STAFF RESPONSES TO PUBLIC COMMENTS ON DRAFT NUREG-1709 — SELECTION OF SAMPLE RATE AND COMPUTER WORDLENGTH IN DIGITAL INSTRUMENTATION AND CONTROL SYSTEMS

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1. INTRODUCTION

Draft NUREG-1709, “Selection of Sample Rate and Computer Wordlength in Digital Instrumentation and Control Systems,” was issued for public comment as announced in the Federal Register.

Comments were received from the following sources:

ID	Company Name
I	Virginia Power
II	Commonwealth Edison

Responses have been arranged by the chapter and section to which the comment refers. Responses applicable to general comments on NUREG-1709 are presented first. Specific comments were received on the following chapters of NUREG-1709.

Chapter 3, “Sample Rate Selection”
Chapter 4, “Computer Wordlength Selection”

In the following pages, the response to each comment consists of three parts. First, the comment is presented. Each comment is identified by a roman numeral which designates the comment source. The comment identifier used by the correspondent is provided and each comment is reproduced verbatim from the letters submitted. Since they have not been edited in tone, substance, or in any other way, the comments are presented in quotation marks. A number of inserts were placed in the comments by the staff reviewers and are enclosed in <pointed brackets>. These inserts reflect a unique number, assigned across the entire set of responses, to better link the staff responses to different elements of a comment. Second, the staff technical response to the comment is presented. Finally, the proposed revision to draft NUREG-1709, if any, which was developed in response to the comment, is presented.

A note to the reader is warranted. This report is not a stand-alone document. A copy of draft NUREG-1709 is needed to fully understand both the comments and the staff responses. For example, a comment may cite a page number or guideline and provide a comment on the material without specifically repeating the material to which it is directed. Such comments are not always intelligible. In such cases, reference to draft NUREG-1709, and possibly material cited by the NUREG, usually provides the appropriate context.

2. RESPONSES TO GENERAL COMMENTS

Submitted Comments

I "Sample rate and wordlength issues are addressed in this report in an isolated manner and are not placed in the context of a total digital system design. The concerns raised are valid but they represent only a small fraction of the many design considerations required to develop a successful digital system."

"There are numerous existing NRC and industry standards and guidelines which do address the total process of digital system design, including the issues raised in this draft report. It appears from the content of the draft report and the absence of pertinent existing documents in the Reference section, that no attempt was made to coordinate the review guidance presented in this report with existing guidance."<1>

"Consideration should be given to integrating the concerns raised in this draft report with existing guidance on NRC review of digital systems rather than creating a separate review with a limited and narrow focus."

"**Report should be coordinated with existing guidance** — It appears from the content of the draft report and the absence of the documents listed below in the Reference section, that no attempt was made to coordinate the review guidance presented in this report with existing guidance. Consideration should be given to integrating the concerns raised in this draft report with existing guidance on NRC review of digital systems rather than creating a separate review with a limited and narrow focus. Existing guidance documents include:

NUREG/CR-6082, "Data Communications" <2>

NUREG/CR-6083, "Reviewing Real-Time Performance of Nuclear Reactor Safety Systems" <3>

Branch Technical Position HICB-14, "Guidance on Software Reviews for Digital Computer-Based Instrumentation and Control Systems" <4>

Branch Technical Position HICB-21, "Guidance on Digital Computer Real-Time Performance" <5>

ANSI/ISA-S67.04, "Setpoints for Nuclear Safety-Related Instrumentation" <6>

Draft Reg. Guide DG-1045, "Proposed revision 3 to Reg. Guide 1.105, Instrument Setpoints for Safety Systems" (Endorses ISA S67.04) <7>

Technical Response

<1> The intent of draft NUREG-1709 is to provide information on engineering practice related to sample rate and computer wordlength selection. As stated in the comment, there are many issues regarding digital systems reviews. Most of these issues are not related to sample rate

and computer wordlength selection, so they are not discussed. Furthermore, other documents already address many of those issues. Rather, the goal is to provide technical information to an area that was not adequately addressed by other NRC or industry documents. Chapter 2, "Regulatory Background," provides several references to NRC and industry standards that have relation to sample rate and computer wordlength selection issues. In referencing those documents, the intent is to relate sample rate and computer wordlength selection to the overall review of nuclear safety instrumentation and control systems. Documents referenced in Chapter 2 include the following.

- Various portions of 10 CFR Part 50, including Appendix A
- ANSI/IEEE Standard 279-1971, "Criteria for Protection Systems for Nuclear Power Generating Stations"
- Reg. Guide 1.105-1986, "Instrument Setpoints for Safety-Related Systems"
- ISA Standard S67.04-1982, "Setpoints for Nuclear Safety-Related Instrumentation Used in Nuclear Power Plants"
- Reg. Guide 1.153-1996, "Criteria for Safety Systems"
- IEEE Standard 7-4.3.2-1993, "IEEE Standard Criteria for Digital Computers in Safety Systems of Nuclear Power Generating Stations"
- ANSI/ISA Standard S67.06-1984, "Response-Time Testing of Nuclear Safety-Related Instrument Channels in Nuclear Power Plants"
- Chapter 7: Instrumentation and Control, Standard Review Plan, NUREG-0800, including Branch Technical Position HICB-21, "Guidance on Digital Computer Real-Time Performance"

The following responses address specific documents mentioned in the comment.

<2> NUREG/CR-6082, "Data Communications," was reviewed for its relevance to sample rate and computer wordlength selection. While data communication is a real-time computer issue, most of the topics discussed in NUREG/CR-6082 provide little contribution to the issues discussed in draft NUREG-1709. However, those issues relating data communications and sample rate/computer wordlength selection will be discussed in draft NUREG-1709.

<3> NUREG/CR-6083, "Reviewing Real-Time Performance of Nuclear Reactor Safety Systems," was reviewed for its relevance to sample rate and computer wordlength selection. Since the topics discussed in this document are also referenced in Branch Technical Position HICB-21, only the branch technical position was referenced. However, changes will be made to reference NUREG/CR-6083 also.

<4> Branch Technical Position HICB-14, "Guidance on Software Reviews for Digital Computer-Based Instrumentation and Control Systems," mainly involves the development of safety software for nuclear power plants. The issues discussed in this branch technical position have little relation to sample rate and computer wordlength selection, except for the possibility of sample rate selection influencing the software requirements specification. However, this possibility is not unique to sample rate and computer wordlength selection as compared to other real-time computer issues that would also impact software requirements specifications.

<5> Branch Technical Position HICB-21, "Guidance on Digital Computer Real-Time Performance," is referenced in Section 2.3 of draft NUREG-1709.

<6> ANSI/ISA Standard S67.04, "Setpoints for Nuclear Safety-Related Instrumentation" is referenced in Section 2.1 of draft NUREG-1709. The 1982 version is referenced since it is still the standard that the NRC endorses through Reg. Guide 1.105. There does not appear to be any differences between the 1982 and Part I of the 1994 versions that would impact sample rate and computer wordlength selection. ISA-RP67.04-Part II-1994 accompanies ANSI/ISA S67.04-Part I-1994 and provides some discussion on uncertainty calculations. While Part II is not endorsed by the NRC, it will be discussed in draft NUREG-1709 since it provides some pertinent information.

<7> Draft Reg. Guide DG-1045, "Proposed revision 3 to Reg. Guide 1.105, Instrument Setpoints for Safety Systems" is not referenced in the draft NUREG; rather Reg. Guide 1.105 is referenced since it is still the valid regulatory guide. It does not appear that Draft Reg. Guide DG-1045 adds any information that is not covered in Reg. Guide 1.105 concerning sample rate and computer wordlength selection. Therefore, Reg. Guide 1.105 will remain the referenced document.

Proposed Revisions

<1> Revise the discussion of "Scope" in Section 1.3, first paragraph to read as follows.

> This document is intended for NRC staff use when reviewing digital I&C equipment in nuclear facilities. The review of digital I&C equipment involves many issues, two of which include sample rate and computer wordlength selection. The review of sample rate and computer wordlength selections is conducted at the same time other real-time computer issues are investigated. While the review of sample rate and computer wordlength selection is somewhat independent of other digital I&C system issues, the topics discussed in this document may influence other digital review issues such as requirements specifications and data communications. The goal of this document is to provide technical information on proper sample rate and computer wordlength selection. While aliasing and finite wordlength errors can never be eliminated, they can be minimized through proper design and equipment selection.

<2> Revise the discussion of "Other Documents" in Section 2.3 to add the following subtitle.

> Data Communication Requirements
> Sample rate selection may impose timing requirements for the data communication system. Computer wordlength selection may impose requirements on data transmission equipment or protocols [see NUREG/CR-6082, "Data Communications"] (USNRC, 1993b).

<3> Revise the discussion of "Other Documents" in Section 2.3 to add the following subtitle.

> Real-Time Computer Requirements
> Sample rate selection would impose timing requirements on computer operations [see NUREG/CR-6083, "Reviewing Real-Time Performance of Nuclear Reactor

Safety Systems," and BTP HICB-21, "Guidance on Digital Computer Real-Time Performance,"] (USNRC, 1993a; USNRC, 1997a)

Also, see the proposed revision made in point <1>.

<4> Revise the discussion of "Other Documents" in Section 2.3 to add the following subtitle.

Software Requirements Specifications

Computer wordlength selection may limit the types of operations and structure of algorithms for use on software variables [see BTP HICB-14, "Guidance on Software Reviews for Digital Computer-Based Instrumentation and Control Systems"] (USNRC, 1997a),

<5> See the proposed revision made under point <3>.

<6> Revise the discussion of "Setpoint Accuracy" in Section 2.1 to add the following footnote.

ANSI/ISA Standard S67.04-1994 is the revision to ISA S67.04-1982 (ANSI/ISA, 1994). At the time of publication, the NRC staff is proposing to update Reg. Guide 1.105 with the revised standard. However, differences between the Reg. Guide and standard revisions do not impact sample rate and computer wordlength discussion in this document.

Revise the discussion of "Setpoint Accuracy" in Section 2.1 to modify the third paragraph.

Aliasing and finite wordlength errors contribute to uncertainty in setpoint calculations. For example, aliasing causes digital I&C systems to attribute lower, or higher deviations, to plant variables. Round-off and truncation also cause deviations in such variables. While the NRC staff does not endorse ISA-RP67.04-Part II-1994, Appendix H of that document lists aliasing, round off, and truncation errors as sources of uncertainty for setpoint calculations (ISA, 1994). Chapter 3 contains more detail on aliasing and its impact on setpoint accuracy. It also provides methods for aliasing measurement. Chapter 4 provides similar insight for finite wordlength errors.

<7> See proposed revision under point <6>.

I "**Analog and digital systems should be more closely related** — It would be useful to more closely relate analog systems to digital systems. For example, analog systems have gain and offset errors which are analogous to those of digital systems. Likewise, analog systems have frequency response errors which correspond to those caused by sample rate problems in digital systems."

Technical Response

The Staff agrees that analog and digital systems have similarities including gain, offset, and frequency response errors. Discussion on such similarities will be included in areas where it would help explain concepts.

Proposed Revisions

Revise the discussion of "A/D Converter Error Sources" in Section 3.1.2 to modify the following subtitles.

> LSB error: This error is present in all A/D converters. LSB represents the smallest change resolved by an *n*-bit converter, which is equal to 1 part in 2^n. Because an A/D converter cannot resolve voltage below the LSB, some amount of error exists. The maximum LSB error is ½ the LSB. For example, a 12-bit A/D converter has 0.5 part in 2^{12}, or 0.0122% of full-scale input voltage as its maximum LSB error. As an analogy to an analog error source, LSB error is similar to instrument measurement error since the actual error lies between zero and +/- some observed maximum boundary. The A/D transfer function in Figure 3.2, illustrates LSB error.
>
> Linearity error: Linearity error, measured in LSB, describes the departure from the linear A/D transfer function curve. This type of error is similar to the nonlinear behavior experienced in many instruments. In Figure 3.3, the dashed, diagonal line illustrates the linear characteristic of the ideal A/D converter. If the steps are skewed so the line is curved instead of straight, the transfer function exhibits a linearity error.
>
> Gain error: Gain error, or *full-scale error*, occurs when the voltage increment is greater or less than the ideal voltage increment between transition points for all binary codes. This type of error causes the slope of the A/D transfer function to deviate from the ideal, and it is similar to the gain error that would appear in analog amplifiers. Figure 3.4 illustrates gain error.
>
> Offset error: Offset error, or *zero error*, creates a right or left shift in the A/D transfer function. Offset errors are a result of internal converter imperfections, amplifier offsets, or ground problems. Since this error results from analog problems internal to the A/D converter, the result of offset error is similar to offset errors experienced with some analog components. With offset error, all digital transition points deviate from the ideal by the offset voltage amount.

I "**Error magnitude relative to analog systems should be addressed —** The report should give an idea of the relative error magnitudes when compared to analog systems. For example, in Section 3.1.2 it should be noted that the least significant bit error introduced by A/D converters is much smaller than the measurement uncertainty of most analog instrument channels."

Technical Response

The Staff agrees that, in general, uncertainties due to aliasing and finite wordlength errors are less than some of the other error sources, such as those associated with the instrument itself. However, it is not possible to make an overall statement that aliasing and finite wordlength errors are less than other sources of uncertainties by a certain magnitude for the following reasons:

- Aliasing errors are affected by the frequency content of the signal. Therefore, the same digital device using the same sample rate may contain different levels of aliasing depending upon the application. Likewise, finite wordlength errors are dependent upon the input signal range. Therefore, unlike many other sources of measurement uncertainty, aliasing and finite wordlength errors are influenced, not only by the equipment, but also the application.

- As some of the other measurement uncertainties are decreased through technological advances (i.e., advanced instruments with lower measurement error), the magnitude difference between various error sources will change.

While it is not possible to give the magnitude difference between various sources of uncertainty, efforts have been made in draft NUREG-1709 to describe the expected level of error associated with aliasing and finite wordlength errors. For example, Table 3.2 provides a tool to estimate the maximum level of aliasing and Table 4.2 illustrates the percent error experienced by A/D converter resolution (i.e., least significant bit error).

Proposed Revisions

No revisions are planned to address this comment.

II **"Mathematical validation should not be recommended where a program of Electro Magnetic Interference (EMI) / Radio Frequency Interference (RFI) validation and reduction and a program of signal noise monitoring, reduction, and filtering is utilized in conjunction with industry experience relative to acceptable cycle time for the particular control system."**

"Draft NUREG-1709 expands the recommendation to apply this document beyond the traditional Safety Related classification. Systems that are important to safety or have a requirement for high functional reliability are stated to be within the scope of the document. Thus, NUREG-1709 will apply to systems under consideration for upgrade to digital control that are non-Safety Related. While NUREG-1709 does stipulate many items that are important to a stable overall system, it will add burden to the design process to validate and document many of the issues identified in the "review guidelines."<1> Many of these are taken care of by the vendor design and experience with product line equipment that has demonstrated process stability in similar applications at other power plants or process industries. Other items in the review guidelines will require extensive testing to validate frequency spectrums and then show mathematically the appropriate cycle times. There is ample industry experience that applies directly to control applications such as Boiling Water Reactor (BWR) pressure regulator systems need relatively fast total cycle times (i.e., on the order of 50 milliseconds). However, BWR Reactor Water Level Control systems need medium range total cycle times (i.e., approximately 250 milliseconds or less) to provide stable and yet responsive control. Other systems such as the BWR Reactor Recirculation Systems do not need such fast cycle times and will perform acceptably with relatively slow cycle times (i.e., 500 milliseconds or less). Each of the above referenced systems is non-Safety Related. Appropriate input filtering and appropriate Analog-to-Digital (A/D) converter process times are known by the vendors and take care of aliasing problems. Vendors have addressed stability issues in the design of their products for the process control industry, which, in many cases, has applications that exceed the design requirements of nuclear power plant process control. Recommendations for mathematical validation will not add significant value to the overall design process." <2>

Technical Response

<1> In the past, the NRC staff has reviewed systems that are considered non-safety but have significant impact on plant safety. For example, draft NUREG-1709 references LER Docket Number 05000220, which involves digital BWR recirculation and feedwater control systems.

During this event, a digital control system failure caused the BWR to enter a power/flow relationship technical specification violation. As a result, the NRC sent a special inspection team to investigate the event. Furthermore, Chapter 7: Instrumentation and Control of NUREG-0800, *Standard Review Plan*, states the following in Section 7.1:

> "Non-safety I&C systems are reviewed to ensure that they conform to the acceptance criteria and guidelines, that the controlled variables can be maintained within prescribed operating ranges, and that effects of operation or failure of these systems are bounded by the accident analyses in Chapter 15 of the SAR. This includes verification that non-safety systems are appropriately isolated from safety systems and that the quality and reliability of these systems is sufficient to minimize challenges to safety systems."

Selection of sample rates affects the stability of some digital control systems that could challenge safety systems if they are unreliable.

<2> The Staff agrees that there is industry experience at selecting sample rates, both within the nuclear industry and other process-related industries. This experience covers many successes in sample rate and computer wordlength selection, but also contains some failures, such as those mentioned in draft NUREG-1709.

One intent of draft NUREG-1709 is to address the inconsistency among nuclear vendors and utilities concerning sample rate selection. In many cases, sample rates are selected as a best guess, and then the system is tested to see if adequate performance is met. For systems that have little impact on plant safety, this sample rate selection process may be acceptable. However, there is a engineering process to sample rate selection, which is based on engineering principles. In order for the Staff to gain adequate confidence in digital systems (particularly safety systems), it is important to use technically sound engineering processes to demonstrate the quality and reliability of such systems. The mathematical procedures outlined in the draft NUREG provide technical information to the NRC staff on various sample rate selection techniques. If technically sound engineering methods are used in sample rate selection, then there is no need for additional validation. Draft NUREG-1709 will be modified to discuss the background for its development.

As mentioned in an earlier comment, sample rate selection is influenced, not only by the digital equipment, but by the frequency content of the analog signal. Therefore, experience in one application may not be directly transferable to another application. In nuclear safety systems, the allowable aliasing error, type of anti-aliasing filter, and frequency spectrum of the input signal are needed to calculate the sample rate. The allowable aliasing error and anti-aliasing filter are easily obtained information from setpoint calculation and the equipment vendor. In many cases the nuclear vendor or plant would have information on the frequency spectrum of the analog input signal. If the frequency spectrum data is not available from those sources, it could be calculated from thermohydraulic code models or plant simulators, as mentioned in Appendix D of draft NUREG-1709. While the use of engineering techniques for sample rate selection does pose additional effort, it should not impose an undue burden that is above the expected effort for developing and installing digital systems.

Proposed Revisions

Revise the document to add Section 1.2, "Purpose."

> The motivation of this report is to address the inconsistency concerning sample rate and computer wordlength selection. In past reviews, the NRC Staff has encountered various techniques and methodologies for sample rate selection; some having little technical bases. In state-of-the-practice digital design, there are processes for sample rate selection based on engineering principles. For the NRC staff to gain adequate confidence in the safety of digital systems, it is important to use technically sound engineering processes to demonstrate the quality and reliability of such systems. The purpose of this document is to outline those engineering processes.

II **"No additional mathematical analysis or modeling should be recommended to demonstrate worst case transient compliance with signal compatibility if the EMI/RFI and noise analysis has been completed for the system. These analyses will envelop plant conditions for normal operation and transients."** <1>

"The draft NUREG-1709 may require some extensive modeling to obtain representation of signal spectrums during worst case transients. Many of the concerns implicit in the NUREG-1709 emanated from early problems as digital systems were first introduced to the power plant. These resulted primarily from early digital systems that used 8-Bit technology, which created large steps in the end signal to the driven components. With advances in technology, modern systems available to us now use much higher resolution and very fast processor speeds that create very fine control signals."

"For Safety Related systems, several vendors are in process with the NRC to obtain Safety Evaluations (SEs) on their entire product lines to qualify them for Safety Related applications. The issues addressed in this NUREG-1709 should be covered at the vendor level during the SE process with the NRC. Following the guidance in Draft NUREG-1709 will necessitate that we obtain detailed vendor design information to provide written evidence of the consideration of all the “Review Guidelines” in our design process. It will also result in performing additional calculations or even modeling to demonstrate signal frequency spectrums that would be obtained in the worst case transients for Safety Related functions." <2>

Technical Response

<1> While meeting EMI/RFI susceptability guidelines for input signal lines assists in minimizing aliased high frequencies, the Staff does not agree that it totally addresses the potential for aliasing. One practice for reducing EMI/RFI susceptability is to place low-pass filters on input signal lines. As such, the cutoff frequency of the filters would need to be coordinated with the sample rate such that the process signal frequencies are sampled with accuracy and high frequencies are attenuated. EMI/RFI susceptability tests on input signal lines may capture gross failures due to aliasing, but depending on how the tests are carried out, it would likely be unable to capture moderate amounts aliasing. Such aliasing could have appreciable impact on setpoint accuracy in safety systems.

<2> The Staff agrees that vendors can provide much assistance in supporting sample rate selection. For example, the vendor should provide information on the type of A/D converter (along with its error specifications), anti-aliasing filters, and any other components that impact the sample rate and computer wordlength. However, it is important to realize that sample rate and computer wordlength selection is also affected by the application in which the digital I&C system is placed. Some vendors and contractors may be able to identify the frequency spectrum of the input analog signals and assist utilities in sample rate selection.

It is important to obtain the worst-case transients for safety system functions for sample rate selection. The worst-case transients represent the sharpest changes that would be experienced of plant variables. As a result of the sharp changes, the worst-case transients contain the largest amount of high frequency information the plant variable can express. When selecting a sample rate, it is important to capture the high frequency information related to the plant variable, but reject the high frequencies that arise from process and electrical noise. This is the reason for obtaining the frequency spectrum of the worst-case transient. If it is difficult to obtain the frequency spectrum of the worst-case transient, a representative transient signal that would envelop the worst-case transient could be used to obtain the necessary frequency spectrum. Explanation for using the worst-case transient will be expanded upon in draft NUREG-1709.

Proposed Revisions

Revise the discussion of "Sample Rate Selection Techniques" in Section 3.3 to add the following paragraph.

> Sample rate selection is dependent upon the input signal properties. For safety systems, it is important to obtain frequency information on the worst-case transients for sample rate selection. The worst-case transients represent the sharpest changes that would be experienced from plant variables. As a result of the sharp changes, the worst-case transients contain the largest amount of high frequency information the plant variable can express. When selecting a sample rate, it is important to capture the high frequency information related to the plant variable, but reject the high frequencies that arise from process and electrical noise. For this reason, it is best to use the frequency spectrums of the worst-case transients in the sample rate selection process. Techniques for obtaining the frequency spectrum of a signal are provided in Appendix D.

Revise the discussion of "Analytical Calculations" in Appendix D to read as the following.

> Another method to estimate the frequency spectrum of a plant signal is through analytical means. As with simulations, analytical calculations have the advantage of separating the frequency range of interest from unwanted noise. If the largest rate of change is known for a plant signal, it is possible to fabricate an artificial signal that envelopes that rate of change, and calculate the frequency spectrum of the artificial signal. Again, it is necessary to add the signal and noise frequency spectrums together to arrive at a true picture of the actual plant signal. Many control system design techniques use analytical calculations to determine the sample rate.

3. RESPONSES TO COMMENTS ON CHAPTER 3, "SAMPLE RATE SELECTION"

Submitted Comments

II **"Accuracy and uncertainty calculations should be required only for those systems currently requiring accuracy and uncertainty calculations.**"

"The draft NUREG-1709 Review Guideline (RG) 1 allows a sliding scale of application "as safety significance decreases," for the strict application of this guideline which asks for accuracy/uncertainty calculations. This will allow the reviewer undefined latitude to request calculations of uncertainty for applications that previously would not have required such calculations."

Technical Response

Changes will be made to RG #1 to state that accuracy and uncertainty calculations are required only for those systems currently requiring accuracy and uncertainty calculations.

Proposed Revisions

Revise Review Guideline #1 to name it Design Consideration (DC) #1 and read as follows.

> DC1: The A/D converter's least significant bit (LSB), linearity, offset, and gain error are potential sources of signal error.

II **"Similarly, error calculations should be required only for those systems currently requiring error calculations."**

"Draft NUREG-1709 RG3 also allows a sliding scale of application "as safety significance decreases," for the strict application of this guideline which asks for error calculations. RG3 should also only be applicable to systems currently requiring error calculations."

Technical Response

Changes will be made to RG #3 to state that error calculations are required only for those systems currently requiring error calculations.

Proposed Revisions

Revise Review Guideline #3 to name it DC#3 and read as follows.

> DC3: Accuracy of input signals is affected by the level of aliasing.

4. RESPONSES TO COMMENTS ON CHAPTER 4, "COMPUTER WORDLENGTH SELECTION"

Submitted Comments

I **"Round off errors, Section 4.2.2, should be addressed."**

"Section 4.2.2 should note that significant round off error can occur when doing addition and subtraction with floating point numbers when the operands differ in magnitude."

Technical Response

Section 4.2.2 will be modified to discuss floating point round-off error when operands differ significantly in magnitude.

Proposed Revisions

Revise the discussion of "Floating-point Arithmetic" in Section 4.2.2, fourth paragraph to read as follows.

> While high precision is obtainable by floating-point arithmetic, design. When the coefficients are placed into the digital I&C system, truncation or round-off of the coefficients may occur, potentially degrading system performance. This type of error is more likely to occur if the system uses complex algorithms. there are two precautions. First, floating-point arithmetic can suffer from truncation and round-off errors like fixed-point arithmetic, particularly if there is a large magnitude difference between two operands. These errors become more apparent as the number of bits for storing the mantissa decreases.