPROACH AND PROCESS

Two stages of validation have been completed:

- the first stage is to obtain calculation results from both the QUADLOG system and REDNET, based on a common set of input data;
- the second stage is to investigate the discrepancies observed in the first stage results.

First Stage Validation

The first stage validation involves:

- the use of a common set of input data,
- a 3-point calculation (at ~0%, 50% and ~100% signal levels) for every data point in the QUADLOG simulator,
- the corresponding 3-point calculations in the REDNET Scratch Pad, and
- the recording of inputs and outputs of the calculations and comparing the results.

Second Stage Validation

The second stage validation involves:

- calculating the percentage relative errors between the first stage results from the QUADLOG Simulator and the REDNET Scratch Pad,
- identifying those points whose relative error is deemed as a discrepancy that requires further investigation,
- designing code in MATLAB to perform the same calculations for those points,
- applying the same set of input data to the MATLAB code,
- performing the calculations in MATLAB and recording the results, and
- using MATLAB results as a standard for comparison with the results from the QUADLOG and REDNET to resolve the discrepancy issues.

This approach is justifiable for the following reasons:

1) MATLAB is a proven mathematical software package being used by hundreds of thousands of scientists and engineers around the world.
2) MATLAB supports double-precision (64-bit) variables and applies double-precision in all its internal calculations. Therefore, no loss of accuracy will occur in the calculation process.

A 3-point calculation is also performed for subroutines in the Upgrade system to assess the magnitude of any discrepancy they may cause.

4. NON-DERIVED AND DERIVED DATA POINTS

Based on its inputs, a calculation can be categorized into one of the four types:

1) Single-Input Single-Output (SISO) where the Engineering Unit (EU) of a tag is calculated from a single analog input;
2) Dual-Input Single-Output (DISO) where the EU of a tag is calculated from a single analog input and another tag's EU;
3) Triple-Input Single-Output (TISO) where the EU of a tag is calculated from a single analog input and two other tags' EUs;
4) Derived-Point where the EU of a tag is calculated from a number of other tags' EUs.

Type 1-3 above are called 'non-derived data points' or, simply, 'non-derived-points'. Type 4 is called 'derived data points' or, simply, 'derived-points'.

5. COMMON INPUT DATA SET

For comparing the same calculation implemented on different platforms, a common set of input data is required.

Input Data Set for Non-Derived-Points

Table 1 lists the analog input range and the three input levels for the non-derived-points.

Table 1: Input Range and Three Input Levels for Non-Derived-Points

Range (mV)	~0% (mV)	50% (mV)	~100% (mV)
0-5	0.75	2.5	4.999
0-20	3.0	10.0	19.99
0-50	10.0	25.0	49.99
0-100	20.0	50.0	99.9
0-500	100.0	250.0	500.0
190-950	228.0 (1.2 V)	570.0 (3.0 V)	950.0 (5.0 V)
200-1000	250.0 (1.25 V)	600.0 (3.0 V)	999.0 (4.995 V)
0-1000	250.0	500.0	999.0

Note: values within parentheses in Table 1 are applicable to the QUADLOG system only, values beside the parentheses are applicable to REDNET. The values with no parentheses beside them apply to both the QUADLOG and REDNET. The reason for having values in parentheses is the hardware difference of the two systems. Although those values appear to be different, they are considered as the same in their respective range in the validation.

The input values in Table 1 apply to the analog input of non-derived-points. If a non-derived-point also has EU input(s), then the EU input(s) is kept constant. Since the input EUs are the output of some other non-derived-points, and are themselves calculated from some common input values (not necessarily the same as in Table 1), it is conceivable that they may be slightly different (see examples in Table 3) between the QUADLOG and REDNET.

Input Data Set for Derived-Points

The input data set for the derived-points is taken from REDNET. The REDNET data at three different power levels (low, medium, high) are printed out and used.

The mV values from the REDNET printouts are input to the QUADLOG Simulator to obtain the QUADLOG EU values which are then used as inputs for the QUADLOG derived-point calculations.

6. FIRST STAGE VALIDATION RESULTS

Examples of the first stage results for the SISO type calculations are given in Table 2.

Table 2: Examples of the First Stage Results for Calculations of SISO Type

TAG	REDNET MV	MOORE MV	REDNET EU	MOORE EU
U2L261	0.750	0.75	0.51	0.508275
	2.500	2.5	1.69	1.69425
	4.999	4.999	3.39	3.387822
U1L113	228.0	1.2	0.929	0.9286942
	569.9	3.0	8.374	8.375013
	950.0	5.0	16.648	16.6487

The first column in Table 2 is the tag name. The second and the third columns in Table 2 are the analog inputs to the REDNET Scratch Pad and the QUADLOG Simulator. For each tag there are three input lines corresponding to three input values (low, medium, high). The fourth and the fifth columns in Table 2 are the calculation results from the REDNET Scratch Pad and the QUADLOG Simulator. Note that for tag U1L113, the medium-level input to the REDNET Scratch Pad was typed in as 570.0, but was shown on the screen as 569.9. The table records what was shown on the screen.

Examples of the first stage validation results for the calculations of DISO type are given in Table 3.

Table 3: Examples of the First Stage Validation Results for Calculations of DISO Type

TAG	REDNET INPUTS		MOORE INPUTS		REDNET EU	MOORE EU
	NAME	VALUE	NAME	VALUE		
U1L053	U1L052(EU)	75.00	U1L052_EU	75.0	-186.81	-186.7941
	U1L053(mV)	20.00	U1L053_MV	20.0		
	U1L052(EU)	75.00	U1L052_EU	75.0	-85.08	-85.08353
	U1L053(mV)	50.00	U1L053_MV	50.0		
	U1L052(EU)	75.00	U1L052_EU	75.0	84.10	84.09512
	U1L053(mV)	99.90	U1L053_MV	99.9		
U1L111	U1L053(EU)	26.00	U1L053_EU	25.98447	271.38	271.4268
	U1L111(mV)	10.00	U1L111_MV	10.0		
	U1L053(EU)	26.00	U1L053_EU	25.98447	626.67	626.6578
	U1L111(mV)	25.00	U1L111_MV	25.0		
	U1L053(EU)	26.00	U1L053_EU	25.98447	1261.23	1261.276
	U1L111(mV)	49.99	U1L111_MV	49.99		

The second and third columns in Table 3 are input name and value to the REDNET Scratch Pad. The fourth and fifth columns are input name and value to the QUADLOG Simulator. The sixth and seventh columns in Table 3 are calculation results from the REDNET Scratch Pad and the QUADLOG Simulator.

Note that for tag U1L111 in Table 3, the EU input U1L053(EU) and U1L053_EU have different values resulting from the same inputs:
U1L053(EU)=26.0 which is obtained in the REDNET Scratch Pad with inputs:
U1L052(EU) = 75.0, and U1L053(MV) = 82.76;
whereas U1L053_EU=25.98447, which is obtained in the QUADLOG Simulator with inputs: U1L052_EU = 75.0, and U1L053_MV = 82.76.

Examples of the first stage results for the derived-point calculations are given in Table 4.

Table 4: Examples of the First Stage Validation Results for Derived-Point Calculations

TAG	REDNET INPUTS		MOORE INPUTS		REDNET EU	MOORE EU
	NAME	VALUE	NAME	VALUE		
U1L823	U1L189(EU)	276.0	U1L189_EU	276.0	436.4	434.5574
	U1L190(EU)	281.1	U1L190_EU	281.0526		
	U1L820(EU)	16.516	U1L820_EU	16.51701		
	U1L189(EU)	275.4	U1L189_EU	275.4211	1112.1	1108.068
	U1L190(EU)	288.2	U1L190_EU	288.1579		
	U1L820(EU)	16.536	U1L820_EU	16.53821		
	U1L189(EU)	276.6	U1L189_EU	276.5789	2230.9	2228.137
	U1L190(EU)	301.5	U1L190_EU	301.4737		
	U1L820(EU)	16.594	U1L820_EU	16.59513		
U1L824	U1L183(EU)	277.4	U1L183_EU	277.4538	502.9	502.8836
	U1L184(EU)	283.2	U1L184_EU	283.2686		
	U1L820(EU)	16.516	U1L820_EU	16.51701		
	U1L183(EU)	276.9	U1L183_EU	276.9592	1187.7	1186.929
	U1L184(EU)	290.5	U1L184_EU	290.5185		
	U1L820(EU)	16.536	U1L820_EU	16.53821		
	U1L183(EU)	278.1	U1L183_EU	278.1341	2322.0	2321.924
	U1L184(EU)	303.9	U1L184_EU	303.891		
	U1L820(EU)	16.594	U1L820_EU	16.59513		

7. SECOND STAGE VALIDATION AND RESULTS

The first stage validation results show that except for a few tags, most tags have differences, albeit fairly small, between the outputs from the QUADLOG and the REDNET. These differences (referred to as "discrepancies") are examined in the second stage validation to determine if they are acceptable.

Procedure for Second Stage Validation

The second stage validation process consists of following steps:

1) Calculate the percentage relative errors between the first stage results from the QUADLOG Simulator and the REDNET Scratch Pad, record the error under the column "Delta". (see Table 5)

2) Implement the same calculation in MATLAB with the same input as the QUADLOG Simulator input, record the result in 7-digit under the column "MATLAB".

3) Implement the same calculation in MATLAB with the same input as the REDNET calculation input, record the result in 7-digit under the column "MR". Skip this step if the input(s) is the same as in step 2.

4) Compare the "MATLAB" result to the QUADLOG output, and the "MR" result to the REDNET output and determine the accuracy of those two outputs.

Second Stage Validation for Subroutines in Derived-Point Calculations

Derived-points are calculated from input(s) of EU(s). These EUs are the outputs of non-derived-points. Therefore, discrepancies found in the derived-point calculations in the first stage results between the QUADLOG and the REDNET originate from the following two sources (It is assumed that no extra discrepancies would be introduced due to the use of standard mathematical calculation function blocks (e.g., addition, subtraction, … in the QUADLOG system):

1) the discrepancies of EU input(s) carried forward from non-derived-point calculations,

2) the subroutines in derived-point calculations (on different h/w and s/w platforms).

The first source of discrepancies has been addressed in the second stage validation using separate inputs in the MATLAB calculations (step 2, 3 in the procedure above).

The second stage validation is performed on these subroutines following the steps below to assess how much discrepancy they may cause.

1) Apply a common set of 3-point input data to the subroutines in the QUADLOG Simulator, the REDNET Scratch Pad, and MATLAB, and record the results.

2) Compare the MATLAB results with results from the QUADLOG Simulator and the REDNET Scratch Pad.

3) Determine if subroutines in QUADLOG have introduced any errors.

Second Stage Validation Results

Examples of the second stage results for the non-derived-points of SISO type are given in Table 5.

Table 5: Examples of the Second Stage Validation Results for Non-Derived-Points of SISO Type

Tag	REDNET mV	Moore mV	REDNET EU	Moore EU	Delta %	MR	MATLAB
	228	1.2	0.929	0.928694	0.032917		0.9286937
U1L113	569.9	3	8.374	8.375013	0.012097	8.372835	8.375012
	950	5	16.648	16.6487	0.004205		16.64870
	10	10	0.56	0.556905	0.552768		0.5569045
U1L261	25	25	1.39	1.392261	0.162662		1.392261
	49.99	49.99	2.78	2.783966	0.142662		2.783966

Examples of the second stage results for non-derived-points of DISO type are given in Table 6.

Table 6: Examples of the Second Stage Validation Results for Non-Derived-Points of DISO Type

Tag	REDNET	Input	Moore	Input	REDNET EU	Moore EU	Delta	MR	MATLAB
	Name	Value	Name	Value			%		
	U1L053(EU)	26	U1L053_EU	25.98447	271.38	271.4268	0.017245	271.4421	271.42684
	U1L111(mV)	10	U1L111_MV	10					
U1L111	U1L053(EU)	26	U1L053_EU	25.98447	626.67	626.6578	0.001947	626.6726	626.6578
	U1L111(mV)	25	U1L111_MV	25					
	U1L053(EU)	26	U1L053_EU	25.98447	1261.23	1261.276	0.003647	1261.294	1261.276
	U1L111(mV)	49.99	U1L111_MV	49.99					

Examples of the second stage results for derived-points are given in Table 7.

Table 7: Examples of the Second Stage Validation Results for Derived-Points

Tag	REDNET	Input	Moore	Input	REDNET	Moore	Delta	MR	MATLAB
	Name	Value	Name	Value	Output	Output	%		
	U1L189(EU)	276	U1L189_EU	276					
	U1L190(EU)	281.1	U1L190_EU	281.0526	436.4	434.5574	0.4222273	438.6421	434.5611
	U1L820(EU)	16.516	U1L820_EU	16.51701					
	U1L189(EU)	275.4	U1L189_EU	275.4211					
U1L823	U1L190(EU)	288.2	U1L190_EU	288.1579	1112.1	1108.068	0.3625573	1113.439	1108.05
	U1L820(EU)	16.536	U1L820_EU	16.53821					
	U1L189(EU)	276.6	U1L189_EU	276.5789					
	U1L190(EU)	301.5	U1L190_EU	301.4737	2230.9	2228.137	0.1238514	2228.651	2228.152
	U1L820(EU)	16.594	U1L820_EU	16.59513					

Comparing the error between the "REDNET Output" and "MR", with that between the "Moore Output" and "MATLAB", we can see the configured calculations in the Moore QUADLOG system achieved better accuracy than their REDNET counterparts.

Results for Subroutines Used in Derived-Point Calculations

The subroutines in derived-point calculations are also 3-point checked with a set of common input values. Table 8 shows an example. The table displays the outputs from the same set of input data for subroutine TSAT run on different computers.

Table 8: Comparison of Results for the Same Subroutine But Run on Different Computers

SUBROUTINE	INPUT	(MPa)	REDNET	MOORE	MATLAB
	Name	Value	OUTPUT	OUTPUT	OUTPUT
TSAT	Pressure	2.5	224.08	224.0693	224.0693
	Pressure	5	264.06	264.0469	264.0469
	Pressure	10	310.96	310.9617	310.9617

8. ANALYSIS OF VALIDATION RESULTS

The first stage results show that:

- The results from the QUADLOG and REDNET are quite close to each other. They are not exactly the same in most of the calculations.
- The QUADLOG system generally displays more digits than the REDNET.
- The results of non-derived-point calculations are quite close between the two systems.
- Slightly bigger discrepancies are observed in results of derived-points. They originate from the differences in the input EU(s) and/or the subroutines.
- There are a few cases where after truncating/rounding, a QUADLOG result matches the corresponding REDNET result and their relative error is < 0.1%.
- In most cases after truncation/rounding, the QUADLOG result does not match the REDNET result, or although it matches the REDNET result, the relative error is >= 0.1%. There are also cases where the QUADLOG result has fewer digits than the REDNET result and they don’t match.

The second stage validation results show that:

- The calculations for both the non-derived-points and the derived-points in the QUADLOG have achieved at least the same, and in many cases better, accuracy than those in the REDNET.
- The subroutines in the QUADLOG calculations have achieved the same or better accuracy than their REDNET counterparts.

9. CONCLUSIONS

It is concluded, based on the analysis of validation results, that:

- The discrepancies between the calculation results from the QUADLOG and REDNET are fairly small. The worst case in the thermal power calculation when the reactor is at full power is about 0.17% (tag U2L821 data).
- Validation using MATLAB shows that the calculations configured in the QUADLOG system achieved the same or better accuracy than their REDNET counterpart.
- The discrepancies between the calculation results from the QUADLOG and REDNET originate from many factors. Comparing the results from the QUADLOG and REDNET to the standard results from MATLAB, we see an improvement in accuracy with the QUADLOG system compared to that with REDNET.
- There is no deviation or loss of accuracy in the configured calculations in the QUADLOG system compared to that in REDNET. The discrepancies are hence acceptable.

The software validation experience from this work will be a useful reference for the next phase REDNET Upgrade, and other similar projects.

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REFERENCES

[1] Siemens-Moore Product Co. Manual “ProcessSuite Control Simulator Version 4.30”, CG39CTRSIM-1, Rev. 1, 1998 April.

[2] MATLAB Manual, The MathWorks, 1997.