AREVA's Spent Fuel Pool Level Measurement Solutions

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Abstract: Reliable Monitoring of the water level in Spent-Fuel-Pool (SFP), also under degraded ambient conditions, is an essential function from the safety engineering point of view, and has become increased attention recently, as a consequence of the Fukushima accident. The proven and innovative solutions by AREVA NP focus on the fulfillment of the different customer requirements and provide complementary solutions for New Builds and modernization projects worldwide with Augmented Quality (AQ) as well as 1E-qualified severe accident resistant solutions fulfilling post-Fukushima and latest safety authorities requirements.
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1 Introduction

Prior to the accident at Fukushima Daiichi, SFP level monitoring were provided to allow operators to determine that water level remained below the point where flooding of operational areas would be a concern and above the level assumed in safety analyses that evaluated the release of fission products from the pool in the event of a fuel handling accident, so in general for many countries, as operational and non-classified instrumentation. Meanwhile and as a consequence of the Fukushima Daiichi accident in March 2011, new scenario need to be taken into account in case of total loss of SFP cooling, with fall of water level down to the fuel element top, thereby considering related new functional requirements for robust and post-accident SFP level measurement.

2 SFPs description

Following features describe most of the SFPs:

- Storage pools for spent fuel from nuclear reactors (either outside or inside containment).
- They are typically equipped with storage racks designed to hold fuel assemblies removed from the reactor.
- Pool depth is 12/14 m and fuel racks are at about 8 m from water surface
- Spent fuel rods generate intense heat and radiation. (8 Mrad/year)
- The water cools the fuel and provides shielding from radiation. About 8 feet (2.5 m) of water is needed to keep radiation levels below acceptable levels.

The SFP level measurement available before the Fukushima accident did respond to different requirements in different countries:

- <u>USA</u>: No general requirement, Non-Classified (NC) devices for first 1-2 meters, some temporary use during outages,
- <u>China</u>: Redundant switch for first 1.5 meters, temperature and radiation measurement, all NC with normal power supply,
- <u>France</u>: Redundant level switches for first 1-2 meters, NC. in 900MW-fleet, one single analog measurement by radar, NC and not used in post-accident operation with local gauge glass on pool wall.
- <u>Germany</u>: Safety related level measurement.

SFP are normally in continuous operation and can be shut down for short operations, in particular during the filling of the transfer area. A cooling water circuit operates so as to evacuate residual power. SFP water temperature is generally maintained at 50°C. Normal evaporation (5cm/week) is compensated by demineralized water makeup. Following a loss of all cooling systems, the water will be in ebullition after a few hours.

3 SFP new requirements

During the accident at Fukushima-Daiichi, explosions occurred in the reactor buildings of units 1, 3 and 4. Hydrogen release from fuel in the spent fuel pool, due to loss of water inventory had to be considered as a possible cause of the explosions. Instrumentation suitable for checking this hypothesis was not installed and operators could not directly check pool level because of radiation levels and other hazards in the reactor building. Consequently, plant operators had to take action on the assumption that pool inventory had decreased.

Eventually, it was learned that conditions in the fuel pool had never threatened the integrity of stored fuel. Thus considerable resources had been diverted from activities to restore core cooling because of the lack of appropriate fuel pool level instrumentation.

This experience points the need to provide plant operators with instrumentation that allow them to understand the state of spent fuel cooling under design extension conditions. In this sense, new requirements were to be formulated to fulfill the functions required not only for operational state but also for design basis condition (DBA) and design extension conditions (DEC).

The different actions taken since the accident are different between the countries:

France: Functional requirements were updated after Fukushima accident with new requirements and considering now not only normal operation but also ensure Post-accident operation with a robust SFP instrumentation to cope with:

- total loss of SFP cooling,
- fall of water level down to the fuel elements top,
- Fuel elements dewatering,

Following this approach, following new requirements were defined by French authority:

- Seismic qualification: Integrity during and after seism, operability after seism. Acceleration 0,35 to 0,5 g (ground), to be expressed for SFP,
- Harsh environment qualification (K3ad acc. RCC-E),
  - Water temperature: 100°C (212°F)
  - Ambient air temperature: 100°C / 100% humidity
  - Available in post-accident ambiance
- Classification: IPS-NC (non 1E, important for safety)
- Power supply
  - Secured in case of total loss of power supply (battery, diesel, DUS)
  - Keeping of adjustments in case of power loss
- Accuracy: no quantified requirements at this stage

US: In March, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued order EA-12-051[1], directing U.S. utilities to install reliable, wide range spent fuel pool level instrumentation in each spent fuel pool. The NRC has determined that the enhanced SFP level instrumentation required by this order represents an increase in protection to public health and safety. The Order required to be fully implemented by December 2016. The Nuclear Energy Institute (NEI) prepared report NEI-12-02[2] to provide guidance to utilities in complying with the order, Main requirements issued from EA 12-051 order:

- One fixed primary channel + one fixed or portable backup
- Protection against missiles that may result from damage to the structure over the spent fuel pool
- The primary instrument channel shall be independent of the backup instrument channel.

- Mounted to retain its design configuration during and following the maximum seismic ground motion
- Reliability at temperature, humidity and radiation levels consistent with the spent fuel pool water at saturation conditions for an extended period.
- Alternate power connection independent from plant power distribution
- The instrument channels shall maintain their designed accuracy following a power interruption or change in power source without recalibration.
- Testing and calibration capabilities
- Display location in MCR or other accessible location

Moreover, the accurate measurement of the Spent Fuel Pool level will be necessary for instance to detect and differentiate even more different levels, like, as before, Risk of overflow, but also for new Safety-related levels to be defined, like Risk of loss of cooling, assumptions for dropped fuel assembly not met, Inadequate shielding for workers and for risk related to Fuel exposure, for example.

4 AREVA's Solution for SFP level post-Fukushima requirements

4.1 The Radar-based-solution (AQ)

The measuring principle of AREVA's Radar-based-solution is based on through-air radar technology (TAR) which emits short microwave pulses from the sensor, through the waveguide and horn, to the measuring level (water in SFP) and returns. The time from emission to reception of the signal is proportional to the measuring level. The system is Augmented Quality AQ.

The Radar-based SFP level measurement System is well-suited for new as well as for existing pool installations. Major advantages are:

- no fixation points needed on the SFP liner itself (nothing in the pool),
- Positive references and feedback (37 systems and 14 clients as of today, mostly US but also Spain and Taiwan),
- Proven Off-The-Shelf technology (10,000 Radar-based-solution uses)
- Minimal maintenance, surveillance requirements and FME
- No radio exclusion zones like other systems
- Low power consumption
- Auto transfer to battery backup
- Self-Diagnosis and Trending functions
- Proportional 4-20mA output for interface with other plant systems such as Plant Process Computer (PPC)

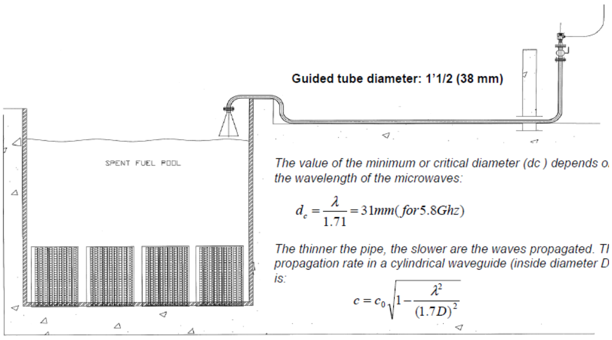

Fig.1: Radar-based-solution

The Technical data of the Radar-based solution are as following:

- Measurement Range: up to 9.1 meters
- System Length: Horn to Sensor: 60 meters, from Sensor to Power Control Panel (PCP): 50 to 300 meters
- Temperature: Horn/waveguide: >100°C Sensor: 80C PCP: 60°C
- Radiation: Horn/waveguide: N/A (stainless steel parts), Sensor/PCP: 10^3 RADs
- Humidity: 100%
- Power: Consumption: <10 watts
- Backup Supply: Auto-transfer with at least 7 days backup capability Accuracy: Within 7 cm (Can go to 2.5 cm depending on layout) Customers reporting accuracy within 1.5 cm
- Seismic: 14g based on EPRI TR-107330

- Seismic , Shock and Vibration, Temperature, Humidity, Radiation Exposure, Accuracy and Repeatability

The Radar-based System meets or exceeds NRC Requirements per USNRC Order 12-051 (Order Modifying Licenses with Regard to Reliable Spent Fuel Pool Instrumentation) for operation during and Beyond Design Basis Events (BDBE)

Fig.2: Through air radar: demonstration in Lynchburg

AREVA's Radar-based System also meets or exceeds all NEI Requirements per NEI 12-02 (Industry Guidance for Compliance with NRC Order EA-12-01) for operation during and Beyond Design Basis Events (BDBE). In this sense, the Radar-based-solution is the ideal solution for US-based NPPs worldwide, as well as for the French fleet requirements, for example.

4.2 AREVA's ALM-solution (1E-classified)

The ALM (Accident Level Measurement) Device is designed to function during and after the occurrence of a postulated severe accident event under extreme pressure-, temperature- and gamma radiation conditions as well as under seismic events.

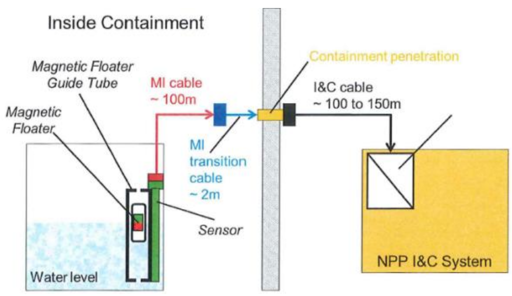

Fig3: ALM-measurement principle for SFP

The related development and qualification program has been launched in 2008 for the EPR^{TM} Nuclear Power Plant and the related increased design basis events and severe accident requirements to monitor the water level in the In-containment Refueling Water Storage Tank (IRWST), with extreme environmental conditions going up to 5 MGy and increased temperature up to 156°C[3][4].

Fig4: Several ALM-instrumentation for OL3

The accident level measurement devices are operating on the principle of a magnetic floater actuating reed contacts connected to a chain of resistors. The integrated sensor unit consists of a guide tube housing the floater and a reed-switch guide containing the reed-switch unit. For the different areas of application several types of measurement ranges are available. This device was designed without organic materials or any active electronic components to ensure robustness, simplicity and reduced qualification duration for accident conditions.

Currently the Technical parameters of ALM are as follows:

- Lengths: 0.4 – 17 m (other possible)
- Weight: 33 kg (for 4 m sensor)
- Operating temp.: 70°C
- Operating press.: Ambient
- Humidity: 100 %
- Operational rad. dose: ≤ 160 kGy
- Accident temp.: 200°C
- Accident press.: 5.5 Bar abs.
- Accident mission time: 1 year

• Accident rad. dose: ≤ 20 MGy
• Seismic acceleration: ≤ 5 g

5 Summary

In the aftermath of the Fukushima accident, utilities have started to reassess the safety margins of their nuclear power plants in order to develop action plans for possible plant upgrades. One requirement of such a safety analysis is the necessity to enhance the robustness of the storage pool monitoring system. The transcription of this increased robustness is made differently by the different countries and safety authorities. AREVA's solution portfolio for SPF level measurement provides Customer complementary solutions for AQ-solutions with the Radar-based solution[5] (like for US or France) as well as for 1E-classified extreme ambient conditions with the recent qualified ALM[6].

References

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