ELECTRIC POWER RESEARCH INSTITUTE

Assessment of Electromagnetic Interference Events in Nuclear Power Plants

Reported to INPO 1975 to 2011

2011 TECHNICAL REPORT

Assessment of Electromagnetic Interference Events in Nuclear Power Plants

Reported to INPO: 1975 to 2011

This document does NOT meet the requirements of 10CFR50 Appendix B, 10CFR Part 21, ANSI N45.2-1977 and/or the intent of ISO-9001 (1994)

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1022984
Final Report, December 2011

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NOTE

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Acknowledgments

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This report describes research sponsored by EPRI. EPRI would like to acknowledge the support of the utility funders of the EPRI Nuclear Instrumentation and Control Program.

This publication is a corporate document that should be cited in the literature in the following manner:

Assessment of Electromagnetic Interference Events in Nuclear Power Plants, Reported to INPO: 1975 to 2011.
EPRI, Palo Alto, CA: 2011.
1022984.

Product Description

This report presents a study and analysis of reported electromagnetic interference– (EMI-) related incidents in nuclear power plants. These incidents were gathered primarily from the total body of incidents reported to the Institute of Nuclear Power Operations (INPO) database, with a few incidents coming from U.S. Nuclear Regulatory Commission (NRC) reports. This report analyzes trends and common factors in these events. The analysis is intended to inform the estimation of risk from EMI and offer suggestions on how that risk can be further mitigated from current levels.

Background

Since at least the 1970s, EMI incidents have been reported in nuclear power plants. INPO has, from its creation in 1979, collected records of plant operating experiences, which include accounts of EMI incidents that have affected plants. This body of EMI-related events is the focus of this report.

In 1983, the NRC issued an information notice to plant operators, alerting them to the potential for EMI to become more common with the increasing use of newer electronic technologies. In 1994, the Electric Power Research Institute (EPRI) issued *Guidelines for Electromagnetic Interference Testing in Power Plants: Revision 1* (TR-102323-R1), providing guidance for electromagnetic compatibility (EMC) in nuclear plants. In 2000, the NRC issued Regulatory Guide 1.180, which referenced EPRI TR-102323. These and related actions created a conformity assessment system, intended to ensure that EMC protection of nuclear plants is adequate. This report presents feedback on how this composite system is performing.

Objectives

This report seeks to identify, collect, and analyze the EMI-related incidents in an effort to understand the level and trends in these events. Beyond trends, the analysis probes the causal factors of the events. The fundamental physics of the events is studied with the objective of using an improved understanding of the physics of interference for evaluating the range of mitigations that are possible.

Approach

The report begins with a review of the EMI-related incidents that were identified in the INPO database searches performed by EPRI. Trends are identified and groups of events with common factors analyzed.

Following the event analysis, trends in both EMC engineering and risk management are reviewed. The interactive impacts of developments in both the discipline of EMC and risk management are explored. Both EMC and risk management have and continue to undergo significant development. The understanding of EMI-related interference events changes with the developing sophistication of these disciplines. From their interactions and identifiable direction, the future for control of interference events is projected.

Results

The number of EMI-related interference events has been increasing over the past 20 years. The report describes many explanations for this.

Applications, Value, and Use

The analysis presented in this report provides a basis for system improvement and industrywide reduction of interference events. In the end, the goal being sought is improved risk management and a significant advancement in containment of EMI-related risks.

Keywords

Electromagnetic compatibility (EMC)
Electromagnetic interference (EMI)
Electrostatic discharge (ESD)
Lightning
Radio frequency interference (RFI)
Risk management

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Section 1: Introduction

In response to it member utilities who either own or operate nuclear power plants, the EPRI Nuclear Sector begin to address electromagnetic interference (EMI) problems, issues, and concerns for these plants in 1990. EPRI has published a number of guidance documents on the following primary subjects on EMI for these plants:

- Survey mapping of selected areas of electromagnetic fields in plants
- Point-of-installation measurement and recording of radiated and conducted emissions in support of specific digital upgrade projects
- Testing of instrumentation and control (I&C) equipment for digital upgrades in existing plants
- Digital upgrades (with mention of the importance of electromagnetic compatibility (EMC) and EMI for upgrade programs)
- Use of existing EMC industry standards promulgated by various standards bodies including the International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE) as well as military standards produced for the United States Military and regulatory guidance produced by the Nuclear Regulatory Commission (NRC)
- Application of specific EMC tests such as the well-known *CS114 – Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz* published in MIL-STD 461 series documents.

The series of reports that have been published over the past 21 years have established a firm foundation to begin understanding, identifying, and controlling EMI problems in nuclear power plants. This foundation is spawning new research in the areas of EMC, radio-frequency interference (RFI), and EMI for these plants. This is critical to the continued operation of the existing fleet of plants over the next several decades. One of the areas of research presently undertaken is the analysis of past EMI-related events that have occurred in these plants and have been reported to the Institute of Nuclear Power Operations (INPO). Much can be learned about understanding, identifying, solving, and preventing these events by analyzing them. This is the subject of Rev. 0 of this report. And, because of the in-sight to better understanding and preventing EMI that this type of analysis provides to nuclear plant operations, the authors of this report recommend continued research in this area.

Section 2: Electromagnetic Interference Events in Nuclear Power Plants

The potential for electromagnetic energy to cause interference has been known for many decades. For nuclear power plants, efforts to appropriately manage this risk go back at least into the 1970's. In 1983 in the conclusion of Information Notice 83-83, the NRC stated:

> *To date, solid-state devices installed in nuclear power plants have been responsible for all of the known cases of radio-frequency interference (RFI) generated by portable radio transmitters. Three of the four examples cited in this Information Notice occurred during pre-operational testing or early in-plant operation.*
>
> *Many of the older nuclear power plants have so few solid-state devices that this explains their apparent invulnerability to RFI generated by portable radio transmitters. As newer plants are built that use more solid-state equipment and as older plants retrofit solid-state equipment, more cases of RFI by portable radio transmitters are likely to result.*[1]

In the early days, the isolated and controlled nature of plants and the nature of the electronics used in them provided a certain level of protection from electromagnetic disturbances. However, as the NRC Information Notice states the combination of increasing use of solid-state devices and the rising use of portable transmitting devices, e.g. walkie-talkies, man-made electromagnetic interference is a growing reality and concern.

What Causes EMI Events to Occur in Plants?

Interference occurs when three ingredients come together.

1. There must be a source of electromagnetic energy. It might be a portable transmitter, like a walkie-talkie or cell phone. However, it can also be a natural event like an electrostatic discharge or lightning strike. Oddly enough, it can also be a radiated pulse from the high-voltage igniter used to strike a failing high-pressure sodium lamp operated by a magnetic ballast in the plant.

[1] NRC IN 83-83, included as an annex to this report.

2. A coupling path must take the energy from the source to the receptor. The path may be radiated but the energy is often coupled onto a conducted media (e.g., a power conductor, signal conductor, plenum, pipe, piece of building steel, etc.), which then carries it to the receptor. Often there is a metallic structure connected to the source, which allows it to radiate its energy, and a second structure connected to the receptor that acts as a receiving antenna, applying the energy to the receptor.

3. Finally, there must be receptor (i.e., a piece of I&C equipment), a circuit that receives the energy and responds to it in an undesired way.

Without any of the three elements, interference will not occur. A variety of strategies have been developed over the years to deal with electromagnetic interference. Source suppression seeks to deal with electromagnetic energy at its source (This is the preferred method of EMI control, but not always possible to implement.), so that there is nothing to radiate or conduct to a receptor circuit. A variety of techniques, like specific types of filtering and shielding, seek to block or at least reduce the amount of electromagnetic energy which can be delivered to a receptor. Immunity design techniques, like decoupling and use of signal lines, designed as transmission lines, and multiple ground plants on a printed circuit board make receptor circuits more resistant to electromagnetic energy.

Recorded EMI Events

Table 2-1 lists 32 EMI-related events reported in the INPO database. Because these events are representative of the different types of events that have occurred in nuclear plants, these events were selected from the many events that EPRI downloaded from the INPO database for the EMI event analysis. These events have been sanitized to prevent identification of the nuclear plant where the event occurred.

Table 2-1
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
1	1997	Control board failed to operate on demand.	In the spring of 1997 while operating at 100% reactor power an intermediate range channel spiked up scale from approximately from 6.08 e - 4 amperes to approximately 6.85 e - 4 amperes. This spike lasted for approximately 5 - 10 seconds and has not reoccurred since that time. Instrument and control performed which checked the drawer power supplies for proper dc voltage output and AC ripple / noise. All power supplies were within specifications. A strip chart recorder was connected to the input and output of the channel's isolation amplifier in an attempt to determine the cause of the spiking. Cable and wire connections within the drawer were physically and visually inspected with no problems identified. During the evening when no testing was occurring, a sharp downward spike of very short duration was recorded at the output of the isolation amplifier with no change / spike at the input to the amplifier. The amplifier was replaced with a new amplifier from stock and the channel monitored for another day. During the course of the following day, the channel again spiked downward once as before and then returned to normal. The original isolation amplifier was re - installed and the recorder connected to monitor two (2) additional outputs from the isolation amplifier. No additional spikes were seen in any output from the amplifier for a period of 3 days. Discussions with operations, system engineer and I&C occurred and it was decided to return the channel to normal operation. Operator logs and the ppcs historical alarm log were checked to try to correlate the spikes to other plant operations. No common event could be attributed to any two spikes or events. One spike was close to an alarm received on r - 36, cr noble gas monitor and another occurred close to a reactor make-up. The exact cause of the initial up - scale spike and the other sharp down - scale spikes could not be determined and remains unresolved. Possible causes of the induced spikes could be from electromagnetic interferences (EMI) caused by the operation of plant equipment, electrical storms, ground loops, or Walkie-Talkie operation. None of the above could be directly attributed to this event. EMI has been a problem throughout the industry and remains an area of concern in relationship to instrumentation at this plant.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
2	2003	False reading on electronic dosimeter	Cellular telephone interference caused an unexpected dose rate alarm. Reason for Message: Identify the potential need to restrict use of cellular phones in areas where electronic dosimetry is in use. A truck driver received an unexpected electronic dosimeter (ED) dose rate alarm when he backed a shipment of new fuel into the Auxiliary Building. The Radiation Protection (RP) technician covering the fuel shipment observed 120 mr/hr on the ED. A survey of the area by the RP Technician did not identify elevated dose rates. The truck driver was carrying a cellular phone, which has been known to cause ED interference. Cause: The apparent cause of the dose rate alarm was interference caused by the cellular phone when it lost communication with the tower and activated a "roaming" signal. The cellular phone was tested for ED interference by placing the cellular phone next to the ED when the cellular phone was ringing. The ED indicated a false reading of 1 mr; therefore, the cellular phone was determined to be a cause of interference. Safety Significance: Significance is low in this event but, could cause confusion, delays and additional exposure in other circumstances. This event is NOT SIGNIFICANT because the elevated dose rate indication was easily shown to be false.
3	2006	Plant Trip	In the spring of 2006, this plant experienced a Reactor Trip as a result of a Turbine Trip at greater than 49% power (P-9). The turbine trip was created by a false turbine speed input to the electro-hydraulic control (EHC) system of greater than 103%. Investigation indicates stray EMI/RFI signals created the over-speed signal; however, the origin of the signals could not be determined. At the time of the event, this plant was generating 100% power. Plant and operating crew response was as expected. REASON FOR MESSAGE: This event highlights plant effects due to stray EMI/RFI signals.
4	2001	False reading on electronic dosimeter	In the fall of 2001, during this plant's refueling outage, workers reported receiving erroneous electronic dosimeter dose and dose rate alarms. A health physics (HP) investigation determined that, in each instance, radiological conditions were not abnormal and the alarms resulted from some other condition. Further investigation revealed that the workers were wearing radio frequency (RF) emitting devices, specifically cell phones. At the time the alarms occurred, the workers were using their cell phones near their electronic dosimeters.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
4 (cont.)	2001	False reading on electronic dosimeter	There were two electronic dosimeters involved in these events and cellular phones made by one manufacturer. A wireless office system (WOS) was put into service at this plant in September of 2000 in order to support the Unit 2 refueling outage, as well as assess the performance of the wireless communications system. The system operates with a specific brand of cellular phones. Approximately 100 phones were issued for use with the system and phone usage monitored. During the Unit 2 refueling outage, there were no reports of any dosimeter devices being affected by a cell phone. Since that time, the WOS was expanded and additional phones issued. During the Unit 1 refueling outage, phones were provided to personnel involved in refueling work activities in containment. With this increased usage, an increased number of dosimeter alarm events were reported. The electronic dosimeters were previously tested by health-physics personnel using cell phones; however, they were unable to cause a dosimeter alarm. Subsequent testing was performed by engineering, which resulted in the phone triggering a dosimeter unit into alarm. These alarms occurred only when the telephone antenna was less than 1 inch from or touching the battery compartment of the dosimeter. The use of a vibrating battery amplified the condition by causing a faster alarm response and higher dose and dose rate readings. The dosimeter manufacturer was contacted regarding the above condition. The manufacturer acknowledged the condition and indicated that a cracked case or a damaged electromagnetic interference (EMI) filter can cause such a condition. A damaged dosimeter would likely be more susceptible to EMI than an undamaged one. A test was performed using the cell phone to determine the conditions that could cause a dosimeter alarm. The phone was setup for a specific service operation, where it was expected that a higher than normal radio frequency (RF) output would occur. The test was performed by initiating a telephone call to a test cell phone. The cell phone display would indicate an incoming call and then generate an audible ringing tone. The test phone's antenna would be held near or touching the test dosimeter. After numerous attempts, electronic dosimeter alarm conditions were created when the antenna was held on or near the battery compartment located at the base of the dosimeter. Interviews with plant staff revealed that some workers might have been wearing their cell phones close to their dosimeters, and in a configuration where the antenna would be near or touching the base of the dosimeter. The condition could not be duplicated when holding the cell phone antenna 6 inches or more away from the dosimeter. When using a vibrating battery with the cell phone, the results were more dramatic. In these cases, the cell phone antenna appears to release a higher RF output, which in turn causes the dosimeter to go into the alarm state sooner and display higher dose rate and dose values. Based on testing performed by engineering and the nominal RF output rating of the two model cell phones, a policy was issued requiring workers to maintain at least a 6-inch distance between the cell phone and the electronic dosimeter. This event is Not Significant. Although the cellular phones caused invalid alarms and dose readings on the electronic dosimeters, there were no overexposures or other radiological problems because of the alarms. The dosimeters were affected in a conservative manner.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
5	2009	False readings in the control room	In the spring of 2009, an Operator inadvertently keyed his radio in the exciter switchgear room. The area was narrow, and the operator's radio was on his belt when it touched a protruding stud on the wall. The operator heard the beep from the radio being keyed and immediately turned to the alarm panel. He noted the alarms and proceeded immediately to the nearest telephone to inform the control room. The Control Room received an action, GENERATOR VOLTAGE REG TRANSFER TO MANUAL and another action, EXCITATION SWGR LOSS OF BACKUP. The transfer of the voltage regulator to manual had the potential to result in a plant transient. Operations verified the plant was stable and worked through the Main Generator off-normal procedure to restore the voltage regulator back in service.
6	2008	Not listed	In the fall of 2008, while this plant was returning Unit 2 to service after a refueling outage, what appeared to be a severe grid disturbance was experienced shortly after the Unit 2 main generator synchronized to the grid. At the time, Unit 1 was at full power (approximately 960 MW). The disturbance experienced, resulted in Unit 2 main generator current oscillations on the order of 3.5kA which is approximately 12 percent of full range for the main generator current capacity. Perturbations were also noticed in terms of the affected unit's kV output (typically 22.5kV) which oscillated approximately two percent. Also affected, was the MVAR output which oscillated approximately 40 percent of the minimum and maximum ranges. The event duration was six minutes. The disturbance self remedied after the time interval and Unit 2 was brought to full power output. This incident resulted in corrective action to identify the apparent cause of the disturbance. Efforts were made to identify issues that could have caused the event. No direct causes have been revealed for the event. During a recent refueling outage which commenced at this time of year at this plant, the previously described event was discussed with the field engineering office of a major equipment supplier. In particular, Plant Systems Engineering questioned the possibility of EMI/RFI interference causing the voltage regulator to oscillate in the manner as explained above. As part of the system functional testing that is routinely performed with Siemens during refueling outages, a 5-Watt walkie-talkie portable radio was brought to the vicinity of the voltage regulator to understand if EMI/RFI was able to impact the system. It was found that the EMI/RFI pickup caused the voltage regulator to oscillate in output voltage approximately 120VDC depending on the distance the portable radio was in respect to the voltage regulator. The portable radio was able to induce oscillations up to a 10 foot radial distance surrounding the voltage regulator. Distances within 2 feet of the voltage regulator's isolation transducers most drastically affected the system. The effect observed from EMI/RFI pickup was the ability to manipulate excitation to the main generator with the portable radio. The full range fluctuations observed at the voltage regulator equated to the ability of changing generator output over the entire range. It is not certain whether a previous event in the fall of 2008 was caused by EMI/RFI pickup; however, the data recorded during the system functional testing of the Unit One's voltage regulator closely mimicked the events that occurred during the disturbance on Unit 2.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
7	2000	False reading on electronic dosimeter	In the spring of 2000, at this plant, while reviewing dose reports to update the plan of the day report, radiation protection personnel noted a security officer had picked up 7 mrem. This appeared outside of the normally expected exposure, and the officer was contacted to find out the location of the post. The security officer reported noticing the electronic dosimeter (ED) dose at 3 mrem while using a personal cell phone. When using the cell phone again, the ED dose went from 3 to 4 then to 7 mrem. A radiation survey showed that the post, located on the cooling tower roof, had an area dose rate less than 0.1 mrem/hr. The electronic dosimeter (ED) involved in this event was a specific model. The electronic dosimeter (ED) and the cell phone used by the individual were placed back together in an effort to reproduce the condition. The combination did not cause the ED to record any exposure; therefore, the cause of the malfunctioning ED was indeterminate. However, cell phone interference with certain other electronic equipment has been recognized and documented by the manufacturer industry-wide. These incidents are not frequent occurrences. The liability of the interference has been weighed against the overall benefits of the electronic dosimeter and is considered an acceptable risk. This event is NOT SIGNIFICANT because the security officer did not receive an excess radiation dose.
8	2000	False reading on electronic dosimeter	In the winter of 2000, with this plant at approximately 100 percent power, an equipment operator heard his electronic dosimeter (ED) sound a rate alarm when in close proximity to his digital cellular phone. The operator was in the operations break room with his ED on a lanyard around his neck and his cellular phone in his shirt breast pocket. When he leaned forward, the ED and phone came in contact, causing a rate alarm. The ED indicated a maximum of 400 mrem/hr dose rate and a maximum accumulated dose of 3-4 mrem. When the dosimeter was moved away from the phone, the rate would drop back down to zero. The operator brought the phone and the dosimeter to the health physics office and reported the phenomenon. The apparent cause of this event was the digital cellular phone signal. The event could be recreated with different dosimeters. The phenomenon occurs with the phone in the ready mode (no call in progress) and does not appear to increase the integrated dose on the ED. The vendor was notified of the event. This event is NOT SIGNIFICANT because no actual increase in dose actually occurred and the operator involved was made aware of the inaccurate dose rate by the ED alarm function mode.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
9	2005	Instrument model failure	The ATTS Trip Unit, LOW PRESSURE VESSEL, was found in a failed condition with the Gross Failure light lit and the instrument indicating downscale. The failure of the unit was detected by annunciation, ECCS/RPS Division 1 Trouble. Investigation into this problem was performed per a specific work order. Investigation included monitoring the output of a specific transmitter. Using a specific calibration procedure, I&C removed the transmitter from service. I&C found the positive leg EMI filter shorted to housing which caused all power supply current to go to ground and bypass the transmitter. Based on markings on the EMI filter and disassembly of one of the filters by I&C personnel, the EMI filter is comprised of a coil and capacitor inside a housing which is filled with an epoxy. Why was vessel in a failed condition with the Gross Failure light lit and the instrument indicating downscale? It was indicating downscale due to having no voltage signal from the transmitter. Why was no voltage signal received from the transmitter? A short was found in the positive leg of the EMI filter, which is a part of the transmitter. Since this apparent cause was performed for an equipment failure, the additional issues considered IAW the apparent cause determination guideline are as follows: Barriers that should have prevented the event or should be used to preclude future events. The most likely cause of the short in the EMI filter is shorting of a capacitor internal to the EMI filter. Per the EPRI technical report TR-112175, Capacitor Application and Maintenance Guide, pg 2-9, text books and manufacturers typically state that short circuits are the most common failure mode during the period of useful life, caused by random breakdown of the dielectric materials under operating stress. The EMI filter has been in service since initial installation around the mid to late 1980's or just under 20 years. The rated life could not be obtained from the available documentation on the EMI filters. There are about 125 MPLs linked to the corresponding stock number in (name of a parts management software) and about 90 other Unit 1 MPLs listed on a specific drawing for a total of 215 EMI filter assembly installations. Each assembly has two filters. Based on the number of installed EMI filters and the absence of similar recent failures, it is not expected that this failure is a result of design or application or that the EMI filters have reached the wear out period. Based on a walk down of the area, the environment, including temperature, humidity, atmospheric pressure and vibration, is not expected to have been a factor in the failure of this EMI filter. Per TR-112175, pg 2-9, after a capacitor is installed and operating within its rated parameters, the failure rate tends to be low for several years. Random failures should rarely occur for many years of operation, unless application conditions are severe. Per walk down observations, the application condition is not severe. It is possible that this failure was the first to occur in the wear out period; however, at this time, due to absence of other failures, this failure is considered to have occurred as a random failure during the useful life of the EMI filter with no apparent degradation indicators; therefore, no barriers are applicable.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
9 (cont.)	2005	Instrument model failure	Damage due to environmental conditions. Based on the location of the EMI filter and walk down conducted in the spring of 2005, no environmental conditions were identified that could have contributed to the equipment failure. Inadequate preventive maintenance including type and frequency. No preventive maintenance recommendations were found in the associated manuals or through OE review that would be applicable to a random breakdown of the dielectric materials during the useful life of the EMI filter. This is the only known occurrence of this type of failure. Multiple failures of this type would indicate that the EMI filters have reached the "wear out period." **Aging issues** No aging issues such as thermal or mechanical exposures were identified that could have contributed to this equipment failure. This EMI filter was replaced without recurrence; thus, electrical stresses are not considered to have contributed to the cause. Discussion with equipment reliability program knowledgeable individual(s) to consider why this program did not prevent the failure. Neither preventive maintenance nor monitoring is applicable for a random breakdown of the dielectric materials during the useful life of the EMI filter. What other components are susceptible to this failure mechanism; what is the extent of this condition? EMI filters are used in various transmitters as stated above. A review of warehouse issues of the filters indicates that there are no other recent occurrences of this type of failure. This supports the conclusion that this failure was a result of random breakdown during the useful life of the EMI filter. The cause of the failure was end of life. The EMI filter was replaced without recurrence, which supports the conclusion that a malfunction elsewhere in the circuit, or capacitor failure due to an overload condition exceeding its rating was not a contributor. The most applicable cause code was Man-machine Interface or Equip Cond/Equipment Condition/Component aging. However, no aging issues were identified that contributed to the failure. Since the cause of failure was end of life and it is expected that the failure occurred prior to the wear out period, no other corrective or preventive actions are recommended as a result of the investigation of this failure.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
10	1999	False reading on electronic dosimeter	In the fall of 1999, a contract employee at this plant was wearing an electronic dosimeter on his belt adjacent to a cellular telephone. The dosimeter alarmed on high dose rate. The employee left the work area and checked to see that the alarming stopped. After a few minutes he returned to work and asked others in the area if their dosimeters had alarmed or showed a reading other than zero, which they had not. Later, his dosimeter alarmed again and he again left the area and the alarming stopped. He reentered the area and the dosimeter alarmed again. After being prompted by a regulator, he then went to the radiation protection (RP) office to discuss the issue with them. It was surmised that the alarm was false, caused by his phone, even though the phone was not being used, but in the "on" position. The RP personnel corrected the dosage to that which the contractor likely received (0 mr), based on other employees in the area and the actual dose rate in the area. Radiation worker training (RWT) contains requirements about wearing dosimetry on the chest and specifically not on your belt. It also addresses not keying radios or cell phones near a dosimeter which may cause alarms, and states to report to RP if dosimeter alarms occur. The contract worker was initially trained in RWT during Unit 2 refueling outage 4 This was his first experience as a radiation worker. The contractor returned 6 months later for Unit 1 refueling a previous outage, and no recurrent training was performed because initial training had been performed in the spring of 1999. The individual stated he did not recall the specific RWT requirements for donning the dosimetry or its use around cellular telephones or handsets. The station determined that the cause of the event was insufficient refresher training and a personal choice by the worker. This event is not significant because no dose was received. This event is NOTEWORTHY because the worker may have behaved in the same manner if an actual alarm had been received, and the individual could have been overexposed if he responded in similar manner. In addition, station radiation worker refresher training was not sufficient to reinforce radiation protection requirements.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
11	2002	Radiation warning from cellular phone	Abstract: In the late fall of 2002, at this plant, troubleshooting was being conducted in the main turbine electro-hydraulic control (EHC) panel in the main control room. A vendor, associated with a monitoring recorder used to monitor EHC electrical parameters, used his cell phone to contact his office. The recorder triggered on speed error signals being generated in the EHC panel. This was not just an impact on the recorder, but on the actual process signals. Steps were taken to prohibit use of personal cell phones in the control room. Description: In the late fall of 2002, troubleshooting was being conducted in the main turbine electro-hydraulic control (EHC) panel in the main control room. RBS has a specific system made by a large manufacturer. The panel doors were open with unshielded cable leads to a recorder for monitoring electrical signals. As part of reconfiguring recorder points, the vendor was brought on site for assistance. The vendor was periodically using his cell phone to contact his office for technical assistance. Three (3) different incidences occurred over a one hour period before it was recognized the cause was the cell phone. The first triggered a speed error signal. During the second incident, the deviation caused a main turbine bypass valve open alarm to be received and the main turbine backup speed amplifier out of saturation indicator light to come on. One of the bypass valves opened briefly about 11% but no change in reactor pressure was seen. On the third incident, the system engineer observed that the EHC signals displayed on the recorder were increasing as the vendor's cell phone came close to the panel. Causes: These particular incidents happened with a Nextel cell phone which can also operate as a two way radio. It is not known if the occurrence is specific to a phone manufacturer or to cell phones with two way radio capability. The site did testing in the MCR several years ago with certain company owned cell phones used for site communications. The major difference between the in-plant phone and commercial cell phones is the operating power. The in-plant phones operate in a range of 1 to 10 milliwatts whereas commercial cell phones operate in a range of 100 to 250 milliwatts. We have not experience any problems with the in-plant phones. One possible contributor to this is the type and power of the cell phone and the fact that the cabinet doors were open with unshielded leads from the control system to the recorder. The impact of cell phone usage is still under investigation. Corrective Actions: a. Steps have been taken to prohibit personal cell phones in the main control room and plant protected areas.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
12	2005	State change of safety injection bi-stable	In late spring of 2005, this plant's Unit 2 Control Room received an unexpected annunciator for "SG 2B STEAM PRESSURE LO ALERT." The associated Safety Injection bi-stable also changed state. This situation occurred again very shortly thereafter. Control Room personnel noted that the alarm occurred while radio transmissions were in progress with personnel in the Isolation Valve Cubicle; specifically, near the Main Steam lines. Investigation of the radio transmissions showed that the radio transceiver was activated within 6 inches of the main steam outlet pressure transmitter. No signs or other cautions were posted in the area to warn of radio effects. Such postings are present in critical areas, such as near protection cabinets, that can cause plant transients. Based on an EPRI document, TR-102323 Rev.3, an Electromagnetic Interference threshold for potential effects on electronic components is about 10 volts/meter. For example, the typical 3-watt radio transceiver will produce 9.5 volts/meter, resulting in a minimum separation distance of about 3 feet to essentially prevent interference. Plant experience also indicates this is a practical and effective general exclusion distance. Other effects such as component tolerances, cable locations, cable types, and shielding can affect component susceptibility. The EPRI document also recommends additional margin by lowering the threshold to 4 volts/meter to assure that no adverse effects will occur. This margin results in an effective exclusion distance of about 8 feet.
13	1989	Automatic reactor scram sensed by the Reactor Protection System (RPS)	In late spring of 1989, this plant's reactor was operating 100% power when an automatic reactor scram occurred upon an induced Average Power Range Monitor (APRM) upscale trip as sensed by the Reactor Protection System (RPS). Upon the RPS signal, all control rods fully inserted. Reactor level decreased as expected in response to vessel inventory void collapse, and was recovered using normal feedwater flow. As reactor level passed through the "low" water level set point, Primary Containment Isolation System (PCIS) Groups II-V isolated and the Standby Gas Treatment System (SGTS) initiated as expected. Reactor pressure remained within the normal band with the Electro-Hydraulic Control (EHC) System operating to control pressure. Operations personnel responded to the event and performed the immediate post-scram procedural actions. Some difficulties were experienced in feedwater level control during the scram recovery due to equipment problems. Reactor level increased above the high level set point and the feed pumps tripped as expected. Level reached 220 inches at 0021 hours before being reduced. Difficulties with level control continued, and approximately 38 minutes after the initial scram, at 0054 hours, an RPS trip and the expected PCIS and SGTS actuations occurred as the reactor water level approached the 170 inch above TAF low level set point. A low of 174 inches above TAF was reached. (Set points of low water level instruments are conservatively set higher than 170 inches above TAF). Operator action increased vessel level to the normal value of 190 inches above TAF within one minute. The shutdown then proceeded to a hot standby condition.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
14	1984	Automatic reactor scram sensed by the Reactor Protection System (RPS)	In late spring of 1984 while the reactor was in cold shutdown, channel number 3 neutron monitor experienced a radio-induced trip. Channel number 1 neutron monitor was out of service for repairs. The two out of three logic devices for the Reactor Protection System (RPS) trip were satisfied, resulting in a challenge to the EWS. No control rod drive movement occurred.
15	2006	Radio Frequency Interference (RFI) or Electro Magnetic Interference (EMI) from an unknown source	In the spring of 2006 this plant's Unit 1 reactor while at 100% power experienced a "first-our Overhead Alarm Turbine trip & P-9 (Reactor above 49% power) was received in the main control room with an immediate reactor trip. The reactor trip actions and plant recovery were performed without complications; however, two equipment issues were noted during the trip. The two issues were: (1) one control rod position indication for one of the shutdown rod indicated that the rod was at approximately 17 steps, and (2) reports from field operators (non-licensed personnel) indicated a leak on the condensate line at the suction of one of the Steam Generator Feedwater Pumps. Control room operators (Licensed personnel) initiated a Main Steam Line Isolation to isolate steam flow to the secondary plant and controlled Reactor Coolant system average temperature using the atmospheric dump valves. The leak on the condensate line was due to the momentary secondary system pressure perturbation that caused a flange gasket to fail. The report appears to offer two possible explanations of the event. In one place it reports: "The erroneous ISCI position indication was the result of residual magnetic flux in the individual rod position indicator coil that induced a voltage on the secondary side of the coil. The secondary coil voltage is used to provide the relative rod position and as such any error introduced will directly affect the rod position indication. The rod position indication would have eventually decreased to indicate full insertion through natural decay of the residual magnetic flux. De-energizing the individual rod position indication system let the residual flux decay almost immediately. The individual position indicator was calibrated during the outage." However, later the report concludes, "The investigation team explored several possible failure methods which could have resulted in the turbine over-speed trip and determined that the most probable cause was Radio Frequency Interference (RFI) or Electro Magnetic Interference (EMI) by an unknown source."

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
16	1985	Radio Frequency Interference (RFI) from a portable radio transmitter	In the winter of 1985 during normal power operation, a safety injection signal, turbine trip, and reactor trip resulted from security personnel using a portable radio transmitter. The plant had previously established "no radio transmission" areas based on testing and analysis. However, during this event the metal cabinet doors to the main steam line pressure transmitters were open for temporary startup test connections. With the cabinet doors open, the pressure transmitters are susceptible to radio transmissions from greater distances. Unit 1 was surveyed for areas sensitive to RFI in the late spring of 1981, as recommended in a specific circular. At that time, all Unit 1 areas found susceptible to RFI was posted, and warnings of instrumentation susceptibility were added to general employee and security training. The cause of this event was an inadequate RFI survey performed by plant engineering personnel in late spring of 1981. The list of areas surveyed did not include at area around the steam line pressure transmitters; thus, there were no radio use warning signs posted in the area. The plant has expanded the boundaries of its "no radio transmission" areas to account for the longer distances needed to prevent spurious signals with the cabinet doors open.
17	1989	Reactor Scram	In the late spring of 1989, while at full power a Reactor Protection System (RPS) actuation and reactor scram occurred. Two flow transmitters which help to determine the Average Power Range Monitor upscale set point were affected by hand-held radio frequency interference. The Primary Treatment System initiated as expected on low level following void collapse. Some feedwater control problems during recovery resulted in vessel level approaching the low level set point thirty-eight minutes after the reactor scram. Due to conservative instrument set points, an RPS trip and the aforementioned safety systems were initiated. The root cause of the scram was Containment Isolation System Groups II through V isolated and the Standby Gas the unanticipated response of the flow transmitters to hand-held radio frequencies. The transmitters were in a low traffic area where radios are infrequently used. The root cause of the second low level event was inadequate preventive maintenance on a feedwater valve position indicator in the Control Room. A loose adjustment spring locknut on a feedwater valve pneumatic positioner also contributed. Corrective actions were to place further restrictions on hand-held radio use, shorten the calibration frequency of the position indicator, and require the use of a specific brand of bolt-nut glue when adjusting the pneumatic positioner.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
18	1992	Reactor Scram	In the late summer of 1992, with the plant operating at 100% power, an automatic reactor scram was initiated due to a perceived high average power range neutron flux level. The cause was a noise signal which affected the recirculation flow signals and reduced the flow-biased scram set point below the current operating power level. Reactor level lowered as expected below the low level trip set point in response to the scram and all required primary containment isolations were automatically initiated. Reactor level was promptly restored with normal feedwater flow. Corrective actions for the event include installation of circuit inductors on the effected flow transmitters and added restrictions on the use of potential noise signal sources.
19	1985	False indications	While in the shutdown mode, a scram signal was generated when one of the intermediate range monitors (IRMs) spiked HI-HI. Spurious walkie-talkie signals in an open IRM cabinet generated the false signals. Maintenance personnel were instructed to close the cabinet doors and stop work. A modification was initiated to move the walkie-talkie repeater antenna away from the cabinets.
20	1984	False indications	In the early spring of 1984, while in refueling, at a time when the instrument maintenance department had a preamplifier door open, a scram signal was received from one of the intermediate range monitors (IRMs). RF signals of unknown source had entered the cabinet. The temporary corrective action was to close the cabinet door. The source of the signal was later determined to be a walkie-talkie repeater antenna, which was moved to another location.
21	1980	False indications	In the early winter of 1980, this plant lost offsite power to its 4160V non-safeguards buses. Since the system used for internal communications, paging and evacuation alarm purposes was powered from a non-safeguards bus, plant communications were degraded during the outage. This degraded condition persisted until power was restored to the affected bus thru an emergency safeguards bus. While in the degraded mode, the licensee used two-way portable radios for internal communications. The radios performed satisfactorily, per se; however, when transmitting in the vicinity of certain electronic equipment, they induced false signals into the electronic equipment.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
22	1988	Initiation of high-pressure core spray system and emergency generator	In the fall of 1988, the High Pressure Core Spray (HPCS) system (EIIS system code: BG) and the HPCS emergency diesel generator (EIIS system code: EK) automatically initiated when an operator keyed a radio in the vicinity of the low level instrument transmitters. The plant was operating at 100 percent reactor power at the time of the incident. An operator had keyed a portable radio on the 139 foot elevation of the containment, while walking past the instrument rack containing the channel 'C' and 'G' transmitters. Subsequent testing confirmed that a radio keyed at close range could cause current fluctuations sufficient to trip the transmitters. The operator had attempted to contact the Control Room with his radio while in another area on the 139 foot elevation. He was unsuccessful and proceeded to the plant pager. He noticed that the transmitting indicator light on the hand-held radio was not on. He keyed the radio several times as a check as he passed by the instrument rack. The bulb on the radio had failed and the radio was actually transmitting. Radio use in this area was not restricted. The radio used was a specific model from a major manufacturer. Testing of different model radios on the night of the event indicated that this model radio caused adverse current fluctuations at a greater distance than the other model radios. Other model radios had to be placed directly adjacent to the transmitter rack to give large enough fluctuations to actuate the trip units. Current fluctuations were observed while keying this model radio as far as 4 feet from the level transmitters. This model radio used was shipped to the vendor for power setting verification and was found to be set at the normal power of 4 watts. There is minimal difference in the power settings and the frequency of the radios.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
23	2000	False reading on electronic dosimeter	Electronic Alarming Dosimeter (EAD) Response to Electromagnetic Interference (EMI). In the late spring of 2000, a security guard was outside the radiologically controlled area and received a call on his 800 MHz radio. When he responded to the call, he noted that his electronic dosimetry reading jumped from 0 mR to 18 mR. It was initially thought that the action of keying the external microphone for this radio had caused this response, but this could not be reproduced. It was noted however, that the antenna of the radio would cause spurious readings when the tip came within an inch of certain areas of the electronic dosimeter, notably the LCD display and the case directly adjacent to the detector. The distance required to cause the spurious response seemed to vary from dosimeter to dosimeter, some required the antenna to be in direct contact with the case before spurious counts were observed. In addition, another dosimeter was completely unaffected by the interference. The 800 MHz radio that caused the interference is a 3-watt unit from a major radio manufacturer. A representative of another utility who uses this dosimeter type was contacted and he stated that their 1-watt (400 MHz) radios did not cause this effect.
24	2000	False reading electronic dosimeter	Microwave Ovens Cause False Dose Accumulation on Electronic Dosimeters A radworker wearing a dosimeter accumulated one mrem of exposure while standing in front of a new consumer-grade microwave oven while it was operating. The ovens were taken out of service while tests were performed. A follow-up investigation with two of the dosimeters revealed that one of the dosimeters was sensitive to the operation of the microwave ovens when held within six inches of the front and top surfaces of the ovens. This dosimeter accumulated a dose of approximately 3,000 mrem in under one minute. The other dosimeter did not respond to the operation of the microwave ovens and none of the dosimeters responded to the operation of the other brand of ovens.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
25	2004	Automatic Feedwater Isolation System (AFIS) digital control modules experience a transient	In the winter of 2004, the Automatic Feedwater Isolation System (AFIS) digital control modules reacted to a major transient within the AFIS system. This transient caused the analog inputs to the system to show artificially low readings on both digital channels (redundant trains) and both steam headers. Simultaneously, an AFIS power supply showed an extreme dip in output voltage and two of the AFIS digital control modules powered by this power supply began rebooting after losing power. The entire transient lasted less than 5 seconds and the system returned to normal immediately afterwards. The only common point between both digital channels (redundant trains) and both steam headers is the ground bus within the AFIS cabinet. This cabinet is located in the Unit 2 cable room. The investigation found that welding activities were taking place on the 5th floor of the turbine building and that welding was occurring when the transient took place. Welding activities were stopped and an EMI expert visited the site to determine if EMI produced by the welding process may have affected nearby AFIS transmitter (analog) inputs. The EMI expert established that improper welding practices were being used. These improper practices were allowing large EMI fields to be produced during arc strikes. They were also allowing for unpredictable current flow paths through the structural steel of the turbine building. This current flow through the structural steel of the turbine building affected the ground bus of the AFIS cabinet and caused the digital control system, along with its analog inputs, to experience a significant voltage transient.
26	2004	False reading on electronic dosimeter	In early winter of 2004, a maintenance technician logged into Controlled Access Area at the central control point and realized that he had his personal cell phone on. When he turned the cell phone off, it caused his Direct Reading Dosimeter to go into a dose rate alarm (128mR/hr). The technician stopped, exited the control point and reported to radiation protection personnel at the control point station.
27	2005	False reading on electronic dosimeter	Recently released cell phones broadcast with more power than earlier models. Some models will broadcast a signal while they are in the OFF state, e.g. when an incoming call is received. Some models periodically broadcast a signal to the nearest tower, again while in the OFF state. The only way to disable this feature is to disconnect the battery. Previously, cell phones were allowed in the RCA when placed in OFF status

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
28	2000	False reading on electronic dosimeter	In mid-summer of 2000, during TIG welding operation one contract welder and one pipe fitter experienced dose rate and dose alarms on their dosimeters. The employees were performing TIG welding work on a ventilation duct. Their work location was inside a radiologically controlled area. The workers were logged in on a Radiation Work Permit and issued another dosimeter. The workers obtained their dosimeters at approximately 0800 and began work. Their dosimeters went in to alarm that morning. The workers exited the area and reported to the RP control point where the dosimeters were turned off and retained for evaluation. The dose indicated by the welder's dosimeter was 503 mrem and the dose indicated by the pipe fitter's dosimeter was 2660 mrem. Surveys of the work area indicated dose rates <0.1 mrem/hr. The dosimeter parameters were verified correct and an event history was run on each dosimeter. The events history time period was set to 1-minute intervals. The events history showed that from the time that the workers had logged in on their RWP no dose had been received until approximately mid-morning. At this time the dosimeter went into rate alarm, 2 seconds later dose alarm, 2 seconds later rate saturation, and 14 seconds later events history indicated "rate alarm ends". The vendor's Quality Assurance Manager was contacted concerning the problem with the dosimeter. The QA Manager indicated that the problem is caused by EMI/RF interference. He then forwarded a letter that was written in the winter of 2000. This letter indicated that the second model of dosimeter put into use far exceeds the ANSI/IEC recommendations for EMI/RFI interference. The letter also states that at a frequency range of 10 kHz to 1 GHz at a field Intensity of 200 V/m, 1 GHz to 4 GHz at a field intensity of 200 V/m, and 4 GHz to 10 GHz at a field intensity of 100 V/m no change in operation and no increase in dose was observed. The letter concludes that welding will typically produce field strengths of 500 to 1500 volts per meter in proximity to or on contact with the welding cable under certain conditions. A consultant recommends the following for newer model electronic dosimeters: "Wherever possible the dosimeter should not be placed in close proximity to the weld cable proper placement on the body / lanyard and attention to the proximity can greatly reduce the false dose / dose rate alarms." "Welder cable should avoid being coiled when in proximity to the dosimeter." "Welders should avoid placing the cable over the shoulder of the worker." On site testing of newer model dosimeters with an operating welding machine revealed that under normal conditions with welding cables uncoiled laying in a linear configuration, no affect was observed. When the welding cable was configured with a loop or coils in the line, the dosimeter would go into alarm when placed within close proximity of the bend. Dosimeters placed at one and two foot intervals from the loop had no adverse effect from the welding cable.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
29	2006	Plant trip	Follow-up to Event #15 CAUSES: The investigation team explored several possible failure methods which could have resulted in the turbine over-speed trip and determined that the most probable cause was Radio Frequency Interference (RFI). This event identified the vulnerability of the digital EHC system to EFI/RFI which was compounded by having the three channels of turbine over-speed routed together in the same cable tray in the plant. Efforts to pinpoint the exact initiating cause and location of the interference signals are continuing; however, due to the length of cable that is associated with this circuit and the transient nature of the interference, it may be difficult to determine the specific device and location that initiated the EMI/RFI.
30	2007	A radiosensitive temperature-indicating switch was actuated which isolated the RWCU system	In the late summer of 2007, a diagnostic test was in progress on the HPCI valve. The pre-job brief for the test included a discussion of the use of self-check, and questioning attitude during the performance of the test. Following the pre-job brief, two Electrical Maintenance (EM) Technicians proceeded to the HPCI room to set up equipment at the valve and two EM Technicians were dispatched to the MCC to install jumpers to support the test and communicate the breaker position to the Technicians at the valve. Upon arrival at the MCC the workers performed a two-minute drill per human performance readiness requirements. One technician left the area to obtain additional equipment while the other technician remained at the MCC to report the breaker position. When the breaker was opened to support the test, the technician at the breaker informed the workers at the valve of this action by transmitting the information using a radio. The technician did not observe that he was standing on a floor that was painted with orange and white stripes and labeled, "No Radio Use." A radiosensitive temperature-indicating switch in the area was actuated when the radio was keyed which isolated the RWCU system. A Shift Manager investigating the automatic isolation determined that the technician was using a radio in the posted, "No Radio Use," zone. The technicians did not recognize that they were in a "No Radio Use" zone.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
31	2010	False reading on electronic dosimeter	A pipefitter was stick welding on pipe supports in an underground tunnel when his personal electronic dosimeter alarmed for high dose rate. The tunnel was evacuated, and health physics personnel verified that there were no uncharacterized radiological conditions. The pipefitter was returned to work with a substitute (different model) dosimeter that was considered to be more resistant to EMI. On the next shift, another pipefitter performing similar stick welding also received a spurious dose rate alarm. The tunnel was again evacuated, and the area was confirmed to have no unusual or unknown radiation field. Health physics personnel returned the pipefitter to work with a pocket ion chamber (PIC), a more traditional approach for high EMI areas. No further spurious alarms occurred. Although not promoted as "EMI-proof," the vendor did state the substitute dosimeters would be more resistant to EMI. The main attraction of the better dosimeter was its improved compatibility with the plant's access control systems compared to the traditional dosimeters. The substitute dosimeters might be more EMI resistant than standard dosimeters but are still challenged in some situations such as stick welding.

Table 2-1 (continued)
EMI-related interference events occurring in nuclear power plants

#	Year	Impact	Event
32	2005	Water level indicator issued several half scram signals	The ATTS RPV WATER LEVEL 3 indicator generated several 'B' Channel half scram signals to be received. The investigation of this problem involved running a calibration of the ATTS circuit card, the transmitter, and the EMI filter. 1st Why Question: Why did the ATTS RPV WATER LEVEL 3 indicator generate several 'B' Channel half scram signals? The trip signal was received due to indicator receiving a water level signal that was below the trip set point. The ATTS RPV WATER LEVEL 3 indicator maintained this signal until the panel door to the transmitter was opened. When the panel door was opened the indicator went to reading normal reactor water level which agreed with the other 3 indicators. 2nd Why Question: Why did the water level indicator receive a reading below the trip set point? Through investigation it was determined that the cause of the faulty reading was due to an intermittent problem with the EMI filter. While completing the assigned work order, a calibration was done to determine if the problem was the transmitter or the EMI filter. The calibration did not give any indication that the transmitter nor the EMI filter had problems. I&C went on to replace the EMI filter per that work order, and a loop check was performed in order to justify operability. The old EMI filter was discarded before proper test could determine if it was the true cause. Due to the fact that the trip signal stopped when the panel door was opened and the EMI filter was discarded after replacement. Engineering could not confirm that the faulty level reading was attributed to an intermittent problem with the EMI filter. Based on the experience of I&C personnel working with similar instruments, the decision was made to replace the EMI filter. Since the problem did not recur following replacement of the EMI filter and successful performance of a loop check, it is the judgment of Engineering that the apparent cause for the false low level indication was due to an intermittent problem with the EMI filter.

Types of Events by Year

The number of EMI-related events shows an increase in frequency (i.e., how often they occur) over time as illustrated in Figure 2-1. Since 2000, there has been a steady rate of one to five events per year reported into the INPO system.

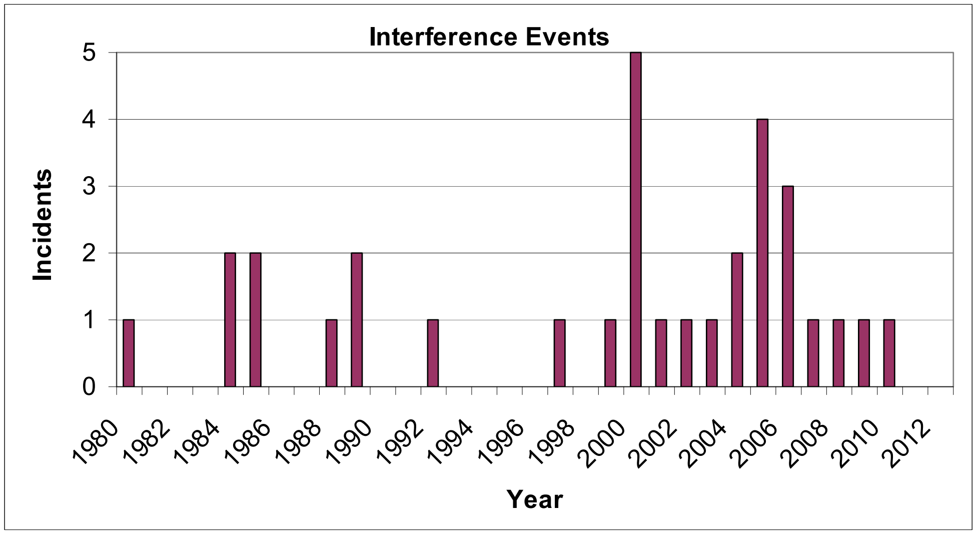

Figure 2-1
Base (Rev. 0) Analysis: Total EMI Related Events

Types of Events by I&C Equipment

Interference to instrumentation and control (I&C) systems is a major concern when evaluating the risk to plant operations from EMI. As Figure 2-2 shows, if anything the number of reported events has risen or at best stayed constant in recent years.

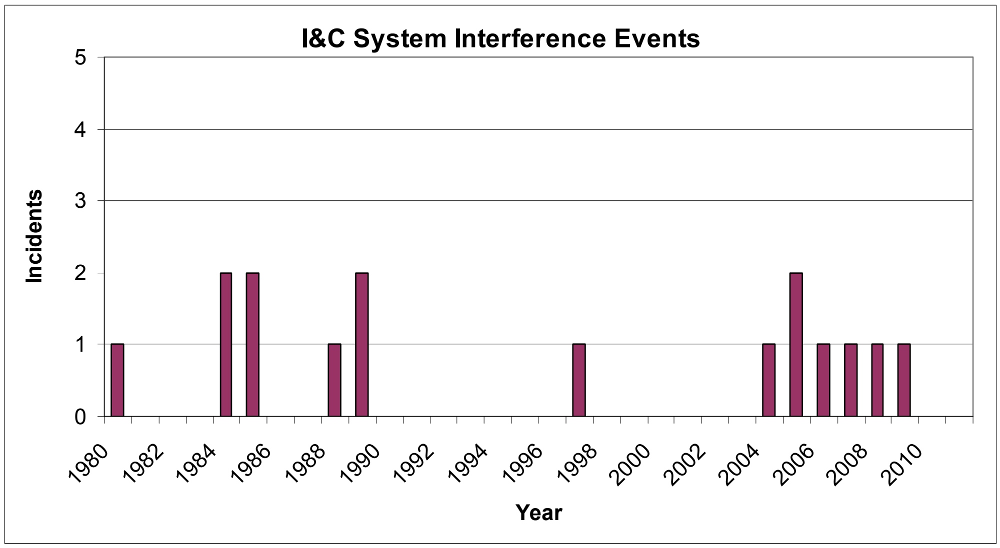

Figure 2-2
I&C System Interference Events

EHC System EMI Events

Because there have been multiple cases of interference to Electro Hydraulic Control (EHC) systems these were tracked separately, as shown in Figure 2-3, they are shown in addition to the I&C system interference events in Figure 2-2.

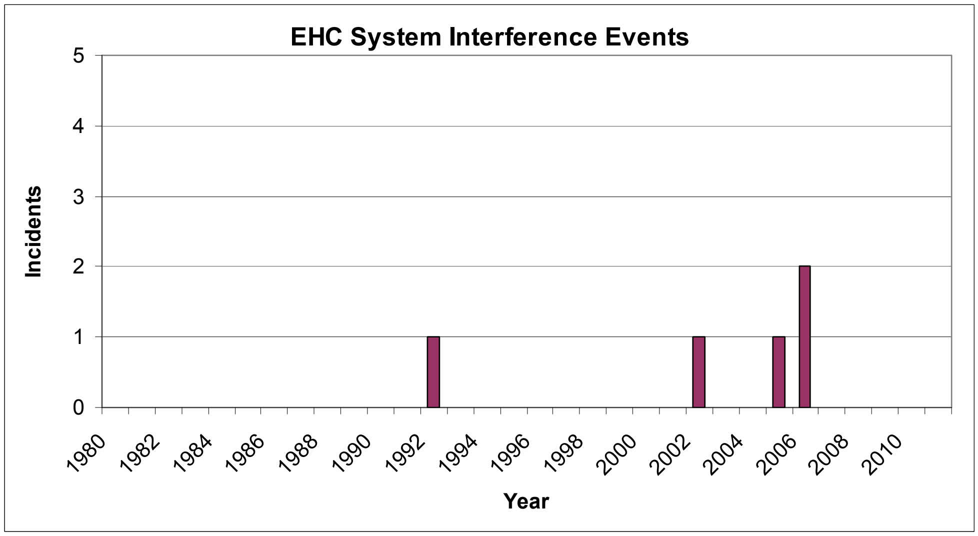

Figure 2-3
EHC System Interference Events

When a series of events occurs, as is the case with EHC systems, detailed EMC-related questions can and should be explored to fully understand the causes, continuing risk exposure and potential mitigations available.

Cabinet Doors Open

Having interference when the cabinet doors are open on I&C cabinets is a common pattern observed. In the winter of 1980, a set of interference incidents occurred at a nuclear power plant. At the time portable transmitters were being used because of problems with the wired telephone system. The portable radios were found to create false signals into the electronic equipment. NRC IE Circular 80-09 reports this incident specifically and gave the following advice (specifically number as in the circular):

> *3. Determine whether any plant electronic equipment may be adversely affected by portable radio transmissions. This determination should include, but no be limited to, the computer system, electro-hydraulic system, and nuclear instrumentation system; and*
>
> *4. Instruct employees on the use radios in areas susceptible to electromagnetic interference.*

Open cabinet doors is a common contributor observed in a set of interference incidents.

It is also noted that while the risk of interference from RF transmitters was known and exclusion zones have established as a protective measure for some time, in a number of cases the exclusion zone strategy was not effective.

In early spring of 1984 a walkie-talkie repeater at one nuclear plant caused interference and false indications when, during refueling, a cabinet door was open. The following year in the late spring of1985, an almost identical incident occurred a sister plant a walkie-talkie repeater again caused interference and false indications, generating a SCRAM signal, but the unit was already in shutdown mode, again, when the cabinet doors were open.

In mid-winter of 1985 at one unit at another nuclear plant during normal power operation, a safety injection signal, turbine trip, and reactor trip resulted from security personnel using a portable radio transmitter. The plant had previously established "no-radio-transmission" areas based on testing and analysis. However, during this event the metal cabinet doors to the main steam-line pressure transmitters were open for temporary startup test connections.

In the analysis of the 1985 incident at this plant, specific mention was made of the 1980 warning. It was stated that the recommended RF immunity survey was performed, but was flawed in that is missed the vulnerability experienced:

> *Unit 1 was surveyed for areas sensitive to RFI in the late spring of 1981, as recommended in IE Circular 80-09. At that time, all Unit 1 areas found susceptible to RFI were posted, and warnings of instrumentation susceptibility were added to general employee and security training. The cause of this event was an inadequate RFI survey performed by plant engineering personnel in that same month of 1981. The list of areas surveyed did not include at area around the steam line pressure transmitters; thus, there were no radio use warning signs posted in the area.*

Two observations are made here but discussed in greater detail later in this report in the context of analyzing the full EMC protection system. First, it is observed that open cabinet doors are a common component to these interference incidents. Second, while the risk of interference from RF transmitters was known and exclusion zones were established as a protective measure; in these cases the exclusion zone strategy was not effective.

As Figure 2-4 will illustrate, there are many levels at which EMC protection can be applied. At the most fundamental level EMC protection can be provided in components.

An example is in the design of the amplifier chips used in hearing aids. In the early 1990's these chips seldom had an RF immunity of more than 1 V/m. However, the introduction of second generation digital cell phones introduced widespread hearing aid interference. The chip designers were able to improve the immunity of these critical components by a factor of more than 100! Today, hearing aid amplifier chips typically have RF immunities of over 100 V/m. Similar improvements have been demonstrated in other industry sectors having previous EMI problems.

The next level above components is to build the EMC protection into the printed wiring boards (PWBs) and subassemblies. Such protection typically takes the form of well-designed ground systems and use of transmission line techniques on signal and control lines.

A third level of protection can be provided by the relative placement of subassemblies, routing of cables and internal shielding within a device. The forth level illustrated here is the shielding and filtering provided in the housing.

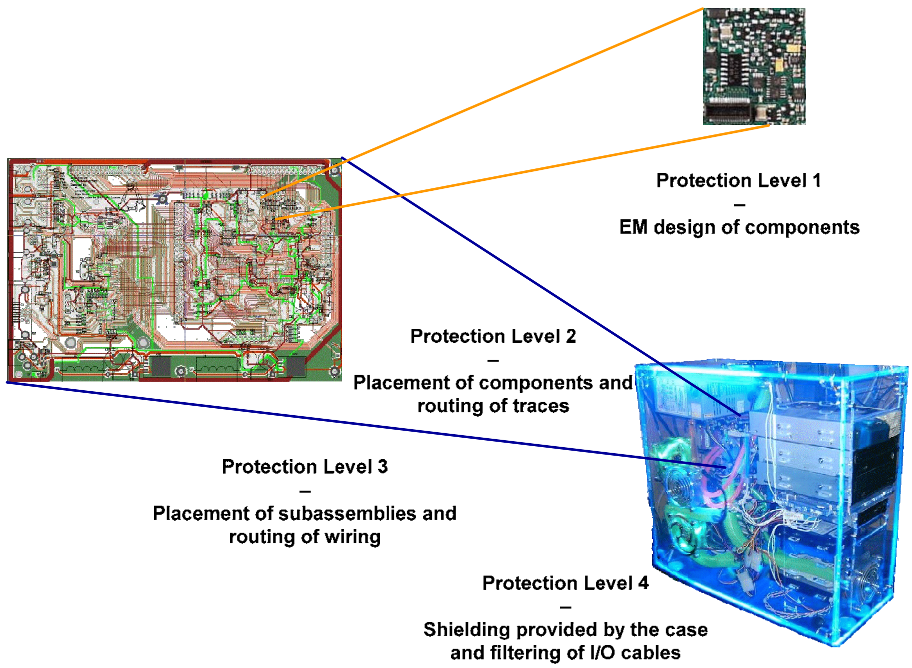

Figure 2-4
Depiction of Four EMC Control Levels

The incidents discussed in this section give the indication that all or most of the EMC protection was built into the forth protection level. When the cabinet doors are open, the protection is compromised and all protection is lost. However, this is not the only way that EMC protection can be provided. Examples of this are found in the sensitive microphones, GPS receivers and microprocessor circuits in cell phones themselves but also in laptops and tablet personal computers. These devices all have powerful cell phone transmitters built right into them, sometimes placing the RF power amplifier and antenna mere millimeters away from sensitive electronics. However, they do not suffer interference, the EMC protection is built into the components and PWB layout of these devices. Hence, the observation is made that the designers of the I&C systems that proved to be vulnerable in these reports, chose to place their EMC protection at a point which has proven to be problematic.

Common Failure Modes

In some, but not all cases, EMI presents a common failure mode. An incident at one nuclear-related facility reported that two adjacent recirculation flow transmitters gave false readings due to the same EMI event:

> *Four flow transmitters, located on two separate instrument racks, monitor core flow and provide signals to the APRM flow-biasing network. A mechanism which might disturb these transmitters' output was sought. Interviews with plant personnel determined that a radio signal had been transmitted at the time of the SCRAM in the vicinity of two of the flow transmitters. This signal came from a hand-held radio (walkie-talkie) in use by a utility employee during routine plant activities. Further review of the APRM flow biasing logic found that a change in the output signal of these two flow transmitters, if severe, could result in a reduction of the APRM upscale trip set points to below actual reactor power level.*

The reports of this incident also recorded:

> *Review of data indicated the output signal of two flow transmitters had spiked downward. The two instruments are located next to each other on an instrument rack. Several spikes were noted over a one-minute timeframe, beginning before and ending after the SCRAM. A detailed investigation was begun to locate the source of the interference. This investigation included instrument tubing walk-downs, extensive walkie-talkie radio testing, vibration tests, and several other potential signal sources were checked to determine if a noise spike could be induced. Additionally, electronics contractors were contacted for assistance in determining the source and suggesting potential corrective actions. The only credible source identified was external Radio Frequency (RF), although a specific RF emitter was not identified. Previous plant data was reviewed and no evidence was located to indicate the remaining six recirculation flow transmitters had ever been subjected to spurious noise signals.*

However, positively, as is reported, six other recirculation flow transmitters were sufficiently isolated that they were not impacted by this EMI event.

Another example occurred at another nuclear plant, when the EHC system falsely reported a generator speed of 103%, resulting in a plant trip:

> *Analysis of computer data shows all three turbine over-speed circuits simultaneously recognized an over-speed condition at 103% and tripped the main turbine as designed, though no actual over-speed condition existed at the time, (e.g., constant 1800 rpm as controlled by the grid).*
>
> …..
>
> *This event identified the vulnerability of the digital EHC system to EFI/RFI which was compounded by having the three channels of turbine over-speed routed together in the same cable tray in the plant.*

A follow-up report was filed giving information on additional investigation which was performed. That reports concludes:

> *This event revealed a vulnerability of the Digital Electro Hydraulic Control (DEHC) system to EMI/RFI that was compounded by having the three turbine speed signal wires routed together in the same cable through the plant.*

In this plant incident, all three over-speed circuits gave the same false reading, demonstrating the presence of a common failure condition.

A counter example is seen in an incident at another plant in which there was sufficient isolation, so that only one of three units gave false readings, allowing the two out of three logic to function as designed:

> *The two out of three logic for the Reactor Protection System (RPS) trip was satisfied, resulting in a challenge to the EWS. No control rod drive movement occurred.*

EMI can be a common failure mode, causing multiple false readings to occur simultaneously. Since the EMI was able to rise to levels to disrupt readings it can be assumed that at some higher, perhaps much higher level, hard damage would have been induced. Hence, instead of multiple false readings, these reports predict that multiple systems could be damaged from a common cause.

Dosimeter Interference

A number of cases of interference to dosimeters have been reported as illustrated in Figure 2-5.

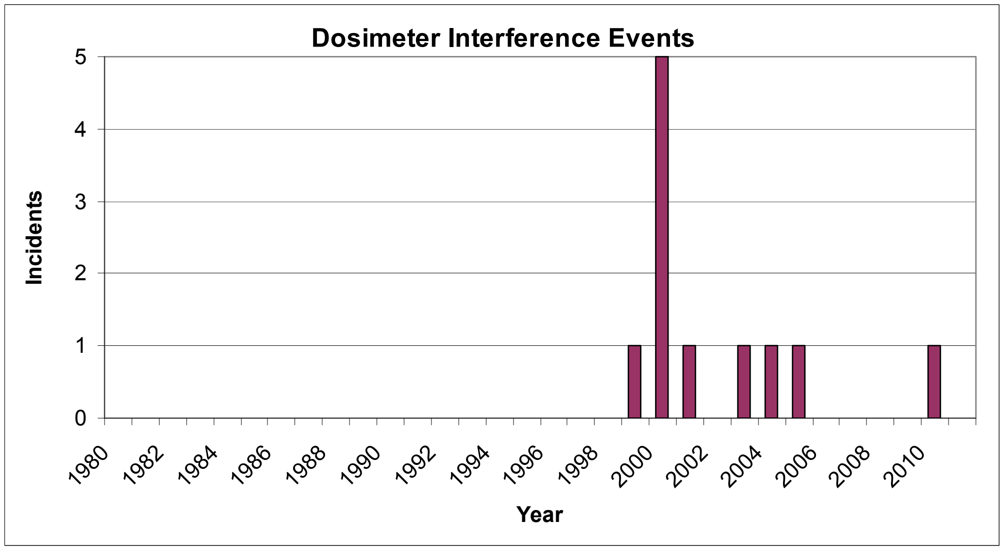

Figure 2-5
Dosimeter Interference Events

Most of the events involved two models from two different manufacturers. The most common source of interference was a portable radio or cell phone. The second most common source was from welding. One case of interference from a microwave over was reported.

It is perhaps noteworthy that the reports start and become common after 1999. It was in the mid-90's that second-generation cell phones came into widespread use. First-generation cellular phones used analog transmission, with a relatively constant carrier, modulated to carry the voice transmission. Second-generation devices encoded and transmitted a digitally encoded voice signal. Those digital protocols that used Time-Division Multiple-Access (TDMA) techniques were found to create a widespread interference. The amplitude variation in TDMA transmissions has been found to be particularly interfering. What has not been reported and may be of significant interest here is the degree to which the number of interference events is due to changes in communications protocol. Table 2-2 provides a list of OE events, quarter and year of event, event title (per the OE report) and a correlation regarding dosimeter manufacturer.

Table 2-2
Interference to electronic dosimeters

#	OE[2]	Quarter and Year	Event	Dosimeter[2]
1	OE1	1Q2000	Electronic Dosimeter Alarmed With a Rate Alarm When Brought Into Close Proximity of a Cellular Phone That was On	1
2	OE2	1Q2000	Electronic Dosimetry Alarmed Due to Cell Phone	1
3	OE3	2Q2000	Electronic Alarming Dosimeter (EAD) Response to Electromagnetic Interference (EMI)	2
4	OE4	2Q2000	Electronic Dosimetry and Cell Phone Interference	3
5	OE5	3Q2000	Erroneous dose rate and dose readings with the dosimeter were found to be caused by electro-magnetic interference during welding activities	4
6	OE6	4Q2000	Microwave Ovens Cause False Dose Accumulation on Electronic Dosimeters	3
7	OE7	3Q2001	Cell Phones Caused Electronic Dosimeters to Alarm	2
8	OE8	3Q2003	Cellular Phone Interference Causes an Unexpected Dose Rate Alarm	2
9	OE9	4Q2004	Cellular Phone Interference Causes an Unexpected Dose Rate Alarm	3
10	OE10	2Q2005	Station policy changed due to cell phone interference with dosimeters.	Not Provided
11	OE11	1Q2010	Spurious PED Dose Rate Alarms Induced by EMI from Stick Welding	5

[2] The specific OE number and dosimeter manufacturer are not shown to ensure sanitization of events.

In the analysis of two events examined in this report, the source of interference came from the electromagnetic fields produced by welding. The analysis from the dosimeter vendor was that the fields from the welding exceeded the immunity level of the dosimeter. In both cases, the dosimeter design had been tested and found to have a level of immunity at 200 V/m. The vendor stated that welding can produce fields of 500 V/m or more. That position is both reasonable and very likely correct. However, ending the analysis there fails to ask other very important questions. Among those questions:

- Did the units involved in fact have the same level of immunity as those originally tested?
- Is there evidence of significant manufacturing variance between units?
- Do the laboratory tests correlate to field experience, or could there be differences in the field situation that negatively impact the correlation?

Some of the dosimeter interference reports found significant variation in the immunity between individual dosimeters:

> *The distance required to cause the spurious response seemed to vary from dosimeter to dosimeter, some required the antenna to be in direct contact with the case before spurious counts were observed. In addition, another dosimeter was completely unaffected by the interference.*

It is potentially important to get some objective evidence of the variation in immunity between deployed units. It is common, once EMC becomes an intentional part of the design that the variation in immunity is reduced to what can reasonably be expected due to manufacturing variance. Designs, presumably such as those involved in early reports, may have very wide variance in immunity because the factors that impact immunity to EMI are not controlled in production. However, while it is usually the case that manufacturing variance in immunity improves with EMC being addressed as a design requirement, it is worth confirming this with some kind of objective evidence.

Another question that should be probed is whether the correlation from EMC laboratory testing to field experience is adequate. There is an unstated assumption in some of the reports that RF is RF. In fact, there are a number of variables at play and differences other than the raw RF amplitude can make dramatic differences in immunity performance. One of those variables is the modulation on the RF. EMC laboratory testing is typically done with a narrowband CW (carrier wave) signal modulated by 80% AM (amplitude modulation). This has been the standard operating procedure per the IEC 61000 series of standards, namely the radiated RF immunity standards. However, intentional radiators use much more complex types of modulation. With hearing aid interference it has been shown that there can be a difference of 20 to 30 dB in the interference caused by one kind of modulation versus another! If dosimeters have a similar response pattern, it may well be that some kinds of cell phones will be much more impacting than others.

Welding produces a very different waveform from what is used in EMC laboratory testing. The fields produced by welding are broadband, versus the narrowband signals used in laboratory testing. Welding also produces intensely impulsive signals whereas the laboratory tests typically are constantly on. It is worth exploring how well the laboratory test actually correlates to the very different fields produced by welding. At some level, designers design their fixes to pass a test. The test is the feedback to their design process. However, it may be that to provide good immunity to a broadband impulsive signal they should use different design techniques in the EMC design of their products. It is possible that the test is 'blinding them' to the consequences of the design choices they are making. These are questions which are worth exploring. If significant differences between laboratory test results and field experience are found, then improvements in the test methodology and design approach can be explored.

Lightning Events

Lightning is one of the most powerful, naturally occurring sources of electromagnetic interference. There are 45 lightning-related incidents reported in the INPO database, recognized in this base analysis. Lightning has the following characteristics:

- High power
- Wide geographic impact
- Wide spectrum energy distribution

Because of these characteristics, when lightning strikes close to a plant it tends to stress all the equipment in the plant over a wide range of frequencies. In some ways, lightning may be considered to be a broad spectrum plant-wide test. The vulnerabilities exposed by lightning could equally be excited by lower power, but more localized and frequency-specific sources. Hence, the lightning incidents are of interest both in their own right but also because they give insight to vulnerabilities that may not have been exposed by other sources of electromagnetic energy. Figure 2-6 illustrates the distribution of these 45 events from 1980 to present.

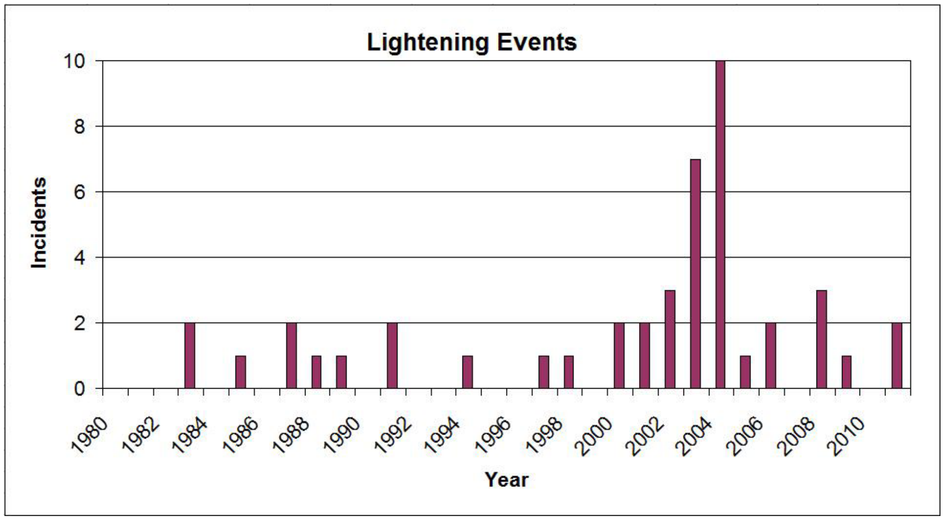

Figure 2-6
Base (Rev. 0) Analysis: Lightning Events by Year

Table 2-3 lists six example categorical lightning events of the 45 lightning events that were analyzed in this project. Additional events will be provided in the next level revision of this report.

Table 2-3
EMC-related lightning events occurring in nuclear power plants

#	Year	Impact	Event
1	2006	Failure of system resistance amplifier	Description: In mid-summer of 2006, the failure of all four (4) Unit One RCS cold leg wide range temperature channels during a thunderstorm with lightning strikes near the station. The reason for the resistance amplifier (NRA) circuit card failures was thought to be an electrical transient caused by the lightning strikes near the station. Causes: The cause of the failures is unknown. Failure analysis identified the failure of an operational amplifier on all four (4) circuit cards, but could not determine the failure mode. No visual arcing, scorch marks, or other damage was identified and all upstream and downstream components on the circuit cards were found to be operable. The circuit cards were manufactured in the early 1980s and had been installed in the plant for many years. Corrective Actions: The failed circuit cards were replaced and the loops calibrated to restore the loops. The circuit cards were sent out for failure analysis, but no cause for the Operating Amplifier failures was identified. Station will work with Corporate personnel to determine if surge protection can be applied to the plant control system to eliminate/reduce failures in the future. Safety Significance: The safety significance of the RCS cold leg wide range temperature channels failing, or spiking and returning to normal values at full reactor power are minimal. The channel signal goes to indicators, a computer point, Main Control Room recorders, alarms (RC Temperature Below Arm Low Temp Set Point and RC System Cold Press High), loop stop valve logic (which is de-energized in the open position during power operations), and Pressurizer Pressure Power Relief Valve (PORV) 'A'
2	2003	Inoperable wind speed indicator	In mid spring of 2003, a meteorology system review was performed on the wind speed indication using the keywords wind speed and lightning. This review found that over the past 2-1/2 years there have been five occasions where the wind speed indication was unavailable to Control Room personnel. Two events were due to the wind speed sensor freezing and three events were due to lightning damaging the wind speed sensors and/or blowing fuses. Reason for Message: The reason for this report is to alert plants that inadequately protected equipment is subject to voltage transients generated by lightning.

Table 2-3 (continued)
EMC-related lightning events occurring in nuclear power plants

#	Year	Impact	Event
2 (cont.)	2003	Inoperable wind speed indicator	Event Date: Late spring of 2003; Manufacturer Maintenance Rule Applicability: No Component Information (as applicable): Manufacturer: NA Model Number: NA Part Number: NA Description: In mid spring of 2003, a CR review was performed on the wind speed indication using the keywords wind speed and lightning. This review found that over the past 2-1/2 years there have been five occasions where the wind speed indication was unavailable (early winter of 2001 - frozen, late spring of 2001 - lightning, mid spring of 2002 - frozen, mid spring of 2003 - lightning, and mid spring of 2003 - lightning). Lightning has damaged Control Room chart recorders but not the computer points and in these cases wind speed indication was not lost because computer points provided the information. Frozen wind speed sensors have not been a problem since the vendor installed heaters for the wind speed sensors. This leaves voltage transients induced by lightning as the cause of the other failures. New paperless chart recorders installed for met tower indication were being damaged during severe lightning storms. In the spring of 2003, a modification was performed on the signal cables from the met tower that installed devices to suppress voltage transients that were caused during the storms. The modification included the installation of fuses, a device called "transient eliminator," and a metal oxide varistor (MOV) on the chart recorders. This was in addition to fuses and a transient eliminator previously installed by the vendor. Due to the nature of lightning, it is difficult to know if this mod provided an improved resistance to voltage transients. There have been many severe thunderstorms between in mid spring and mid summer of 2003 with only a few cases where the wind speed was lost. A failure rate of one sensor per two years would be a normal failure of met tower sensors due to lightning according to the vendor. This average was confirmed with two stations system engineers. One station still has an occasional failure with Control Room chart recorders due to lightning. The other station installed new updated equipment three years ago and has not seen any failures since. The vendor stated that there has been very little trouble with sites that have installed the new equipment. The vendor also recommended that if Byron is going to move toward a license extension that the met tower equipment would need to be upgraded. Options that were considered: * A lightning protection umbrella located on the top of the tower. * Adding another section to the top of the tower, moving the top of the tower (and the umbrella) further from the sensor height. * An analysis of the current tower grounding. * Moving the upper level meteorological equipment (250' wind speed sensor) to a lower point on the tower. * Upgrading the current meteorological monitoring equipment. * Evaluate the transient suppression between the met tower and the Control Room chart recorders for improvements. Causes: The apparent cause is due to inadequately protected equipment being damaged by lightning. Corrective Actions: Evaluate met tower grounding, improve signal cables response to voltage transients, and upgrade met tower equipment. Safety Significance: None Information This event is NOT SIGNIFICANT. Meteorological equipment is not safety-related equipment or required for reliable station operation. The failure rate is also low when compared to previous OE reports.

Table 2-3 (continued)
EMC-related lightning events occurring in nuclear power plants

#	Year	Impact	Event
3	1998	Instrument channels for level function inoperable	In mid summer of 1998, at approximately, control room annunciators and alarms were received due to nearby lightning strikes during severe thunderstorm activity. The lightning activity rendered two instrument channels (Channels 2 and 4) for the Unit 1 Refueling Water Storage Tank (RWST) level function inoperable. A few minutes later the unit entered Technical Specification (TS) 3.0.3. Unit 1 exited TS 3.0.3 at 2015 hours when one channel was restored to operable status and was verified to be operating properly. The second channel for Unit 1 was restored to operable status at 0553 two days later.
4	2003	Not Significant	In late summer of 2003, with both units at 100 percent power, an unplanned entry to Tech Spec 3.0.3 occurred due to Unit 2 Channels 1 & 3 of Refueling Water Storage Tank (FWST) Level failing high. Both channels were placed in bypass and power reduced to comply with the Tech Specs. The failure of both channels was due to lightning strikes. Reason for Message: To provide additional information concerning the previously posted LER event posted two week earlier both channels 1 and 3 of the Unit 2 FWST (Refueling Water Storage Tank) level instrumentation failed high due to a lightning strike. This placed Unit 2 in Tech Spec 3.0.3 action statement requiring the unit to be in mode 3 within 7 hours. The power reduction was started at 0830 hours and a NOED (Notice of Enforcement Discretion) was submitted to allow to continued operation for up to 48 hours to repair the level channels. NRC approved the NOED and later than morning power reduction was halted at 82 percent. Channel 1 of the level instrumentation was repaired and returned to service at a few hours later allowing the station to exit the Tech Spec action statement and return to full power. Causes: The failure of Unit 2, FWST Level Channels 1 & 3, was due to lightning. The reason only these channels failed due to lightning is not known. Corrective Actions: A root cause evaluation determined that the instrumentation was sensitive to the effects of lightning. The station plans to improve the grounding circuits and quality of ground connections. Safety Significance: This event is NOT SIGNIFICANT because there was no detectable damage and two of four remaining channels were available for monitoring tank level. The two remaining channels were also available for FWST / Emergency Sump automatic swap on low level.

Table 2-3 (continued)
EMC-related lightning events occurring in nuclear power plants

#	Year	Impact	Event
5	2003	Minimal Significance	At approximately 0800 hours in the mid summer of 2003, both channels 1 and 3 of the Unit 2 FWST (Refueling Water Storage Tank) level instrumentation failed high due to a lightning strike. This placed Unit 2 in Tech Spec 3.0.3 action statement requiring the unit to be in mode 3 within 7 hours. The power reduction was started at 0830 hours and a NOED (Notice of Enforcement Discretion) was submitted to allow to continued operation for up to 48 hours to repair the level channels. NRC approved the NOED and at 1115 hours the licensee halted power reduction at 82%. Channel 1 of the level instrumentation was repaired and returned to service at 1357 hours allowing the station to exit the Tech Spec action statement and return to full power.
6	2001	Not Significant	With the station in a refueling outage, a lightning strike on the 230 kV transmission line led to a lockout of the Startup Transformer (TRS). Multiple grid hits were reported in the area. At the time, most plant power was supplied from the 500 kV main transformers via station back-feed. However, the Division 2 vital bus was aligned to TRS for operability testing of the associated Division 2 diesel generator. The Division 2 vital bus had not yet been declared operable. The 115 kV Backup Transformer was available, and the bus auto-transferred to the Backup source. The line fault occurred outside the zone of protection of both the transformer differential relays and the phase overcurrent relays. Tripping of the lockout relays in the Control Room was initiated by the line protection relays from the adjacent substation, and transmitted via the fiber optic transfer trip.

ESD Events

The database has no reports of electrostatic discharge (ESD)-related events. ESD in some ways is like a small, localized lightning strike. ESD also has a very wide spectral energy distribution and while localized, has a very high energy content in its discharge. The lack of ESD related reports is almost certainly a result of several factors, including:

- ESD tends to be non-recurring, and, unlike lightning, is often unobserved. This makes it easy for the relationship between ESD and an operational upset to be missed.
- The heavy use of concrete and metal in nuclear plants suppresses, but does not entirely prevent the development of ESD.
- ESD disruption tends to be localized and commonly a correctable operational upset, in contrast to hard damage. ESD interference often manifests itself as equipment periodically 'acting funny'. There being many possible reasons equipment will 'glitch', the possibility of it being due to ESD is often either not thought of at all, or if thought of, not reported because it cannot be proven.

The absence of ESD related events is probably more indicative of what events get into the database than evidence of non-occurrence.

The conclusion on this topic is that the absence of ESD related events is probably more indicative of what events get into the database than evidence of non-occurrence.

Section 3: Development of EMC

The science and discipline of electromagnetic compatibility (EMC) have matured and changed over time. In its early days, when interference was poorly understood, EMC was often considered something like a 'black art', practiced by a select group of sorcerers and gurus. Over time, the discipline has matured and developed. The current practice is far different from what existed 30 years ago.

A series of trends can be discerned over the past half century. One of those trends is to deal with EMC at more fundamental levels. EMC engineers have learned over time that there are different techniques and levels at which they can be applied. At the outermost level, EMC can be controlled at the facility level. Devices that radiate strongly can be excluded from the building. Hospitals for a time tried to exclude cell phones as a means of protecting sensitive medical equipment from interference. While this practice can still be found in use, it is generally deprecated as being both ineffective and burdensome to enforce. Figure 3-1 illustrates the seven concentric layers of control for EMI/RFI.

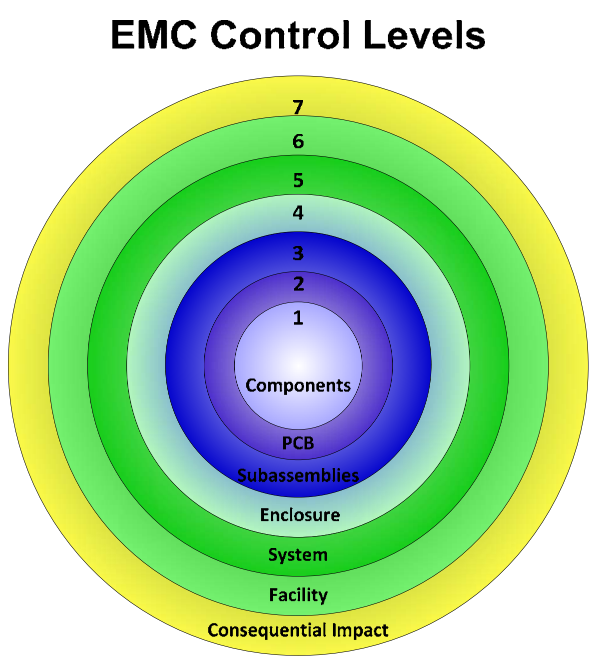

Figure 3-1
EMC Control Levels

Moving inward, early EMC measure focused on the system and enclosure. Shielded cables were connected to full metal enclosures with RF gaskets on the doors. Signal lines were filtered as they entered or exited the enclosure. While shielding and filtering continue to play an important role, for many products moving inward has proven to be both more effective and less costly. Working at the subassembly level, and PCB and component level, EMC engineers have learned that radical improvements in both emissions and immunity can be made by applying EMC protection at the lower levels.

Referring back to Figure 3-1, one can see that it illustrates the various levels at which EMC control can be applied. At the core, shown in shades of blue, is the levels equipment designers strive to control. EMC control can be applied by selecting components with better immunity levels, by using good placement and layout methods, relative placement of subassemblies and in the unit enclosure. Design choices in each of these areas can be critical to the final EMC performance of the device and the system in which it functions.

Moving out further, the system installation, equipment cabinets, type of cables and treatment of shields and grounding are generally under the control of plant engineers although often the system provider will supervise or at least specify the installation. At the facilities level, measures like exclusion zones seek to keep potential sources of EMI away from sensitive electronic systems, like I&C systems.

The consequential impact level stands somewhat on its own. At this level, the challenge is to limit the impact of interference, should it occur. One example is the use of redundant systems, with 2-out-of-3 logic. If three redundant systems are used and action is only taken if two of the three agree, then while one system may suffer interference, the consequential propagation is limited.

Other kinds of checks can be envisioned. RF or power disturbance monitors could be used and integrated into the decision logic for responding to unusual events. Such monitors are finding common use in critical systems in other industries to alert personnel of changing EMI conditions. This conceives of these detection mechanisms providing additional situational awareness to the decision making process. If coincident with an alarm, an RF or power disturbance is reported and perhaps a different course of action should be followed versus the same conditions, absent the monitors detecting a disturbance.

At the consequential impact level the logic domain is brought into the picture. With the other EMC control levels the techniques are almost entirely in hardware. Today, integrated electronic components are designed to be EMC immune. Protective diodes, filters and shielding can guard circuits from disturbances if properly applied to a product design. At the consequential impact level, there may be hardware measures applied that limit the propagation of consequences, however, there is also the potential for application of computational analysis and decision making. It may be, and sometimes it is the case, that the signature of a real event and an interference event are distinctive. Both real and interference events may trigger a threshold, but if their signature is distinct, then it may be possible to distinguish between the two. While the interference will still occur, it is recognized as interference and its consequences can be limited. The potential for applying safeguards at the consequential impact level is an important level to consider. The primary question here is: Are these measures of EMI control worth the trouble to integrate into I&C systems to gain more control of the risks for plant shutdown or worse.

As a general rule, both effectiveness and reliability are highest at the core levels. If an IC (integrated circuit) can be designed to emit less, then there will be little emissions problems from products that use such components. Conversely, if the chips, PCBs and subassemblies are poorly designed from an EMC viewpoint, then the only protection is the shielding in the enclosure. Any breach of this protection immediately opens up a path for substantial RF energy to escape and cause problems.

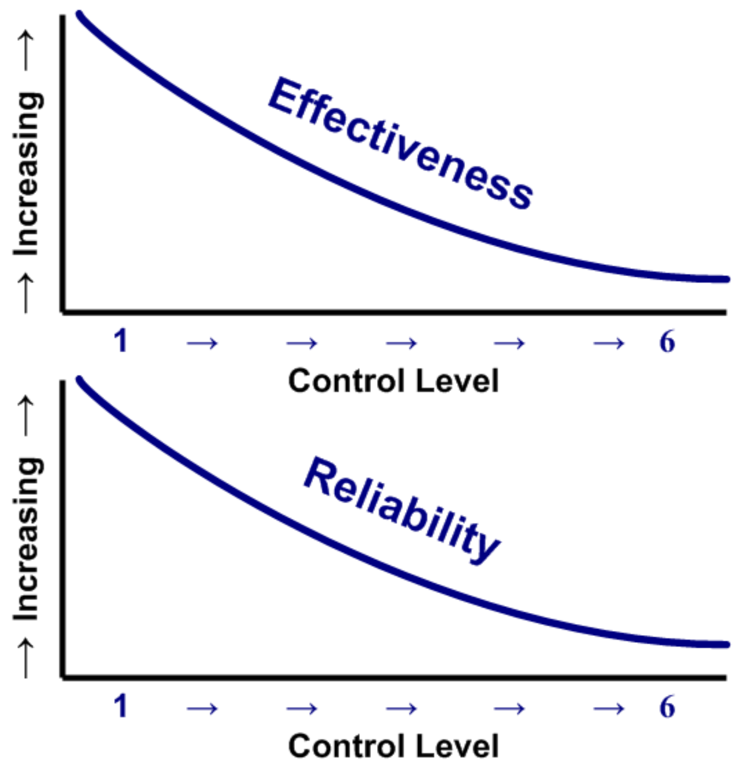

Figure 3-2
Generally effectiveness and reliability are highest when EMC measures are applied at the lower control levels.

Conversely, the consequences from interference and cost of implementation are typically much higher at the outer levels, but dramatically lower at the lower control levels. A rule of thumb in the discipline is that the cost of introducing a solution goes up by a factor of 10 for each change in level. While not a fixed truth, this observation has been experienced by a number of EMC engineers and their companies.

A further benefit is that when EMC measures are introduced at the core level, then whatever is done at the higher levels becomes additive and a defense in depth with overlapping levels of protection is created. If one EMC protection fails then all protection is not lost, only some of it. Especially for safety-critical systems, having a defense-in-depth design provides multiple layers of independent protection and increases total system reliability.

The obvious question is then why anyone would not implement EMC design at the core levels? There are many reasons why EMC design is not applied at the most effective and least expensive level. One of those is typically that the different levels are controlled by different organizations. There is often an asymmetry of cost and consequences. The facilities operator typically must suffer the consequences of interference but the cost of implementing EMC protection falls to the product manufacturer or even to the manufacturer's subassembly and component providers. Figure 3-3 illustrates that the asymmetry of cost and consequences often results in a situation where the costs would fall to one organization but the consequences to another.

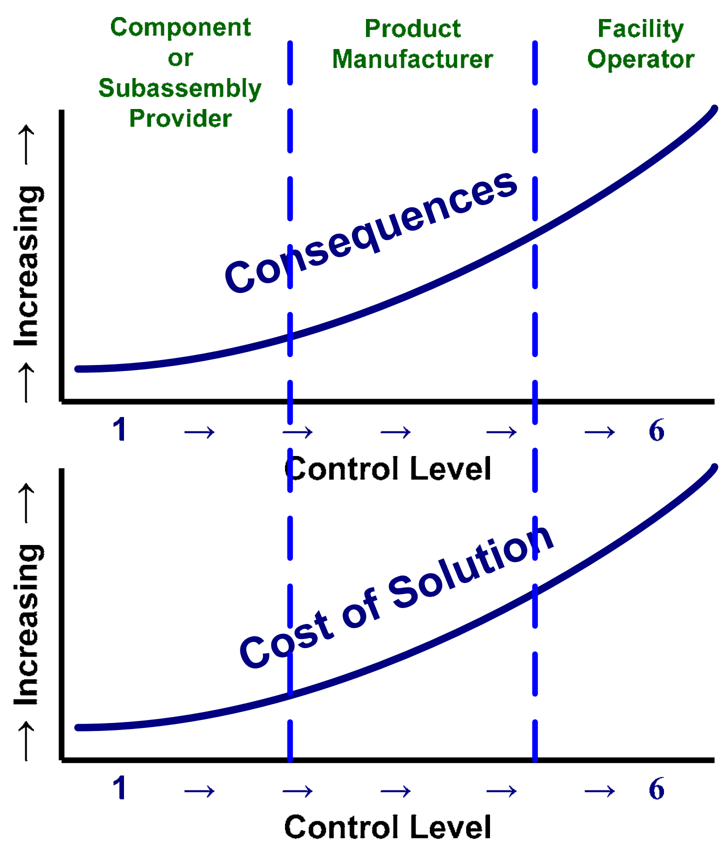

Figure 3-3
Asymmetry of cost and consequences

The remedy is for the facilities operator to effectively communicate their needs for EMC protection to their equipment providers and provide adequate compensation for them to incur the attending cost of implementing good EMC design. Conceptually, this is appears easy but in reality a series of very difficult tasks. EMC requirements must be reduced to a set of limits and tests of compliance that have excellent correlation to the desired field performance. Just that is a formidable task. The EMC discipline has been developing EMC standards for about 50 years and is still hard at work in pursuit of that goal. The good news is that the industries who have taken the interest and initiative to recognize that EMC is a critical factor in the aim to eliminate EMI-related events and managing risks are now reaping the financial benefits of actively pursing EMI control.

Then, most companies want to have a competitive purchasing process, to reduce their costs. However, it is very difficult to both get the lowest price and still get the level of quality required to effectively control EMI. It is a challenging task to both get the best price while also protecting the quality requirements needed from a product. Further, on both sides of the purchasing process typically nobody is an EMC expert. So, non-specialists must effectively communicate highly specialized requirements to another organization through another non-specialist.

Defense-in-Depth

A common methodology in security planning, defense-in-depth is increasingly applied to EMC protection. EMC protections can be placed at multiple levels and there is no reason to only apply them at one level, ignoring other opportunities. The best protection will usually be a mix of overlapping protective measures, providing redundancy and backup levels to the full system.

Any protection measure can fail. Having overlapping protection limits the potential consequence of having a level of protection fail. As discussed previously, because the cost is usually lowest at the core EMC control levels, having even a moderate level of protection there often allows much more economically affordable protection to be accepted at the higher levels. As an example, if a safety-critical circuit is highly sensitive to electromagnetic disturbances, then extremely good shielding must be provided to adequately protect it. Perhaps, a very demanding 120 dB of cabinet and cable shielding will be required to protect an extremely sensitive circuit. An improvement of 40 dB immunity is a level of improvement that is not uncommon when going from a circuit that was designed with no consideration for EMC to what can be accomplished by a skilled EMC design engineer. So, if this sensitive circuit can be designed with 40 dB more immunity, then only 80 dB of cabinet and cable shielding is required. 80 dB is a much easier level of shielding effectiveness to achieve. In fact, what is often experienced is the total protection is often more than what can be achieved dealing with only one level. This is the beauty and luxury of a multi-level EMC protection system.

To have interference requires:

- A source
- A coupling path
- A receptor

Elimination of any one of these will prevent EMI from occurring. So, anytime there is an EMI event each of these elements should be identified and studied. The best solution will often be to eliminate two or all three, providing a defense-in-depth. Take the cases in which an exclusion zone was violated. An exclusion zone is essentially dealing with the coupling path. If sources of RF are kept further away (outside the exclusion zone), their energy will couple less efficiently into sensitive circuits. Certainly, as has been done, when exclusion zones are violated, measures should be taken to enforce them more effectively. However, it should also be asked if the receptor circuit is as RF immune as it might be? Perhaps, there are reasonable measures, such as better treatment of cable shield terminations, which can add protection. In the best cases, the immunity of the core circuits can be improved, when there is opportunity to do so.

The potential to limit the source is also worth exploring. Increasingly, wireless devices include very active power control and increasing their use of intelligent software-based radio control. They reduce or raise their power based on signal conditions. All cell phones have very aggressive power control mechanisms, only transmitting at maximum power when absolutely necessary. If the cell tower is far removed from the plant and the building further reduces signal strength, cell phones will almost always be transmitting at maximum power in order to reach the cell tower. It may seem counter intuitive, but if femtocells[3] are introduced, not only is connectivity improved but cell phones will operate at much lower power, reducing their risk of causing interference.

Beyond dealing with the three components of source, coupling path and receptor, it is always worth evaluating the consequential impact chain. Might it be possible to add safeguards that limit the negative consequences of interference, should it occur?

Each of these components can be treated in a variety of ways and a good analysis will examine multiple options before selecting the most appropriate set of protective measures. In the best cases, methods will be identified to mitigate the source, coupling path, receptor and consequential propagation path. The use of multilevel, defense-in-depth is highly recommended.

[3] A femtocell is a small cellular base station, typically designed for use in a home or small business. It connects to the service provider's network via a broadband connection (such as DSL or cable). Cell phone network operators provide femtocells to improve service to customers who are having difficulty, perhaps because they cannot get a good signal at their home or business.

Development of Conformance Systems

As the need to ensure EMC compliance grew, EMC engineers increasingly adopted and implemented the tools of conformity assessment. Conformity assessment systems were developed to ensure that EMC considerations were implements as required and to the limits necessary to adequately safeguard against interference.

Dan Hoolihan, in his article, *A Historical Look Back: The 1977 CBEMA Paper on Electromagnetic Emanations*,[4] provides useful insights into the development of EMC conformity assessment:

> *In the middle of the 1970s, the United States Federal Communications Commission (FCC) began to look seriously at electromagnetic emissions from electronic data processing (EDP) equipment and office equipment (OE). This growing awareness on the part of the United States telecommunications regulation body was a result of the increasing number of computers being used by society and the increased potential for growth by licensed broadcast services due to the proliferation of electronic-computer sources. The Computer and Business Equipment Manufacturers Association (CBEMA) formed a technical subcommittee to assist in preparing an industry response to the concerns of the FCC. This paper reviews the report developed by that technical subcommittee, made public in May of 1977.*

Title of CBEMA Paper

> *The title of the published paper was Limits and Methods of Measurement of Electromagnetic Emanations from Electronic Data Processing and Office Equipment.*
>
> *The paper was published by CBEMA, a trade association dedicated to expanding knowledge in the manufacture, sale, and use of member products. CBEMA was located in Washington, D. C. (CBEMA is now known as the Information Technology Industry Council and is still located in Washington, D.C.).*
>
> *The report was prepared by Subcommittee 5 on Electromagnetic Interference. SC 5 was organizationally part of the Environment and Safety Committee of CBEMA.*

[4] Dan Hoolihan, A Historical Look Back: The 1977 CBEMA Paper on Electromagnetic Emanations, IN Compliance Magazine, Nov. 2011, pgs. 52-57.

Background

The report generated by the Subcommittee on Electromagnetic Interference (SC5) was a result of several years of technical research by the member companies of CBEMA. It was made public "in the belief that it will be of interest and assistance to the CBEMA membership and to other manufacturers of electronic data processing and office equipment, and also to others having an interest in the general subject matter."

In 1977, members of CBEMA had experienced very few interference issues relative to the licensed broadcast services in the USA. They attributed this partly to the high standards of engineering and manufacturing in existence for its member companies. At the same time, CBEMA acknowledged the challenge of staying abreast of the fast-moving changes inherent in the transistor-integrated circuit-computer trilogy. CBEMA, therefore, had a strong interest in electromagnetic interference issues and their potential impact on the design and manufacture of EDP and OE.[5]

Several observations are relevant. First, the general experience with interference and that in nuclear plants was very similar. It was in the mid-70's that the first interference was reported in nuclear plants, as it was also coming to the attention of the FCC and the IT industry. It is very interesting that the CBEMA report could credibly state that:

Since very few interference problems were being reported in the mid-1970s, the CBEMA report identified that the reason for controlling emanation characteristics of commercial EDP/OE is to prevent future interference problems. [6]

The CBEMA statement has interesting parallels to the following statement from the NRC in its circular, IN-83-83:

Many of the older nuclear power plants have so few solid-state devices that this explains their apparent invulnerability to RFI generated by portable radio transmitters. As newer plants are built that use more solid-state equipment and as older plants retrofit solid-state equipment, more cases of RFI by portable radio transmitters are likely to result.

….

As part of a wider program, the NRC is conducting research in the area of electromagnetic interference (EMI), including RFI as one of its aspects.[7]

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[5] Ibid, pg 53.

[6] Ibid, pg 53.

[7] See full reproduction of NRC IN-83-83 in the annexes.

Second, the reason for the rise of interference issues was the increasing use of solid-state electronics and increasingly the use of integrated circuits and digital electronics, which steady move to higher speeds and lower signal voltages internal to integrated circuits and microchips. The organization of the report shows the same basic analysis of the elements necessary for interference:

> *The material in the report was organized in a logical manner based on the basic elements of an EMC interference relationship; that is, the source of the electromagnetic emissions, the propagation means for transferring the energy from the source to the receptor, and the communications receiver that is potentially capable of being interfered with by the sources of emanations.* [8]

It is interesting to note the impact of business case on EMC.

> *In the 1970s, EDP/OE were expensive and, therefore, frequently leased by the customer. Whether the equipment was leased or sold, the original manufacturer typically maintained the EDP/OE in the operating environment of the customer (on the customer's premises). Thus, the original manufacturer was responsible for the equipment for its lifetime and the manufacturer could exercise some control over the installation of the product to assist in the control of electromagnetic interference situations.* [9]

The equipment manufacturer's ongoing control of the equipment allowed them to implement installation and maintenance measures that would be impossible for most manufacturers today. Further, the cost and consequences of interference were unified and remained with the equipment manufacturer, also very different from the current environment, in which equipment is generally sold outright and often through a third party, with the result that the facilities operator has very little ability to get ongoing support from the manufacturer unless it is separately contracted for.

However, the fundamentals of interference have not changed, as seen in Figure 3-4. Digital signals produce a very broad spectral output and equally 'receive' energy over the same spectrum. When RF impinges on a product, it distorts the signal waveform or impacts sensitive thresholds, causing operational upset.

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[8] Ibid, pg 54.

[9] Ibid, pg 57.

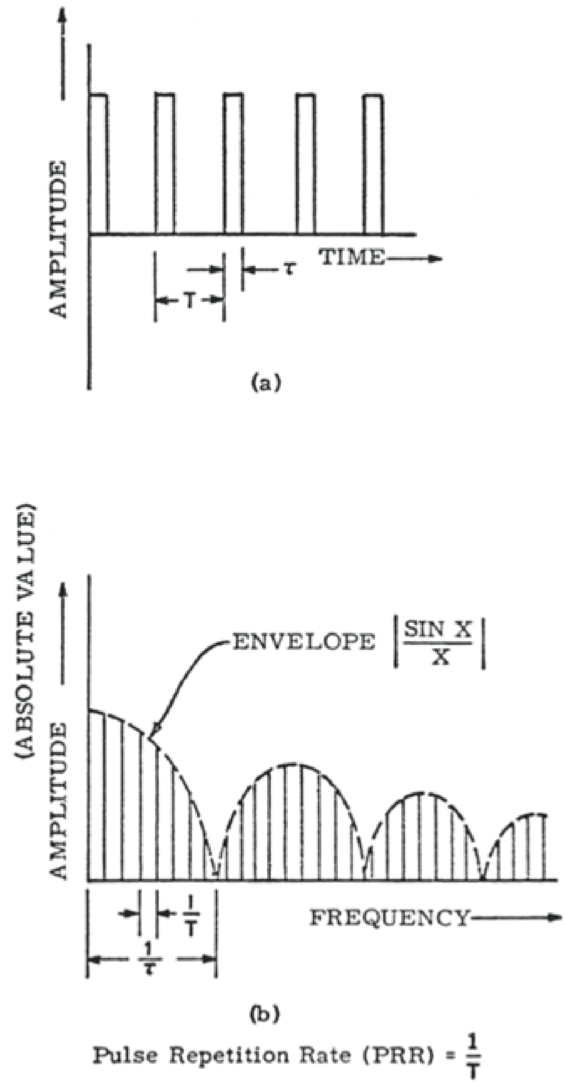

Figure 3-4
Time/frequency line spectrum for pulsed periodic waveforms

Development of Nuclear EMC Requirements

The EMC requirements for nuclear plants have been undergoing relatively constant development for several decades as depicted by Figure 3-5. Over time, these developments have formed an ad-hoc conformity assessment system. However, significantly the system lacks an identified manager, known as a *scheme-owner* in the field of conformity assessment.

In 1983, the NRC issued one of the early advisories to plant operators, warning them of the potential for EMI. This information notice, IN 83-83, was based on early reports of interference incidence and sought to help other plants avoid similar experiences.

EPRI issued an EMC guidance document, TR-102323 with Revision 1 being published in 1994, which the NRC later used as a basis for Regulatory Guide 1.180. From that foundation, the EMC protection system has grown and developed.

New issues have been addressed as they were identified. Recently, there has been an observable increase in EMC training, largely motivated by digital upgrades and the need to insure that the new systems provide the necessary level of EMC protection. Training is part of an ISO 17024 activity, personnel qualification, which in turn is a component of a larger conformity system. The purpose is to ensure that all personnel are properly trained, skilled and experienced for the roles and responsibilities they are assigned. Figure 3-5 illustrates the development history of EMC guidance documents.

Rev. 1 of EPRI TR-102323 is the only EMC guidance document that has been reviewed by the NRC under a Safety Evaluation Report (SER). Rev. 2 and Rev. 3 have not been officially reviewed, but Rev. 3 is frequently quoted as the document-of-use for EMC testing of digital I&C equipment and systems. Under new EPRI research constituted in 2009, Rev. 4 is under development. Based on many learned lessons over the past 17 years of use of these documents, new guidance is being developed in Rev. 4. Topics addressed are presently under discussion. However, one of the key areas of focus is the development of two new ANSI standards—C63.20 and C63.24. ANSI C63.20 will provide a firm foundation for the guidance included in EPRI TR-102323 Rev. 3. The primary benefit of this activity is to provide utilities, manufacturers, and EMC test labs with a standards structure that can be more easily managed and updated based on current guidance. Further discussion will be provided in Rev. 4 to be issued at the beginning of the second quarter in 2012 within EPRI's I&C program.

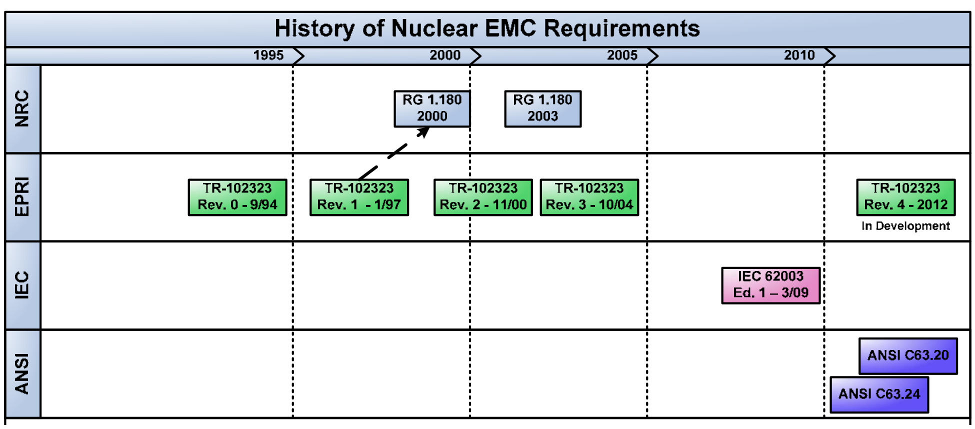

Figure 3-5
Development of Nuclear EMC Requirements

Section 4: Development of Risk Management Methods

Understanding the technical dynamics that resulted in individual interference incidents is important and foundational to preventing future events. Arguably, even more important is understanding these events in light of the EMC control measures and risk protection systems that were supposed to prevent them in the first place. How did these conditions come together in the first place? Shouldn't the protections already in place have prevented them? To answer these questions, it is important to know what requirements and systems were in place at the time the equipment involved in an interference incident was designed and placed into service. What requirements was the equipment supposed to meet? Knowing that, further questions can be asked. Were the requirements inadequate? Were the test methods used to evaluate compliance flawed or deficient in some way? Were changes made so that while one version of the system was tested, something similar but different was shipped to the customer and installed at the job site? Getting answers to these questions is critical to identifying the best ways to make changes that are truly effective in reducing future interference events.

Historically, control of electromagnetic interference has been treated as an isolated specialty, isolated from risk assessment and management. Over time, EMC and risk management methods have developed and matured. Increasingly, they are becoming integrated with EMC being an important component of total risk assessment and management. Understanding the history of this development is important, if we are to discern whether there was a failure of the system or, in contrast, no system in place at the time to fail.

Conformity Assessment

Conformity assessment is the endeavor to ensure that a product, service or system meets normative requirements. A typical conformity assessment system will have standards that define the normative requirements. Then, either in the same standard or in separate standards, tests are defined to be used in evaluating conformity to those requirements. A supervising organization, usually called the *scheme-owner*, is responsible for identifying the requirements, tests and process for showing compliance.

Listed below are some additional topics that warrant careful consideration as the risk management of EMI events is undertaken for nuclear power plants. These will be further explored in the next revision of this report.

- ISO/IEC Guide 65:1996
  General requirements for bodies operating product certification systems
- ISO/IEC Guide 53:2005
  Conformity assessment -- Guidance on the use of an organization's quality management system in product certification
- ISO/IEC 17024:2003
  Conformity assessment -- General requirements for bodies operating certification of persons
- ISO/IEC 17025:2005
  General requirements for the competence of testing and calibration laboratories

Risk Analysis

Risk analysis has proven to be an effective approach for managing undesired events in many mission-critical industries. In fact, risk analysis is commonly used in the nuclear power plant industry to manage different types of undesired events in the operation of nuclear plants. High-impact, low-frequency events is one topic that has gained much application of risk analysis in the past few years. These events are of concern to US utilities as the risks posed to the utility power distribution system caused by high-impact, low-frequency events are real concerns to the future of our power system. One report that should be carefully reviewed for application to nuclear plants when considering the effects of high-impact, low-frequency events on plant operations is the following:

- June 2010 NERC/DOE report titled:
  "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System"

Several EMC risks have already been identified as critical topics of research and study. These include

- Identification of EMC Risks
- Geomagnetic Disturbance (GMD)
- High Altitude Electromagnetic Pulse (HEMP)
- Intentional Electromagnetic Interference (IEMI)

These will be further explored in future EPRI research regarding methods of risk management for EMC for nuclear power plants.

Method of Analysis Used in this Project

Understanding and managing systemic risk is extremely complex, particularly with large operations like nuclear plants, involving equipment and systems from multiple vendors. Complexity comes with change over time.

"In the view of Sears {*Richard Sears is a deepwater oil industry veteran who worked for the presidential commission investigating the Deepwater Horizon oil spill*}, risk builds like plaque. It's cumulative. There's a fundamental mistake that people make: They think that, as they deal with one risky situation after another, they can look at each decision in isolation. That's what happened with the Horizon, he said: The individual decisions were generally reasonable. But the risk was accumulating. And, the people who had to interpret the negative test were not necessarily in the loop on all the previous decisions and judgments. They didn't know what we know now about the matrix of decisions across time and space, decisions that ranged from the rig to Houston, and from British Petroleum to Transocean to Halliburton to M-I Swaco and other contractors."[10]

[10] Joel Achenbach, "A Hole at the Bottom of the Sea; The Race to Kill the BP Oil Gusher", Simon & Schuster, New York, 2011, Pg. 223.

Section 5: Analysis of EMI Events in Nuclear Plants

The study of EMI-related events reveals that there are patterns and groups of similar events. The study can be thought of as analyzing the source, couple path, receptor and consequential propagation of an interference event. Each of these areas was found to produce fruitful insights.

Method of Analysis Used in this Project

This study started with the events reported to INPO, cataloging and analyzing them for common features and trends. When groups of events were identified with common features, the underlying dynamics of the events were probed. The purpose was to understand the dynamics that resulted in interference and from that identify the mitigation measures that might be employed to prevent future events.

Limitations and Challenges in the Analysis Approach

A limitation of the study was that it could only study reported events, and the data that was included in each event. It is clear that these events only represent a fraction of the total interference events. The reported events are the 'tip of the iceberg' to all interference events. Certainly near-miss events have not been reported. However, also absent are any reports of interference from electrostatic discharge (ESD), which given the information from the reported events, must have occurred. EMI events analyzed from many other mission-critical industries and the nature of EMI indicated in past EPRI research that the nature of EMI event reporting results in many unreported events.

Broadband Impulsive Interference

Several of the incidents reported show interference that is broadband and impulsive in nature. Welding, lighting systems that use high-voltage pulses to ignite high-intensity discharge lamps and flash cameras are all examples of interference which emits electromagnetic energy over a broad frequency range with a pulsed envelope. Electrostatic discharges and lightning are naturally occurring examples of broadband impulsive interference. This kind of interference source contrasts with longer duration more narrowband sources, such as most portable transmitters.

The tests used to evaluate product immunity generally test with narrowband energy, moving through the frequency range, exposing the TOE (target of evaluation) to a single frequency at a time. A case can be made that either a narrowband test or a broadband impulsive test is worst case. However, it must be concluded that the most interfering signal will depend on the characteristics of the TOE. A narrowband signal concentrates its energy at a single frequency. A circuit that has a natural sensitivity to that frequency will therefore be maximally stressed by this kind of test. However, in contrast, a broadband signal may reveal that there are multiple frequencies of sensitivity, and the broadband signal will excite them all simultaneously. This raises the possibility that some failure modes may only be seen if two or more areas of the circuit are simultaneously impacted. A narrowband test may only stress one area of the circuitry at a time, if their frequency response differs. For example, one area of the circuit by nature of the design provides a safeguard for the other. However, when both are stressed simultaneously, the product may fail.

There has been relatively little research into the different kinds of failure modes that different spectral representations may reveal. Moreover, there is almost no quantified research on the relative immunity level of a product when tested with impulsive signals versus the standard narrowband signals modulated by 80%, 1 kHz AM. Even if both tests reveal a TOE's immunity and if there are wide differences in the levels required to elicit a response, errant conclusions may be taken as to the general level of protection.

A further factor is the spacing of narrowband test frequencies. A typical test will be run at 1% spacing between test frequencies. Particularly at higher frequencies the spacing between test frequencies becomes significant. This creates the risk that a very frequency-specific, narrow window of susceptibility may be missed in the test. A wideband test in this case is more likely to identify a very frequency-specific sensitivity.

At this time relatively little is known about the correlation of the standard electromagnetic immunity tests for broadband impulsive interference sources.

The conclusion is not that one kind of testing is inherently superior to the other. Rather, it is clear from the events reported to INPO that impulsive sources of interference are common. However, it is unknown how well the current test suite predicts the immunity to such spectral wave-shapes. At this time, relatively little is known about the correlation of the standard electromagnetic immunity tests for broadband impulsive interference sources.

Projected EMI Events Trends

Based on the pattern of interference events reports, the pattern of future trends can be predicted, in some cases with high confidence. It can be said that, as in the past, the future will find sources of EM energy finding their way into plants. In many cases, these electromagnetic sources will be intentionally brought in to serve a needed function, e.g. welding, portable transceivers, Wi-Fi, etc. In other cases, undesired natural, lightning and ESD, and manmade sources of electromagnetic energy will find their way into plants.

Multi-Band Devices

For some time, cell phones have operated in multiple-frequency bands, using a variety of transmission protocols. Similarly, wireless local area networks (LANs) commonly operate in both the 2.4 and 5.8 GHz band, with some also supporting other frequency bands. The trend to have devices that are capable of operating in multiple frequency bands and support a variety of transmission protocols is likely to continue for the foreseeable future. The result is that the RF characteristics of a device may radically change from transmission to transmission.

A growing trend is the ability of devices to support multiple, simultaneous transmissions. This introduces the possibility of interactive effects when two or more different frequencies are coming from the same device at the same time.

A survey of components, such as RF modems and embedded chip antennas, provides a forward looking view of where these component manufacturers see the market going. Table 5-1 lists four bands and frequency ranges used by four embedded antennas for cellular phones.

Table 5-1
Bands and frequency ranges used by four embedded antennas

Band	Frequency Range (MHz)
GSM 850	824-894
GSM 900	880-960
DCS	1710-1880
PCS	1850-1990

Figure 5-1
This quad-band antenna supports 4 different frequency bands listed in Table 5-1

The trend to support more frequency bands and radio access technologies is strong because there are many advantages. The more transmission options a device has, the more likely it is to be able to successfully communicate. That fundamental fact virtually insures the continuation of the trend for some time to come.

One antenna manufacturer offers this low profile switchable antenna for tablet PCs. This switchable antenna for mobile connected PCs is 65 mm long but only 1 mm high. It enables four states for low band: 700 to 750 MHz (LTE low), 750 to 790 MHz (LTE high), 820 to 900 MHz (GSM 850), and 880 to 960 MHz (GSM 900), covering 1800/1900/2100 for high band applications, with switching implemented directly from the device.

Figure 5-2
This quad band antenna also supports four different frequency bands

These examples illustrate the wider trend. For nuclear power plant I&C systems, the need to provide broadband immunity becomes increasingly important. Portable transceivers will increasingly operate over very wide frequency ranges and as a result will be likely to find any frequency specific vulnerabilities a system has.

Changing Form Factors

A strong trend is the increasing use of wireless connectivity in a wider and wider variety of applications. It is increasingly likely that a strong portable transmitter will look nothing like a phone or handheld radio.

One source of wireless being used in new form factors is the adaptation of wireless connectivity in medical devices. Consider, as only one of many examples, research that is developing chip implants to monitor cancer tumors.

Microchip implant monitors tumor growth

> *Researchers in Germany have developed a microchip sensor that can be implanted close to a tumor to monitor its growth.*

The device tracks oxygen levels in nearby tissue to detect if a tumor is expanding.

Results are then transmitted wirelessly to a patient's doctor – reducing the need for frequent hospital scans.

Future designs will include a medication pump that can deliver drugs directly to the affected area.

Researchers hope this will lead to less aggressive and more targeted cancer treatments.

….

The sensor is implanted next to a tumor, and measures the concentration of dissolved oxygen in nearby tissue fluid. If this drops it can indicate aggressive growth, and doctors can be alerted.

"The microelectronic chip has a set of electrodes that detect oxygen saturation. It transmits this sensor data to an external receiving unit that's like a small box you carry around in your pocket."

"From there it goes into the doctor's PC – and they can look at the data and decide whether the tumor activity is getting worse."[11]

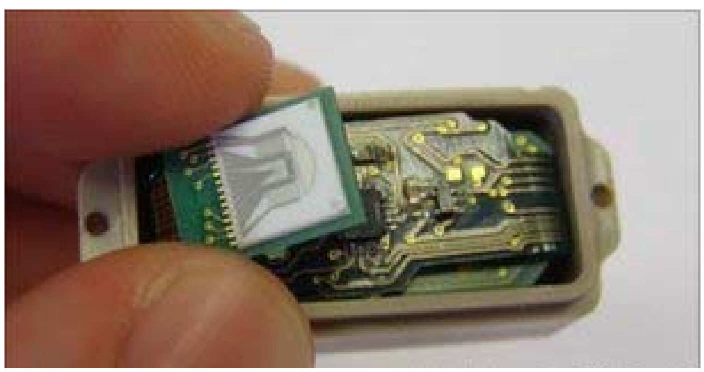

Figure 5-3
A sensor chip being developed to be implanted close to a tumor

[11] August 31, 2011 story by BBC Mobile, available at: http://www.bbc.co.uk/news/technology-14728716.

Section 6: Reporting and Analysis Methods

This report is primarily based on reports to the Institute of Nuclear Power Operations (INPO) database. INPO was established in December 1979 as a not-for-profit organization headquartered in Atlanta. It was largely in response to the Kemeny Commission – set up by President Jimmy Carter to investigate the March 1979 accident at the Three Mile Island nuclear power plant. In its report the Kemeny Commission recommended that:

- The (nuclear power) industry should establish a program that specifies appropriate safety standards including those for management, quality assurance, and operating procedures and practices, and that conducts independent evaluations.
- There must be a systematic gathering, review, and analysis of operating experience at all nuclear power plants coupled with an industry-wide international communications network to facilitate the speedy flow of this information to affected parties.

In addressing those recommendations, the nuclear power industry:

- Established INPO – the Institute of Nuclear Power Operations
- Charged INPO with its mission:

  To promote the highest levels of safety and reliability – to promote excellence – in the operation of commercial nuclear power plants.

The authors realize that nuclear utilities have a mutual understood verbal agreement that events will be reported to INPO for the purposes of education and information sharing. However, the authors of this report would like to assume that not all events get reported. This thinking is necessary to illustrate several points regarding event reporting in this report with the aim of making recommendations for improving the reporting process.

Recommendations for the Reporting Process

An EMC specific diagnosis is needed to give insight to the full range of possible solutions.

The INPO reporting process has be the subject of ongoing quality improvements over its life. The improvements in reporting and quality of information provided are very helpful for analyses such as this. In this section, recommendations are offered for ways in which the system may be further improved.

EMC Specific Diagnosis

A common feature of the reports is to end the diagnostic effort at the point at which an electromagnetic cause is identified. However, ending the evaluation at that point misses the opportunity to provide more in-depth insight, which could be critical in guiding future improvements. All EMI events have three common components, a source, coupling path and receptor. To fully understand the nature of an event, each of these components needs to be understood in detail. Eliminate any one of them and the interference will not occur. Said another way, there are always at least three solutions to EMI, eliminate or moderate the source, coupling path or raise the immunity of the receptor.

When reporting on the source of EMI, specific information is typically not included, but it would be very helpful if it was. Only rarely is the operating frequency and RF power of a walkie-talkie or other intentional radiator reported in the INPO events analyzed in this EPRI research.

Having the FCC ID of a walkie-talkie or other intentional radiator allows access to a great deal of highly useful and publically available information.

It would be very helpful if the FCC ID of any intentional radiator involved in an EMI incident were also reported into the INPO database for each event. With the FCC ID, the operating frequency, maximum RF power and a great deal of other publically available information can be obtained and used in analyzing the problem.

Similarly, it is important to understand the full coupling path. Was the electromagnetic energy conducted to the receptor circuit or radiated to it? Even in cases where the energy radiates to the receptor, there is some structure acting as an antenna, coupling the energy into the receptor. Understanding the path and the exact structure that brings the energy to the receptor opens up insight to possible solutions that would disrupt or modify the coupling path.

Finally, knowing the exact area of circuitry and even component in the receptor which has the key vulnerability is critically important. To gain insight to the full range of potential solutions, the exact point of sensitivity must be understood. A common point of failure will be the first amplifier on the receiving end of a long cable coming from a sensor. RF noise can be demodulated in the amplifier, become mixed with the intended signal, amplified and passed through as a real signal. Once the noise is demodulated and mixed into the intended signal path, little can be done to eliminate it. However, a variety of techniques are available for preventing RF noise from being demodulated and mixed into the intended signal. To know if such techniques might be beneficially applied, requires an EMC analysis of the problem, which identifies the exact failure point within the system.

In a follow-up effort to Event No. 3 included in Chapter 2 which caused a plant trip, extensive EMC testing was done, providing an excellent model to for an EMC diagnosis. The follow-up report states:

A spare DEHC system located at the plant's Nuclear Training Center was tested for susceptibility to EMI/RFI. The following is a synopsis of the test results:

- ***High-Frequency Conducted Susceptibility Test:***

This test was to verify the ability of equipment to withstand radio-frequency signals coupled onto power and signal cables. In accordance with the test standard, a 10 Vrms noise signal was coupled onto the speed probe cable over a frequency range of 150 kHz - 80 MHz. The DEHC test system in the training center exhibited vulnerability when at approximately 34-39 MHz. The system became unstable and sensed probe speed dropped from 1,800 rpm to as low as ~1,690 rpm while the median signal select over-speed trip output reached a peak value of ~1,839 rpm. During the investigation, no EMI/RFI source in this frequency range was discovered.

- ***High-Frequency Radiated Susceptibility Test:***

This test was to verify the ability of equipment to withstand radiated electric fields. In accordance with the test standard, a 10 V/m electric field was directed onto the speed probe cable over a frequency range of 26 MHz - 1 GHz. The DEHC test system exhibited minor, negligible fluctuations over the entire range of tested frequencies. This test was completed with no identified concerns.

- ***Electrical Fast Transient/Burst Immunity Test:***

This test was used to verify the ability of equipment to withstand repetitive electrical fast transients. The fast transient tests were performed at the 1 kV and 2 kV levels with only minor, negligible fluctuations of indicated speed signal.

- ***Testing and Measurement Techniques - Surge Immunity Test:***

This test was to verify the ability of equipment to withstand unidirectional surges caused by overvoltages from switching or lighting transients. The surge tests were performed at the 1 kV and 2 kV levels with only minor, negligible fluctuations of indicated speed signal.

- ***Informal testing:***

The DEHC test system was also exposed to radiated emissions from the following devices:

- *UHF radio* — *Frequency 150 MHz*
- *VHF radio (MT750)* — *Frequency 450 MHz*

- *VHF radio (MT1000)* *Frequency 450 MHz*
- *Wireless phone* *Frequency 902/928 MHz*
- *Cellular Phone* *Frequency 850/1900 MHz*
- *Electric Drill (suspected of potentially causing interference)*

When used in close proximity to the probe cable, none of the above devices interfered with DEHC system over-speed indication. When the UHF & VHF radios were keyed in close proximity to the speed probe input signals with the cabinet doors open, there were large reductions in indicated speed. The portable line-powered electric drill, wireless phone, and cellular phone did not interfere with speed indication even with the cabinet doors opened. The DEHC cabinet is located in the Equipment Room that has always been a posted "No Radio Zone." Security card reader access logs were reviewed, and interviews were conducted on personnel who were in the Control Room. Nobody keyed a radio in the Equipment Room at the time of the trip. UHF/VHF radio usage was eliminated as a cause.

Conformance System Diagnosis

Complimenting the EMC specific diagnosis, a conformance system diagnosis is needed to give insight to how the system allowed the EMI vulnerability. In the reports reviewed, there is no mention of the qualification EMC test reports for the receptor system (i.e., the system that was interfered with). This absence raises a number of important questions, which future reports should answer:

A conformance system diagnosis gives insight to how a vulnerability passed through the EMC protection system and gives insight into system improvements.

i. Was the necessary EMC testing even done? If not, then why?

ii. If EMC testing was done, was it done correctly, or was the testing flawed?

iii. If the EMC testing was done correctly, did the test method or limit allow a vulnerability to pass through?

iv. Was the device that suffered the interference the same as that which was tested? Alternately, were there changes which introduced sensitivity, not present in the device tested?

v. Was the installation of the I&C equipment proper or deficient?

Knowing the answers to these questions would allow system improvement. If required tests are not being performed or being performed incorrectly, then one set of remedial measures would be recommended. Alternately, if the testing was performed correctly but the limit or test method was flawed, then improvements in those areas should be considered. If the problem laid with a difference between the installed system versus the tested system, then the configuration management processes need review.

An exception to the general trend is found in one OE event reviewed in this EPRI research, which can serve as an example of both an EMC and conformity system diagnosis:

> *The vendor's Quality Assurance Manager was contacted concerning the problem with the dosimeter. The QA Manager indicated that the problem is caused by EMI/RF interference. He then forwarded a letter that was written in the winter of 2000. This letter indicated that the dosimeter far exceeds the ANSI/IEC recommendations for EMI/RF interference. The letter also states that at a frequency range of 10 kHz to 1 GHz at a field intensity of 200 V/m, 1 GHz to 4 GHz at a field intensity of 200 V/m, and 4 GHz to 10 GHz at a field intensity of 100 V/m no change in operation and no increase in dose was observed. The letter concludes that welding will typically produce field strengths of 500 to 1,500 volts per meter in proximity to or on contact with the welding cable under certain conditions. The manufacturer recommended the following for electronic dosimeters:*
>
> *"Wherever possible, the dosimeter should not be placed in close proximity to the weld cable proper placement on the body / lanyard and attention to the proximity can greatly reduce the false dose / dose rate alarms."*
>
> *"Welder cable should avoid being coiled when in proximity to the dosimeter."*
>
> *"Welders should avoid placing the cable over the shoulder of the worker."*
>
> *On site testing of these dosimeters with an operating welding machine revealed that under normal conditions with welding cables uncoiled laying in a linear configuration, no affect was observed. When the welding cable was configured with a loop or coils in the line, the dosimeter would go into alarm when placed within close proximity of the bend. Dosimeters placed at one and two foot intervals from the loop had no adverse effect from the welding cable.*

In this report, EPRI finds information about the EMC testing of the receptor device and the levels that the unit tests achieved. Presumably, the full test report could be obtained, should there be reason to explore the specific test procedures uses. However, as the testing shown an immunity level of 200 V/m and the company provided information that welding could exceed those levels under certain conditions a reasonable and testable hypothesis is presented. To their credit, the responsible engineers did test the hypothesis and in fact showed that they could recreate the failure on specified conditions. The only missing item that would have been helpful would have been to measure the field strengths being created when the failure was reproduced, to confirm that that the specific field levels that caused a response in the units at the plant. With this report, we understand both the physics of the interference event and also how the conformity assurance system allowed the vulnerable device to be deployed. In this case, the device meets very significant limits but even those limits were exceeded.

Strengths and Limitation of the Analysis

This project analyzed the known EMI-related incidents currently documented in the INPO database. The question may be asked, "How large a sample are these events to the total of all EMI related events? Obviously, this analysis cannot analyze events which are not known. However, some analysis is possible of what might cause events to not be known. Figure 6-1 illustrates the types of events which are available for analysis in this report. As is made visually apparent in the figure, these known events are only a subset and very likely a small subset of all EMI related events. Figures 6-2 through 6-8 provide an expanded view of Figure 6-1.

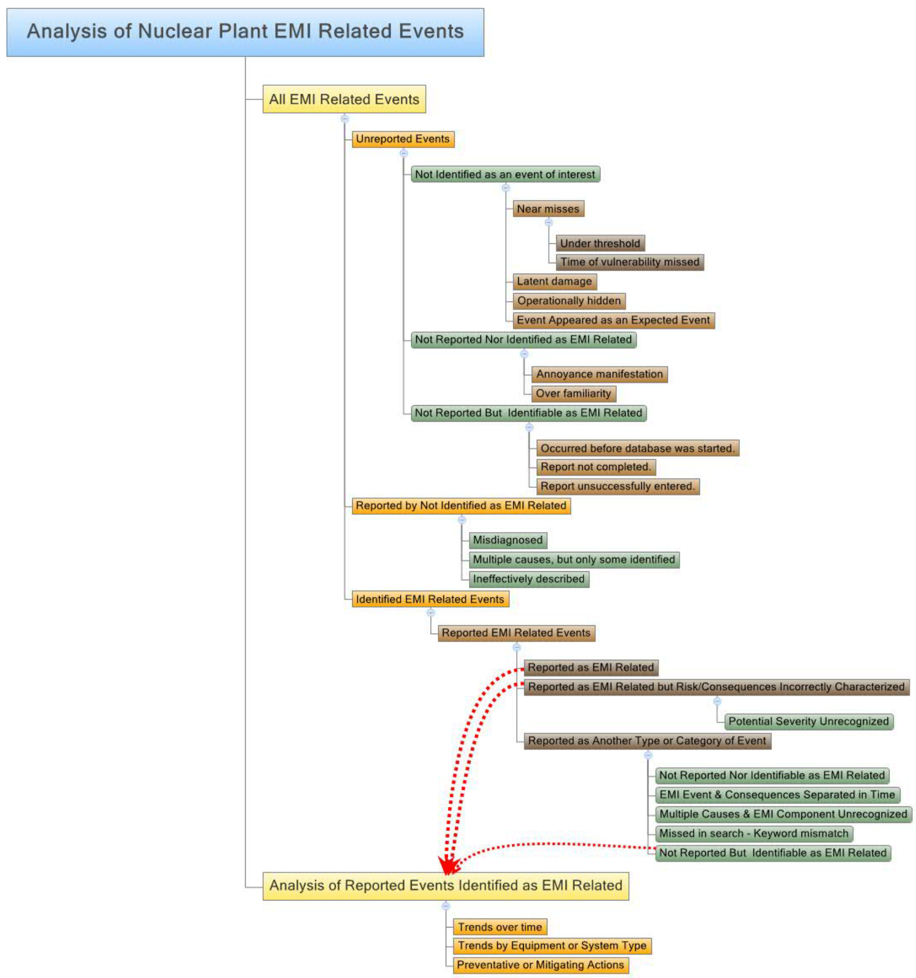

Figure 6-1
Overview of Analyzed EMI Related Events

The total set of all EMI related events can be divided into three categories as shown in Figure 6-2. The first group is the events which are not reported to the INPO data base. The second are those events which are reported but not identified as EMI-related. The third category is the events that are reported and correctly identified as EMI related. It is only this last category of events which can be analyzed in this report.

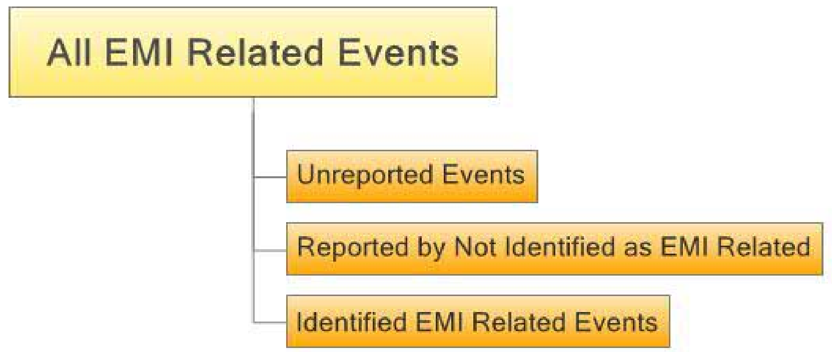

Figure 6-2
Categories of all EMI-Related Events

There are at least three reasons an event would not be reported at all. As these events are not reported, they are not available for analysis. The three categories of unreported events are:

- Incidents which are not identified as warranting a report.
- Incidents which are difficult to determine an EMI causal relationship.
- Incidents which while not reports could be identified as EMI related.

Figure 6-3
Categories of Unreported EMI-Related Events

First, in incident may be incorrectly judged to be not of interest and so not reportable. This is particularly likely if the consequences of an incident were not significant and the personnel involved did not recognize it as a ‘near-miss’ of a more significant event. The personnel who observed the event simply didn’t think it required reporting.

Near-misses represent one group of such events. A near miss might be an event in which the EMI stress did not reach the threshold to cause a disturbance. Knowing how often EMI stresses came close to causing interference would be of great interest to the readers of this report. However, such sub-threshold events are impossible to identify without special monitoring instrumentation.

A related category of near-misses, different from those in which the amplitude did not reach an interference threshold, are those which occurred in a time window during which the system was not susceptible. An example of such a non-vulnerable time window is when a system is out of service. However, even during normal operation, most systems have times, such as when reading sensors, transmitting data or writing data to memory, when they are most vulnerable to electromagnetic (EM) stress events. If electromagnetic stress occurs outside of this window, it will go unnoticed, although the identical event, should it have occurred at a different time, would have caused interference.

Events which cause latent damage are a second group which will not be reported, illustrated in Figure 6-4. In such cases, a component may be damaged or degraded, but continue to operate normally. Only later will it completely fail. In some cases, the EMI damaged the component and a subsequent stress, EMI related or perhaps entirely different, causes the final and complete component failure. These kinds of events are difficult or even impossible to identify.

A third category is the events which are operationally hidden. EMI occurred but for some reason was not observed. The simplest example would be an event which happens when the operator’s attention is elsewhere. However, there are many reasons why other activities might mask an interference event.

Figure 6-4
Reasons an EMI-Related Event May be Judged to Not be of Interest

Unidentified events which appear as expected events are the last category of unreported events. A sensor may be expected to have a certain number of detections. Hence, a specific report of a detected event may not be note worthy, however its cause could have in-fact been due to EMI and not the reported cause. In such cases, the alarm threshold would have been degraded but this would not be noticed until there were enough real events so that the addition of the EMI related events caused an alarm threshold to be exceeded.

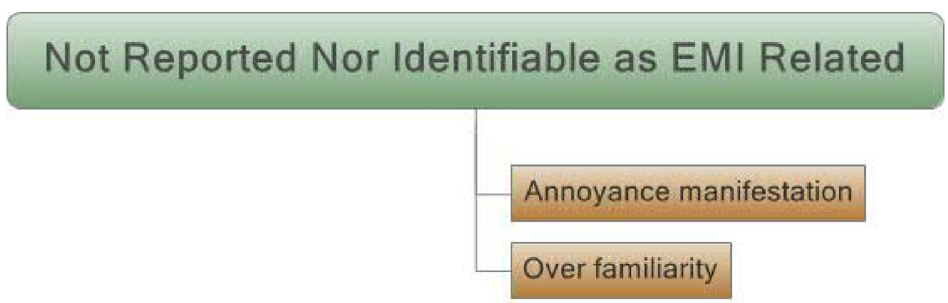

Figure 6-5
Reasons an EMI-Related Event may Not be Reported

A second group of incidents is the events which were not reported for some reason but even if they were reported would not be identified as EMI related. In some cases, the interference may manifest itself as annoyance and the potential for more serious consequences is unrecognized. An example might be some static or popping on a communication link. What can be unrecognized is that under difference circumstances, the interference could have a greater impact and totally disrupt vital communications. It might also be that the operator have become overly familiar with the interference and accept it as normal. ESD can create this category because it is often unobserved and seems to happen randomly. The results of an ESD discharge may, to an operator be “just the way a system functions", not realizing the true cause of the interference nor even identifying it as interference. More will be discussed later on the difficulty of accurately diagnosing an EMI connection for some kinds of events.

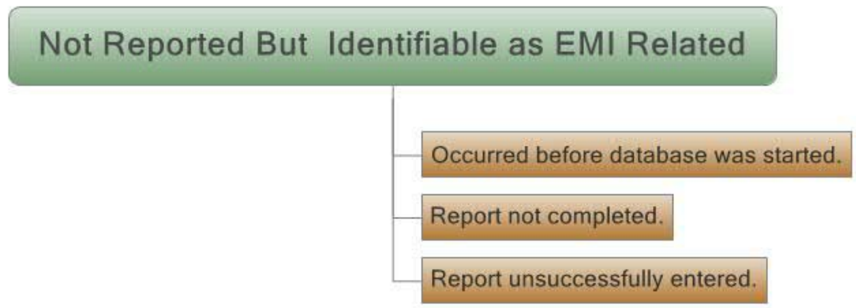

Figure 6-6
Unreported but Identifiable EMI-Related Events

Events which are not reported but which could be identifiable as EMI related make up the third category of unreported events. Some of these are not in the INPO database, because they occurred before the database was created. The NRC and EPRI both have records of some early EMI-related events. One record is found in an LER incident report, where in the discussion of the walkie-talkie interference incident that is the subject of that report, it is stated:

> *At the time of these events, radio operation was prohibited in the first floor of the reactor building and the back panel area of the Control Room due to problems experienced early in the plant's operation.*

NRC IE Circular 80-09 reports a set of interference incidents that occurred in the winter of 1980 at one nuclear plant and the circular advises:

> *3. Determine whether any plant electronic equipment may be adversely affected by portable radio transmissions. This determination should include, but no be limited to, the computer system, electro-hydraulic system, and nuclear instrumentation system; and*
>
> *4. Instruct employees on the use radios in areas susceptible to electromagnetic interference.*

To the extent they are well documented, these are sanitized and are also used in this report. Other reasons for a report not being in the database are that it was not completed or was unsuccessfully entered into the database. There is a possibility that such events might be identified, because they are known and identified as EMI-related. However, for the purposes of this discussion, the possibility must be allowed that known EMI events are not included in this analysis for one of these reasons.

The second major category of events what are not available for analysis, depicted in Figure 6-7, are events in the database which are not identified as EMI related.

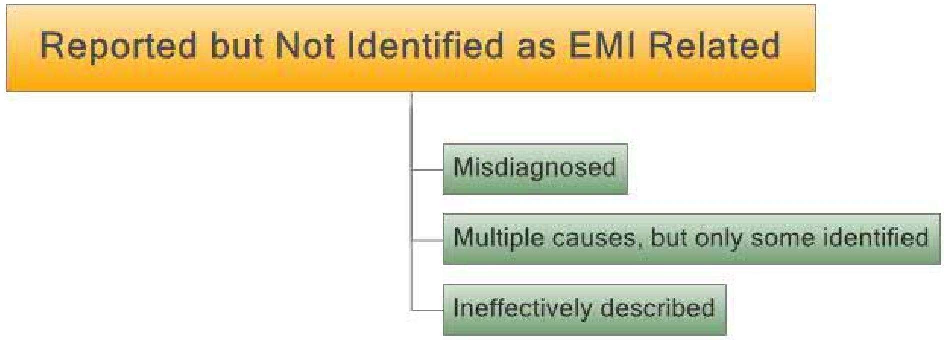

Figure 6-7
Reported but Not Identified EMI-Related Events

An event in the database may simply have been incorrectly diagnosed and the EMI causality missed. In other cases, there may be multiple contributing causes but only some of these were identified. Finally, in some cases the EMI causality may have been identified by ineffectively described in the report. This last category is particularly challenging because EMC has its own vocabulary, as all disciplines do. A non-specialist will likely not be familiar with the correct terminology or use terms incorrectly. The result is that there is a breakdown in communication and the EMI relationship is not understood. This kind of miscommunication, particularly when engineers from different areas of specialization interact, is relatively common. A related problem is that non-specialist may report what they believe to be the important details of an event, but in fact be reporting a lot of unimportant information while failing to report critical information. This problem of communication is an ongoing challenge in areas where multiple specialists must work together.

The net result of the discussion to this point is that there are many reasons why EMI-related events may not be made known for analysis in this report.

It must be assumed that the events analyzed in this report represent only a subset and perhaps a small subset of the total population of EMI related interference incidents.

Figure 6-8 depicts the events which are analyzed in this report. Obviously, there are those events which are both in the database and correctly identified as EMI related. A second category of events will be in the database and identified as EMI related, but risk or consequences of the event will be improperly described. It may be that the potential severity of an event was unrecognized. The risk of more severe consequences being unrecognized may result in the event being described in a way that masks the true importance of the event.

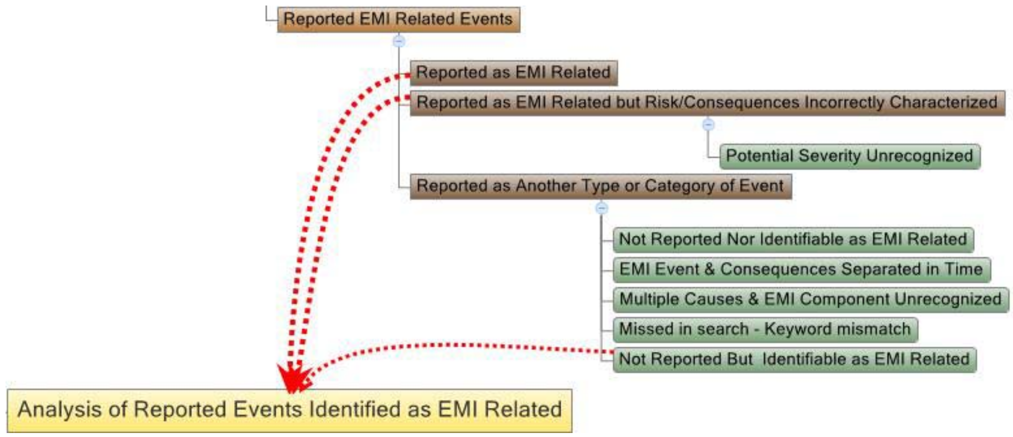

Figure 6-8
Analyzed EMI Related Events

There are a number of reasons that events may be in the database but lost to the purposes of this analysis. The search parameters may have missed some events. Many of the other issues that might cause an event to not be in the database may also cause an event to be in the database but missed for the purposes of this analysis. An example would be an event for which there are multiple causes and the EMI component is inadequately described. Also, the EMI stress may be separated in time from the consequences and so the two are not related.

For all of these reasons, it must be assumed that the events analyzed in this report represent only a subset and perhaps a small subset of the total population of EMI related interference incidents. This understanding is important in evaluating the degree of EMI risk and the appropriate corrective actions to be taken.

Section 7: Systemic Analysis

Systemic analysis seeks to rise above the details of individual incidents and understand the broader picture. It seeks to abstract up from solving interference problems on a case-by-case basis and deal with many problems as a group. To achieve that requires understanding the common elements, the factors that tie many incidents together. Writing about the 2010 Deepwater Horizon blowout explosion and oil spill, one person observes:

> *Viewed broadly, the Deepwater Horizon accident should have been expected. It did not come out of the blue, but out of the system of deepwater drilling. It was a Black Swan event insofar as it was anomalous, unexpected, throwing everyone for a loop – a crisis no one had been thoughtful enough to plan for in advance – but it was also the natural consequence of specific decisions and practices that made it possible and, over time, not so unlikely. The Macondo*[12] *blowout was a bit like the financial crisis of 2008 that sent the US economy into a recession: Something that emerged from a complex system, one in which the participants could not possibly track every moving part or fully comprehend what they were witnessing. In the same way that the bundled financial "instruments" concocted by Wall Street became inscrutably complex, the technology of deepwater oil drilling had become so elaborate that no single individual could possess full clarity on the operation.*
>
> *The presidential oil spill commission discovered that the Horizon disaster joined a long list of mishaps, some of them not well known, in the offshore industry of the Gulf of Mexico. The presidential commission's staff compiled a list of thirty-three major offshore incidents in the gulf, going back to the 1979 Ixtoc I blowout in the Bay of Campeche. Four involved BP, and two involved Arco, which BP had purchased in 2000.*[13]

[12] Macondo was the name of the well the Deepwater Horizon was drilling at the time. So it is equally correct to talk about the Deepwater Horizon blowout, because it was the drilling platform on the well, but the well itself was the Macondo, and so it is also correct to call it the Macondo blowout.

[13] Joel Achenbach, "A Hole at the Bottom of the Sea; The Race to Kill the BP Oil Gusher", Simon & Schuster, New York, 2011, Pg. 241.

What are the patterns and underlying themes of interference events? First, the reporting of events generally tracks the progress of technology. As a new technology rises and comes into increasing use, it finds it way into nuclear power plants, where its electromagnetic characteristics will exhibit themselves. In its 1983 Information Notice, the NRC observed:

> *To date, solid-state devices installed in nuclear power plants have been responsible for all of the known cases of radio-frequency interference (RFI) generated by portable radio transmitters. Three of the four examples cited in this information notice occurred during preoperational testing or early in plant operation.*
>
> *Many of the older nuclear power plants have so few solid-state devices that this explains their apparent invulnerability to RFI generated by portable radio transmitters. As newer plants are built that use more solid-state equipment and as older plants retrofit solid state equipment, more cases of RFI by portable radio transmitters are likely to result.*[14]

So, for a number of very good reasons the then new technology of solid-state devices was adopted for use in nuclear power plants. The older plants had not had a history of electromagnetic interference involving solid-state devices, and so there was little reason to be concerned about a problem that had not existed before.

Then another new innovation came along, the increasing use of portable transmitters. The NRC went on to observe:

> *The use of portable radio transmitters, e.g., walkie-talkies, has been common practice at many operating nuclear power plants, and for the most part, nuclear power plants have shown themselves to be largely, although not entirely, invulnerable to the RFI that such radios generate.*[15]

Older plants had not shown a sensitivity to portable transmitters, and they offered a number of benefits to plant operations. So, there was no reason not to adopt them and gain the benefits they brought. It was the convergence of these innovations that has been shown to be a problem. New technology in the instrumentation and control systems and the then new portable transmitters together had an undesired interaction, resulting in a series of interference problems. It is in the convergence zone of seemingly unrelated innovations that unforeseen problems are likely to emerge. With multiple new innovations, the potential is that ingredients will now be brought together, which have not been brought together before, potentially with unforeseen and disastrous unintended consequences.

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[14] NRC IN 83-83, included as an annex to this report.

[15] NRC IN 83-83, included as an annex to this report.

An example of this kind of risk is created by the current digital upgrades taking place. Digital systems bring a number of changes, some of the less analyzed differences from an EMC viewpoint are that these systems are increasingly controlled by software and their operating characteristics can change by changing the software. An accompanying difference is that these systems have many more operating modes, features and configuration settings. The result is that immunity testing of these systems may miss vulnerabilities because the software in the system during the test did not have that vulnerability. Suddenly, EMC is linked to configuration management and specifically the control of software versions being used in instrumentation and control systems.

A similar risk is created by the tremendous increase in features, functions, configuration settings and operating modes made possible by digital systems. These combine not linearly but combinatoriallly, creating an exponentially growing number of situations to be tested. It is no longer possible to test all the different modes that a digital system can operate in. The problem is made even worse because a digital system may only be sensitive during a particular part of its operation and under certain conditions specific to the process it is intended to control.

Current practice in the industry is for the manufacturer of an instrumentation and control system to contract for and specify the testing of it. This creates multiple problems. First, the vendor has a strong incentive to pass the tests, demonstrating the virtues of the system. The vendor may be tempted to perform "happy path" testing, which means, if there is one way the system can pass the tests, then that is the way we want it tested. However, plant operators are much more interested in knowing if there is one way in which the system can fail the test and have a problem in the plant. Specifying how many operating modes and configurations are to be tested is currently left almost entirely to the vendor. In fact, some vendors refuse to show test reports to plant engineers! The plant operator may have no independent assessment of how the system was tested and how it will perform when subjected to electromagnetic stress. A much better system would be for the plant operator, or a representative of multiple plant operators, to be an integral part of the test plan development for any instrumentation and control system intended for use in a nuclear power plant.

A much better system would be for the plant operator, or a representative of multiple plant operators, to be an integral part of the test plan development for any instrumentation and control system intended for use in a nuclear power plant.

Another unexamined area is the source of the EMC standards used by the nuclear power plant industry. Currently, the industry uses both Mil-Std and IEC EMC test methods. While some adaptation has been made, generally these standards and the pass/fail limits used are largely developed in other bodies for other industries and imported into this industry. Increasingly, only the IEC standards are used and so the remaining discussion will focus on those documents. In contract, some EMC test laboratories may be more comfortable with using the Mil-Std EMC test methods, because much of their core work centers around EMC testing of military equipment.

Section 8: Conclusion and Future Work

This study of EMI-related interference events has found that the number of events has generally increased over the past 20 years. A number of systems and devices have been reported as having suffered from interference.

From the data reported to INPO that was analyzed in this EPRI research, it is concluded that the risk of interference from EMI is significant. Further, many of the reports also report problems with other systems with EMI results in actions to be taken. While EMI events to date have not lead to dramatic failure, it is of concern that a number of events have multiple issues. Statistically, it must be concluded that EMI represents a risk and could combine negatively with other factors to result in a significant safety event.

A deep understanding of the interference physics controlling these events is necessary.

In this report, a multi-level model for EMC protection has been presented, Figure 8-1. The fact of these multiple levels presents the possibility of EMC being implemented with a defense-in-depth philosophy, with multiple and overlapping levels of protection.

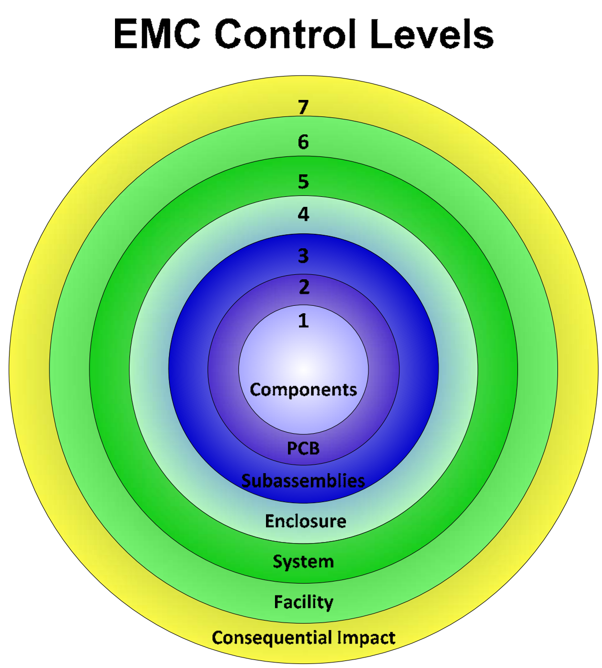

Figure 8-1
EMC Control Levels

Experience in other industries has shown that such an approach is both practical and cost effective, because less protection is needed at any one level when multiple levels contribute a share of EMC protection.

The current system is an ad-hoc collection of limits, test methods and quality systems, with no identifiable system manager.

However, before such a strategy can be pursued a more in-depth and EMC specific study of the EMI incidents is required. A deep understanding of the interference physics controlling these events is necessary. Once this understanding is achieved then the complete catalogue of mitigation measures can be identified and evaluated. The ultimate goal is to develop system designs that provide significantly deeper levels of protection than is currently the case.

The conformity assessment system is also in need of more focused study. The current system is an ad-hoc collection of limits, test methods and quality systems, with no identifiable system manager (or *scheme-owner*). It is clear that from operating experience control loops back into the system should insure that appropriate corrective actions are taken. Currently, it is difficult to determine if a susceptible device was installed due to deficiency in the test methods, limits, manufacturing quality control or any of a number of other factors. The underlying root causes need to be understood. What allows a susceptibility to be introduced and be triggered into an interference event?

Future Work

There are many case projects like this one where it is beneficial to continuing taking a deeper dive into the analysis of undesired events. The value of the knowledge gained from the analysis of such events that can potential result in catastrophic outcomes cannot be underestimated. Using available historical and recent data can reveal not only more detailed information about the nature of events and how they are reported, but can also illustrate a better understanding of events. Just as import is determining how this body of knowledge can be used to develop new relationships between groups and classes of events that can help the industry understand what necessary actions must take place in the future in research, plant design, equipment design, and plant operations to begin reducing the likelihood of EMI-related events occurring in refurbished plants and the new plants currently under design and construction. It is only through careful analysis while considering these relationships that nuclear plant operators will be able to claim that they now have the understanding and data necessary to firmly show that EMI events can be controlled through the application of well-defined procedures while making use of a dynamic conformity assessment system for managing EMC in their plants.

Appendix A: NRC Information Notice 83-83

SSINS No.: 6835
IN 83-83

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF INSPECTION AND ENFORCEMENT
WASHINGTON, D.C. 20555

December 19, 1983

Information Notice No. 83-83: USE OF PORTABLE RADIO TRANSMITTERS INSIDE NUCLEAR POWER PLANTS[16]

Addressees:

All nuclear power reactor facilities holding an operating license (OL) or 1 construction permit (CP).

Purpose:

This information notice is to apprise you of reported instances in which portable radio transmitters caused system malfunctions and spurious actuations in nuclear power plants. No specific action is required in response to this information notice, but it is expected that recipients will review the information for applicability to their facilities.

[16] Available at URL:

http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1983/in83083.html

Description of Circumstances:

Events over the past few years have caused concern in the NRC staff regarding the potential of portable radio transmitters (commonly referred to as walkie-talkies) to cause system malfunctions and spurious actuations. The following four examples describe two events in which a safety-related system was affected and two in which a non-safety-related system was affected.

The first example occurred at Grand Gulf on July 25, 1983, in which shutdown cooling loop B was lost for 30 minutes because of a spurious isolation trip. The isolation was initiated by an RHR equipment area high temperature trip which immediately cleared. Rather than restart the loop immediately, the operators first verified that no leak was present and thus the area high temperature indication was false. Since shutdown cooling loop A was inoperable at the time the reactor water clean up system was used as the alternate heat removal system.

The licensee conducted an investigation, including an after-the-fact interview with personnel who were in the vicinity of the trip circuitry. The licensee concluded that the most plausible cause was an accidental keying of a two-way FM radio near the trip unit. The licensee has and continues to forbid the use of the radios for transmission in the vicinity of the control room or near panels.

The walkie-talkie that was used has a power output of approximately 4 watts in the frequency range of 451-456 MHz. The walkie-talkie was accidently keyed in the upper cable spreading room which is the location of the RHR equipment area high temperature trip unit (a Riley temperature switch model PTGF-EG.) This temperature switch is a solid state device that is connected by 16 AWG copper shielded cable to a thermocouple.

The second example of a spurious actuation caused by a walkie-talkie occurred at Sequoyah 1 on May 31, 1979. A health physics technician who was in the in-core instrument room was attempting to communicate with the control room when he keyed his walkie-talkie resulting in a spurious signal to all four channels of pressurizer pressure initiating a safety injection. The in-core instrument room is located inside containment. The event was duplicated intentionally with the same results.

The third example occurred at Three Mile Island on February 19, 1982. Workers were preparing to enter the containment for some cleanup work when combustible gas monitors they were carrying indicated the presence of hydrogen and low levels of oxygen. The workers became suspicious when the readings varied with the use of their face mask radios. Later gas sampling outside of containment verified that the face mask radios caused false readings on the combustible gas monitors.

The fourth example occurred at Farley in 1975. During initial energization of a 600-V load center, a false operation of the transformer differential relay was observed. The licensee determined that the Differential Relay Type 12 STD

15B5A is radio frequency sensitive and trips with an activated transceiver located within approximately five feet of the relay. A test revealed that the activated transceivers, having frequencies between 150 MHz and 470 MHz with power ratings of 5-watt input to the final radio frequency amplifier and placed within a radius of approximately 5 feet of the relay, caused the differential relay operation. As a further test, the relay was subjected to test currents of 0.5 amps and 5 amps applied to the restraint windings to determine if the relay was less sensitive to radio frequencies under simulated operating conditions. This test again resulted in a false operation of the relay.

This GE Type STD differential relay is a solid state device with certain parts mounted on a printed circuit board which apparently pick up a signal from a transceiver and feed it into the relay amplifier. This would result in the amplified signal passing into the operate section of the relay which causes the false operation.

Discussion:

To date, solid state devices installed in nuclear power plants have been responsible for all of the known cases of radio frequency interference (RFI) generated by portable radio transmitters. Three of the four examples cited in this information notice occurred during preoperational testing or early in plant operation.

Many of the older nuclear power plants have so few solid state devices that this explains their apparent invulnerability to RFI generated by portable radio transmitters. As newer plants are built that use more solid state equipment and as older plants retrofit solid state equipment, more cases of RFI by portable radio transmitters are likely to result.

The use of portable radio transmitters, e.g., walkie-talkies, has been common practice at many operating nuclear power plants, and for the most part, nuclear power plants have shown themselves to be largely, although not entirely, invulnerable to the RFI that such radios generate. When such RFI has been demonstrated to be a problem, nuclear power plants have successfully dealt with the problem by prohibiting the use of portable radio transmitters in certain areas. Nevertheless, the vulnerability of safety systems and non-safety systems to inadvertent actuation or malfunction poses a significant threat to safe operation of the plant if the measures to prevent use of radio transmitters fail under emergency situations.

Emergency situations in which posted restrictions on the use of portable radio transmitters are likely to break down include those instances in which individuals other than plant operating personnel may be present in the plant or in which operating personnel are performing non-routine functions. Such situations include but are not limited to firefighting, bomb searches, and local operation of equipment normally performed from the control room.

Plans for dealing with such emergency situations require consideration of the possibility for RFI if the nuclear power plant has a demonstrated or implied vulnerability. When solid state equipment is retrofitted into an existing plant, the potential for RFI vulnerability suggests that the licensee should evaluate the impact on plant operation and safety.

The use of the increasingly popular cordless telephones presents another possible source of RFI.

If plant operations make the use of portable radio transmitters near RFI sensitive equipment either necessary or likely in an emergency, then administrative prohibitions are not adequate and the licensee should consider hardware fixes. Typically such fixes include use of filters, shielded cables, and modification of the affected equipment. Although there are many industrial standards regarding RFI protection techniques, the NRC has not formally adopted or endorsed any, nor are there any nuclear standards that specifically address RFI protection.

As part of a wider program, the NRC is conducting research in the area of electromagnetic interference (EMI), including RFI as one of its aspects.

Edward L. Jordan Director
Division of Emergency Preparedness and Engineering Response
Office of Inspection and Enforcement

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List of Recently Issued IE Information Notices

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Page Last Reviewed/Updated Wednesday, February 16, 2011

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