Fuel INtegrity Evaluation and Surveillance System (FINESS)

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INTRODUCTION

Fuel failures in nuclear power plants can create consequences ranging from somewhat increased releases of radionuclides to the environment, worker hazards (from exposure to contaminated coolant and fuel bundles) to unplanned shutdowns of the reactor. These failures always lead to some noble fission gas (FG) release, but can also result in the release of volatile fission products (VFP), especially iodine radioisotopes, fissile material (mainly "tramp" uranium) and long-lived, alpha-emitting transuranium nuclides. Additionally, an increase in the levels of ^{60}Co activity outside the core is often observed following severe fuel failures, causing an indirect radiological consequence of fuel rod defects with loss of fissile material. This “tramp” uranium layer is also a source for all fission products (released by direct recoil), Np and other transuranium nuclides; this contribution continues even after the failed fuel assembly has been removed from the core. The latter types of activity release can sometimes result in operational restrictions, increased personnel radiation exposure during outages, and increased amounts of long-lived waste, and are the most important consequences of fuel failures. Any decisions regarding actions to be taken in the event of a fuel failure should be based on the best available information regarding the expected development and consequences of that particular failure. Prompt, detailed, and accurate fuel failure detection in addition to the evaluation of the failure type and its severity is, therefore, very important for the operation of a nuclear power plant. On-line, prompt indications concerning stress of failed fuel due to normal control rod movements can also prevent unnecessary degradations. Early detection and location of a failure increases the chances of reducing or delaying its degradation by adjusting the reactor operation if necessary, and increases the lead time available to plan a possible failed fuel replacement outage, etc.

In recent years, an increased awareness of the negative consequences of severely degraded fuel failures has led to a search for "remedies": design or materials features to prevent or mitigate fuel failures or secondary degradation, and optimum strategies for plants which experience failures. ABB Atom has a long and successful experience of nuclear power systems, including nuclear fuel integrity, and has focused its efforts toward maximizing the fuel reliability and to achieve “Zero-Failure Fuel”. Based on this experience, ABB is developing the **F**uel **IN**tegrity **E**valuation and **S**urveillance **S**ystem (**FINESS)** in collaboration with ORTEC and Forsmarks Kraftgrupp AB.

FINESS is an on-line nuclide specific off-gas monitoring system designed to evaluate the integrity of nuclear fuel by analyzing the noble gas activity levels in the reactor off-gases. Without the real-time measurement and evaluation process, traditional methods of monitoring the fuel integrity can misdiagnose the problem. With **FINESS**, the type, size, and severity of the fuel failure can be determined with recommendations for proper actions to minimize the degradation of the failure and its consequences. Once a fuel failure has been detected, it is possible to locate the leaking assembly (to the nearest control rod super-cell) by power suppression testing/flux tilting. If flux tilting is to be performed, there are a number of points to consider since the flux tilting itself may pose a risk of increasing the secondary degradation due to local power changes. Flux tilting should therefore be carried out at a reduced reactor power, in such a way that the fuel is not subjected to power ramps above its previous operating level. This is particularly important if there are any fuel failures with some secondary degradation or PCI, where local power ramping might possibly lead to PCMI cracks. A time reduction during the power suppression testing/flux tilting operation therefore automatically leads to significant cost savings.

SYSTEM DESCRIPTION

FINESS consists of a High Purity Germanium (HPGe) detector system, digital signal processing electronics (DSPEC*PLUS*), and a data evaluation system (see **Fig. 1**).

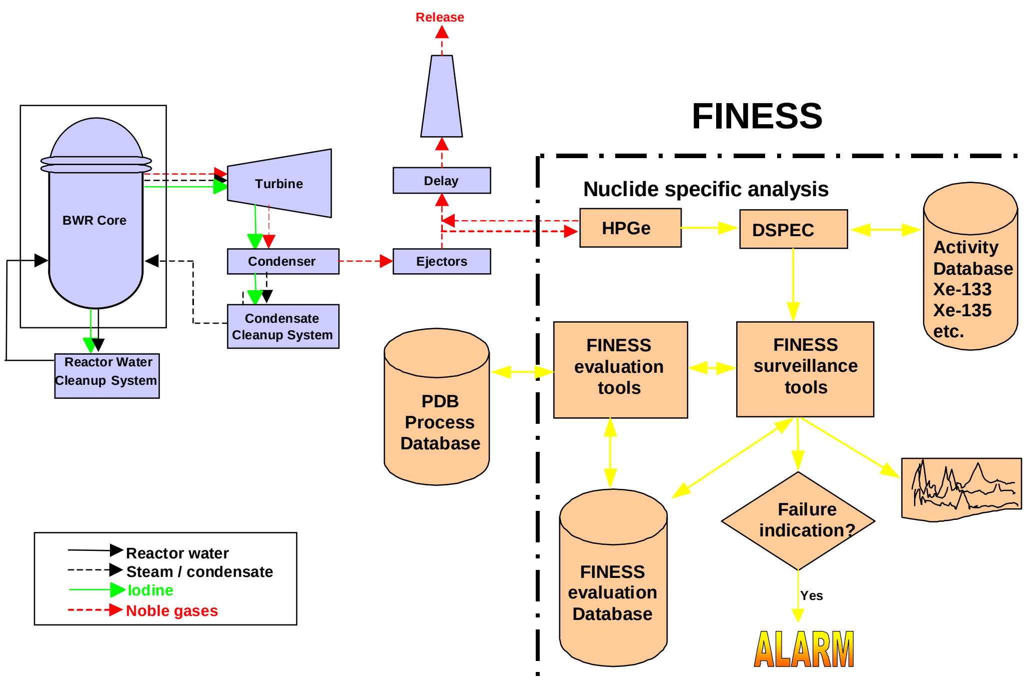

Fig 1. FINESS offers instant and reliable fuel failure detection and ability to determine failure type and degradation.

The HPGe system s a standalone unit (see **Fig 2.**) which analyzes and records the noble gas activity in a continuous manner and provides the nuclide specific results to the data evaluation system, which is a software package that can be installed in most available computer systems.

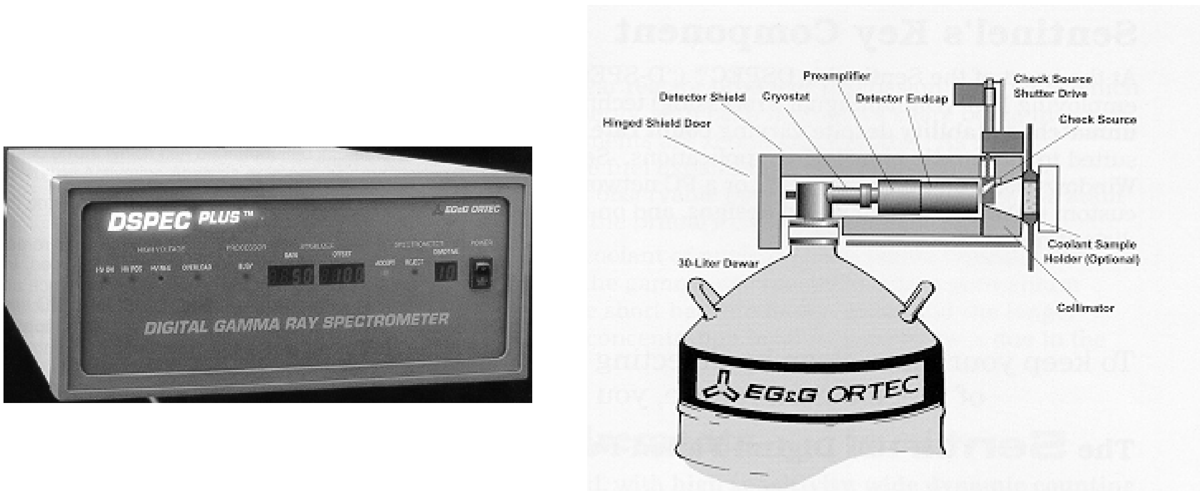

Fig 2. High Purity Germanium (HPGe) detector system with digital signal processing electronics (DSPEC^{PLUS}).

While several detector and electronics combinations are available, the selection of the SGD-36550 Planar detector with the DSPEC^{PLUS} electronics offers several advantages. The key features necessary of this real-time monitoring system include (1) reliable results over a long period of measurement, (2) stability over count rates ranging from 10^5 to 10^{11} Bq/m^3. The SGD-36550 planar detector has better resolution capability at high count rates compared to the traditional planar detectors and an efficiency high enough for the 20-300 keV photons expected in the off-gas. As shown in **Fig. 3**, the ability of the detector to differentiate between the low intensity 81 keV photon from Xe-133 is major advantage for the analysis system.

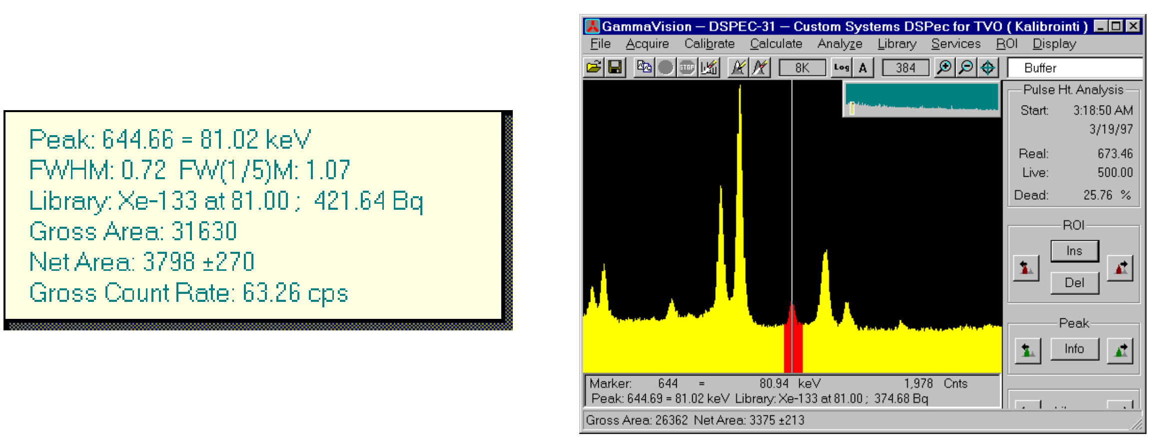

Fig 3. Example of measured gamma spectrum.

When combined with the superior resolution of the SGD-36550 detector, the DSPEC^{PLUS} gives the FINESS acquisition system the ability to fine tune the operation of the detector for the wide variety of count rates expected in such a monitoring system while maintaining the necessary resolution performance of the detector. In addition, peak shifting in long term measurements can be detrimental to the analysis process. Peak shifts due to temperature changes in the ambient environment around the electronics have virtually no affect on the DSPEC^{PLUS}. The proven long term stability performance of the digital signal processing in the DSPEC^{PLUS} supplies reliable data results for the real-time monitoring mode in FINESS.

The design of the shield and collimator assembly, in **Fig. 2**, has been optimized for use in the detection of the low energy photons in the off-gas system. The collimator helps "focus" the low energy photons to the face of the detector. A 1 inch 4π shield is provided to reduce the affects of ambient radiation from high-energy photons. By reducing the interaction of these photons with the detector, the shielding effectively reduces the Compton Continuum and thus the background detected by the system. This allows FINESS to reach its designed sensitivity of 0.1 Standard Pinhole (i.e. 0.2 MBq/s ^{133}Xe).

Data from the process computer and other plant specific information is also entered into **FINESS**. The evaluation software normalizes the on-line measured off-gas activities to the current reactor power, off-gas flows, decay during transport from core etc., and correlates the measured off-gas data to control rod movements, power changes, changes in manually measured coolant activities etc. Based on this information, the occurrence of a fuel failure will be detected and an alarm generated in the control room within a much shorter time frame and much higher reliability than by using gross gamma or beta alarm detectors and traditional "grab sampling". Diffusion analysis (different ratios between long and short lived nuclides indicates that they are released either by diffusion through fuel pellets or by recoil from uranium on the cladding surface, i.e. from "tramp" uranium), are used to detect the occurrence of fuel rod failures and follow their potential degradation. In general, the higher the existing background activity level due to previous failures or tramp uranium, the more difficult it becomes to detect new primary failures. The unique features of **FINESS** makes it possible to detect both very small primary failures at very high background activity levels and severe fuel failures causing high activity release. The system also recommends consequential plant operational strategies based on extensive database and make it possible to analyze coolant activity data, stored on external databases, to estimate fuel washout, iodine release etc.

The first "Pilot System" of **FINESS** will be installed in one of Forsmarks power plants during the winter 1999-2000.

BENEFITS

FINESS aids the nuclear power plant operators in determining the onset and severity of fuel element failures. The use of the automated analysis system during the flux tilting procedure, to locate the fuel failure, reduces the time required by personnel to make the measurements and also the dose received by the personnel during the sample preparation process. Using the grab-sampling method, the plant may utilize 4 to 6 full time personnel for up to 4 days to complete a flux tilt process. These results, however, are less accurate than the on-line method because of uncertainties in sample volumes, accuracy of the sample collection time, and the choice of detection and analysis systems in the counting lab which may not be optimized for the work to be done.

The FINESS system can give instantaneous and accurate results from its real time monitoring system. By integrating the plant specific data with the analysis results, the plant is assured of the accuracy of the results. By performing all these calculations in a computer-based system, FINESS removes the uncertainty and potential for misinterpretation of the results when calculated by hand. Again, as this is done in an on-line manner, the results during the flux tilt process become more meaningful more quickly to the plant control room operators. The system also gives reliable on-line indications concerning leakage from failed fuel during normal control rod movements preventing unnecessary stress and thereby degradation.

By using the FINESS data acquisition system and following the recommendations of the expert analysis system, the plant can take remedial action to prolong the fuel cycle. Alternatively, plant management can plan the removal of the failed fuel in such a way as to reduce worker exposure by knowing beforehand which elements have failed.

SUMMARY

FINESS is an on-line nuclide specific off-gas monitoring system designed to evaluate the integrity of nuclear fuel by analyzing the noble gas activity levels in the reactor off-gas. The system is under development by ABB Atom in collaboration with ORTEC and Forsmarks Kraftgrupp AB. The first “Pilot System” of **FINESS** will be installed in one of Forsmarks power plants during the winter 1999-2000. With **FINESS**, the type, size, and severity of the fuel failure can be determined with recommendations for proper actions to minimize the degradation of the failure and its consequences. **FINESS** produces instant, reliable results operating under a wide range of counting conditions (high/low count rate, contamination build-up, temperature drift, etc.) with the end result being a reduction in performance time of the flux tilt procedure, potential for an unplanned shutdown and worker dose during outages.