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Applications of Current Technology for Continuous Monitoring of Spent Fuel

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ABSTRACT

Advancements in technology have opened many opportunities to improve upon the current infrastructure surrounding the nuclear fuel cycle. Embedded devices, very small sensors, and wireless technology can be applied to Security, Safety, and Nonproliferation of Spent Nuclear Fuel.

Security, separate of current video monitoring systems, can be improved by integrating current wireless technology with a variety of sensors including motion detection, altimeter, accelerometer, and a tagging system. By continually monitoring these sensors, thresholds can be set to sense deviations from nominal values. Then alarms or notifications can be activated as needed.

Safety can be improved in several ways. First, human exposure to ionizing radiation can be reduced by using a wireless sensor package on each spent fuel cask to monitor radiation, temperature, humidity, etc. Since the sensor data is monitored remotely operator stay-time is decreased and distance from the spent fuel increased, so the overall radiation exposure is reduced as compared to visual inspections. The second improvement is the ability to monitor continuously rather than periodically. If changes occur to the material, alarm thresholds could be set and notifications made to provide advanced notice of negative data trends. These sensor packages could also record data to be used for scientific evaluation and studies to improve transportation and storage safety.

Nonproliferation can be improved for spent fuel transportation and storage by designing an integrated tag that uses current infrastructure for reporting and in an event; tracking can be accomplished using the Iridium satellite system. This technology is similar to GPS but with higher signal strength and penetration power, but lower accuracy.

A sensor package can integrate all or some of the above depending on the transportation and storage requirements and regulations. A sensor package can be developed using off the shelf technology and applying it to each specific need. There are products on the market for smart meters, industrial lighting control and home automation that can be applied to the Back End Fuel Cycle. With a little integration and innovation a cost effective solution is achievable.

1.0 Introduction

Advancements in microprocessors, wireless technology and encryption have opened opportunities that previously were not available to the nuclear sector. The back end of the nuclear fuel cycle needs more attention to continuous monitoring of spent nuclear fuel. Applying current technology to continuous monitoring of spent nuclear fuel can improve Security, Safety and protect against proliferation. Integration is the key to the improvement of current methods. By integrating modern microcontrollers with sensors and wireless communication, a platform to improve current monitoring capabilities can be achieved.

2.0 Current Technology

As embedded device manufacturers have increased processor speed and RAM size, the ability to implement complicated algorithms has become possible. These advancements make it possible to produce very small, fast and low powered devices such as tablets and smart phones. Microcontrollers have advanced to the point where they are used in almost every small electronic device. A processor in a smart phone is capable of running an operating system, encrypting a connection to a 4G network and simultaneously running a high level game in the palm of your hand. Smartphones are also low powered devices that have long battery life for the type of operations they perform. This same technology can be implemented to monitor spent nuclear fuel.

Information security is one of the biggest challenges in the nuclear industry today. Using an ARM processor similar to the ones used in modern smartphones and implementing accepted encryption methods (i.e. Advanced Encryption Standard (AES) and Suite B based Public Key Infrastructure (PKI)) a FIPS-140-2 certified device can be achieved. This would allow Sensitive or even Classified information to be passed securely to its destination.

Using on board encryption combined with wireless technology allows secure wireless communication in a small package. Implementing a small wireless sensor platform would limit the impact on current infrastructure. By limiting the impact on infrastructure, costs can be decreased drastically. Several avenues for wireless communication are currently available, including: Magnetic Field Wireless, 802.11 (Wi-Fi), and 802.15.4 (Machine to Machine). Using commercial-off-the-shelf equipment, SRNL has demonstrated several methods of communicating with sensors located inside the containment vessel of various type B certified packages. Some examples of these tests are discussed below.

Using Visible Assets Magnetic Field Wireless, SRNL successfully demonstrated a communication link with sensors located within a closed 9977/9978 containment vessel. (Reference 3) This successful demonstration proves the concept that wireless communication with sensors located within a variety of shipping and storage casks may be possible.

Figure 1. Visual Assets, RuBee tags being tested in 9977/9978 package (Left) and from in a containment vessel that is inserted inside of the 9977/9978 (Right). (Reference 3)

On-Ramp Wireless developed a wireless point to point radio that has the ability to receive a signal below the noise level of standard RF. On-Ramp's Access Point has a receive sensitivity of -133 dBm. This represents a major improvement over the -90 dBm receive sensitivity of most common 802.11 Wi-Fi radios. This improved receive sensitivity allows for transmission of wireless data up to 17 miles with line of sight and increases the ability to communicate through obstructions. The same test, described above, accomplished with the Visible Asset Magnetic Field Wireless system was also successfully completed using the On-Ramp System. The On-Ramp wireless node was able establish a communication link with a radio closed inside the of a 9977/9978 package and from within the lead internal vessel of a 9975 package. (Reference 2)

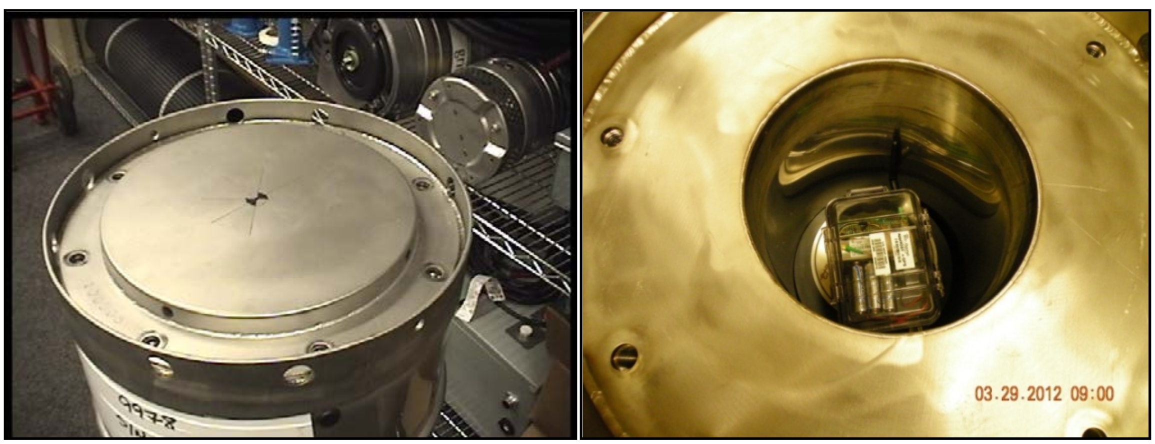
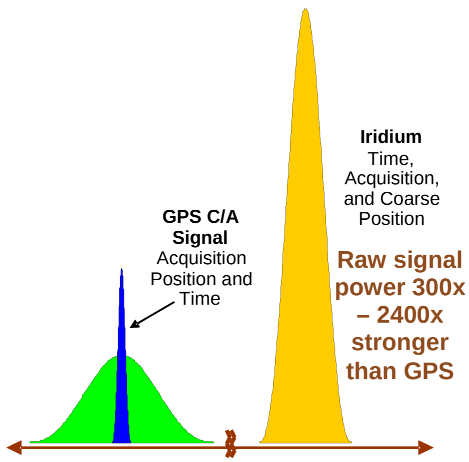


Figure 2. On-Ramp Wireless radio node being tested in 9977/9978 package (Left and Right). (Reference 2)

The Iridium satellite constellation can be used similarly to the GPS satellite constellation to provide global position data. The Iridium system has a 30db signal strength improvement over GPS, but location accuracy is only around 30 to 50 meters. However the Iridium system works in many environments where GPS fails to provide position information. Iridium provides acceptable signal levels in buildings and urban areas where GPS fails. This technology is being tested at SRNL with excellent results. (Reference 1) This new technology can be used in tagging and tracking of the spent nuclear fuel during storage and while in transit to storage. When the Iridium system is used in conjunction with GPS, a combined platform with a high level of accuracy and penetration capability can be achieved. The Iridium system also allows for an uplink or 2 way communication which could be utilized for extended tracking.



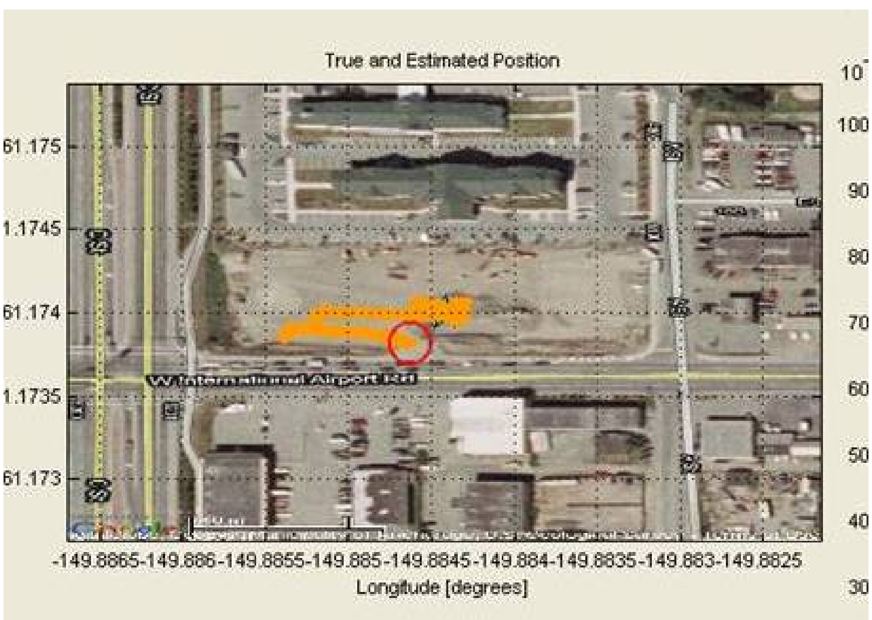
Iridium provides a much "louder" signal than GPS. This signal when properly utilized can penetrate buildings.

Iridium Satellite

Other technical advantages:

- **<u>Reduced handset power consumption</u> due to fast acquisition**
- **<u>Ubiquitous Coverage</u>, i.e. available regionally or globally with no roaming issues**
- **<u>No Additional Carrier Infrastructure Required</u>**

Figure 3. Iridium vs. GPS signal strength (Left) and an Iridium Satellite (Right). (Reference 1)



Note that the Satellite Image was taken before the hotel was built

Figure 4. Tracking inside the 6-story Crown Plaza Hotel Anchorage, AK. (Reference 1)

Energy harvesting is the conversion of one form of energy to usable electrical energy. Advancements in energy harvesting can be utilized to extend the operating time of devices in hard to access areas. Energy harvesting types include thermal, radiation, vibration, solar and wind. A perpetual system can be achieved by integration of energy harvesting technology to a low power embedded device.

Once a platform is developed, different sensors can be integrated to indicate tampering, characterize operating parameters or continually monitor alarm conditions. For example a sensor platform with an accelerometer installed on the inside of a cement cask can be calibrated to indicate tampering from vibrations. With the sensor platform inaccessible from the outside of the cask, the tamper indicator would trip and notify someone before it is reached. An airflow sensor could indicate that the vents have been blocked and send an alert to the appropriate personnel. A radiation sensor can be used to indicate a leak or take extended radiation data continuously. Temperature and humidity sensors can be used to better understand stress corrosion cracking. Small low powered cameras can be used to periodically check different aspects of the spent fuel casks. Just about any small sensor can be implemented once the base platform has been designed.

3.0 Application Significance

Safety aspects that can be addressed by continually monitoring spent fuel casks are stress corrosion cracking, containment, and ALARA for personnel around the spent fuel casks. A platform that monitors temperature and humidity to characterize the environmental conditions that cause stress corrosion cracking is currently under development at SRNL. It is being developed using an off the shelf radio node and a serially connected temperature and humidity sensor.

A small radiation sensor linked to a wireless sensor platform could trigger a containment alarm or characterize the radiation levels in close proximity to the cask. This would give an early warning to a containment leak in the area. Collecting this data could also be useful to determine if a slow leak is in progress.

One safety concern that can be addressed with a wireless sensor platform is monitoring the airflow or the temperature of the inlets and outlets of the spent fuel casks. This sensor platform would remotely monitor for any restriction of the air flow that help cool the spent fuel casks. Monitoring is currently done visually by personnel walking around the casks. Not requiring personnel to manually do these checks by performing them remotely, ALARA and maintenance cost would be improved.

The current solution for securing spent nuclear fuel is to monitor and limit physical access to material. The self-securing aspect of spent fuel is valid but there are individuals which death from the radiation exposure is no longer a deterrent. There are two methods in which physical security is accomplished. First is monitoring the spent fuel areas with security cameras and motion detectors. The second is restricting physical access using fencing and guarded gates. This is a reliable method but, with the advancements in the commercial industry over the past few years, security can be improved.

Protection against proliferation can be addressed by a wireless tagging and tracking system. Using a combination package of Iridium and GPS produces accuracy as well as high signal strength. If the Iridium and GPS were combined with a high end accelerometer and a fast microprocessor a near exact location can be calculated and relayed to monitoring personnel.

4.0 Integration

The key to improving current monitoring systems is to monitor in close proximity to the Spent Fuel Casks. A low powered wireless sensor node is the ideal platform. A low power device ensures extended usage in areas where maintenance may not be an option. Coupling the sensor platform with energy harvesting technology extends its use in unreachable and environmentally hostile areas.

Design Requirements for a Sensor Platform:

1. Low Power Battery Device (Energy Harvesting)
2. Wireless Communication
3. Environmentally Hard (Radiation, Temperature, and Humidity)

4. On Board Encryption at an Acceptable Government Level (FIPS-140-2)
5. Multiple Sensor Inputs (SPI, USB, Serial, I2C, Ethernet, Analog, Digital)
6. Tamper indicating sensors

The above sensor platform can be used to improve Safety, Security and Non-Proliferation. A multi-use integrated platform can be installed when the spent fuel is loaded into a transportation package and tracking it to its destination. The sensor node could remain with the package until storage while transmitting important safety and security related sensor data. The key is to design a secure, reliable platform with the versatility to be used for multiple applications. It could be installed on or within the stainless steel package protecting it from tampering. The sensor platform could harvest heat or radiation from the spent fuel to extend its battery life.

Sensor possibilities include:

- Radiation Detectors (Safety Alarms and Data)
- Accelerometers and Motion Detectors (Tamper Indication)
- Gas Detectors (Leak Detection)
- Temperature, Humidity, and Chloride Sensors (Data for Stress Corrosion Cracking)
- GPS and Iridium (Tagging and Tracking)
- Small Cameras (Visual Detection and Data Collection)
- Air Flow Sensor (Safety Alarms and Tamper Indication)
- Pressure Sensors (Safety Alarms for Containment Pressure)
- Device Tamper Sensors (Security Alarms for Tampering with Sensor Platform)

5.0 Conclusion

The Safety, Security and Non-proliferation aspects of the nuclear industry can be enhanced by utilizing current technology. The advancements in microelectronics and wireless communication in the last 10 years have been so drastic that applications that were not possible can now be achieved. The information security aspects that previously hindered embedded devices from participating in classified or sensitive applications have been addressed. If a combined sensor platform was developed it could be monitored by multiple parties and achieve much more than could be achieved separately. This combined platform would be cheaper, more effective and would continually monitor through the spent fuel life cycle from loading to transport to storage.

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