Based on the German KTA 1503.1 and respective international regulations, the release of any radioactive material through the stack of a Nuclear Power Plant (NPP) must be monitored. Different measurement systems are used for the different components of release. Among these components are the radioactive noble gas isotopes of Argon, Krypton, and Xenon. They can be measured in a non-continuous and a continuous manner. In the non-continuous method, a sample of the air is taken once per week, and the result of the $\gamma$ analysis of this sample is assumed to be representative for the remainder of the week.

A more precise and more reactive method is the continuous measurement of the noble gases using a stack monitor system. Such a system is described in this Application Note.

Measurement Purpose and Method
The following components of the radioactive release from a NPP through the stack have to be quantified:
- C-14
- Alpha Emitters
- Radioactive Sr
- H-3
- Radioactive gaseous Iodine
- Particulate Iodine
- Radioactive Noble Gases

Respective collection and measurement systems have to be installed. The principles are shown in Figure 1.

To quantify the release of noble gases, a stack monitor is installed. It consists of the following components (Figure 2):
- Gas System with Pump
- Measurement Chamber with Lead Shielding
- Germanium Detector System, including Pulse Processing Electronics
- Signal I/O Box
- Computer System with special StackMonitor Software and peripherals
Gas System with Pump
The interconnection of the Stack Monitor to the gas system of the NPP is mostly supplied by the operator of the plant. However, this system includes a mechanism to indicate the air flux through the measurement chamber as well as current amount of air flux through the stack.

Measurement Chamber with Lead Shielding
To get low detection limits for the noble gases, the measurement chamber is embedded in a minimum of 10 cm of lead shielding. The chamber itself is built from aluminium in the form of an 18.5 L Marinelli Beaker. Its internal walls are Teflon covered for ease of decontamination. The air flux through this chamber is monitored.

Germanium Detector System, Includes Pulse Processing Electronics
The detector system consists of a HPGe detector of ca. 30% relative efficiency. This assures that the required detection limits are reached (see below). To avoid dead layer problems, GX type detectors are recommended. Any type of detector cooling (LN₂, Cryo-Cycle™, Pulse Tube) is supported.

As the gas calibration is complicated and not easy to perform, the detector is characterized and the efficiency of the measurement volume is calculated using LabSOCS™.

For the pulse processing electronics and the MCA, a Lynx® Digital Spectrum Analyzer is used.

Signal I/O Box
The power plant delivers several status signals as well as other information. This information is fed into the Stack Monitor System via a Signal I/O box. In turn, the Stack Monitor generates status messages and measurement results, which are sent back to the plant via the same box. Those signals can be both digital and analog. They are plant specific, i.e. different plants have different requirements. Here is a list of signals as an example:

Input to Stack Monitor
Digital
• Status of flux through measurement chamber (OK, not OK)
• Status of temperature in the rack (OK, high)

Analog
• Amount of Stack Air Volume (m³/h or m³/sec)

Output from Stack Monitor
Digital
• System Status (OK, not OK)
• Measurement Status (OK, not OK)
• Activity High

Analog
• Activity Release Rate
• Activity Concentration
Computer system with special StackMonitor Software and peripherals

The controlling computer is installed in a rack which is typically mounted close to the measurement chamber. It is a Server Computer running Windows® Server-2003 or 2008 and is always equipped with a local terminal, keyboard and mouse. Depending on the local situation, a number of additional computers can be connected via the network to this central computer. They can be located in various areas around the plant and are used to externally control and monitor the performance of the system. Also depending on the local situation, a printer may be placed at any location to get daily reports of the released activity.

On the main computer, the following task related software packages are installed:

- Genie™ 2000 Basic Software Package
- Genie 2000 Gamma Spectrometry Package with special algorithm for Kr-85 quantification
- Genie 2000 Quality Assurance Package
- Genie 2000 Interactive Peak Fit
- Genie 2000 Programming Library
- Microsoft® SQL Server®-2008 Express or Microsoft SQL Server-2008
- Microsoft Visual Studio 2008

StackMonitor Package, consisting of:
- StackMonitorService Manager
- Display and Control
- Setup Tools
- Reporting Package
- Package for Periodical System Tests

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Figure 2: Stack Monitor System.
In standard operation, the spectrum is evaluated every hour. This frequency is meaningful because shorter periods do not give additional information, and the fluctuations in activity concentration (or detection limit) are too high. However, if the total count rate exceeds a predefined limit, the evaluation period is shortened to better identify short releases of radioactivity. The hourly results are stored in the database. The results of the measurement are sent as an analog signal to a plotter. At midnight, a daily spectrum is analyzed and the results are stored in the database. The spectrum is cleared, and a new spectrum is acquired.

Display and Control

Figure 4 shows the Display Control Program. It is used to show the spectrum details and to indicate the system status. At the left side, the status of the signals is shown in green, yellow, or red color, indicating a good or bad status of the respective signal. In the lower part of the display, measurement results as well as system messages are shown. This provides the user with an immediate indication about the system performance and results.

This program does not allow controlling acquisition or hardware components, it is only used for showing the system status. Hardware control is performed by either the GAA window of Genie 2000, a special control program for the I/O Box, or the program package for periodic tests.
**Setup Tools**
This program is used to setup the parameters of the system. This is where count rate range, calibration files, user rights, etc. are defined. This program is password protected and is designed to be called up during system installation and setup to define site specific parameters.

**Reporting Package**
Depending on the local requirements, the user can initiate site specific reports including:
- Hourly Report
- Daily Report
- Monthly Summary Report
- Quarterly Summary Report
- Message Report, etc.

Any report is adjusted to the user’s needs, i.e. it may list activity concentrations, total released activity in a given time range, etc.

**Package for Periodic Tests**
This package is used to test the I/O signals. The user can set or clear every individual signal to check its correct operation. At the end, a comprehensive test report is printed out.

This package also enables the user to check the calibration of the measurement chain. The user inserts a calibration source (recommended source: Am-241 and Eu-152), the source is measured, the position and count rates of the lines are monitored and a report is generated indicating the correct or incorrect operation of the measurement chain.

**System Setup and Calibration**
During system installation, an energy calibration of the measurement chain is performed. At the same time, using LabSOCS, the sample geometry is modelled and the efficiency of the detector is calculated. This efficiency curve is used for calculating the activity concentration of the noble gas nuclides.

Additionally, based on regulations, a gas calibration might need to be performed. This is done by inserting a known amount of Kr-85 and Xe-133 into the measurement chamber. This way, two calibration values are acquired and compared to the LabSOCS calculated efficiency values. If the values are in accordance, the system is deemed to be operating correctly.
System Performance

HARDWARE
- Gas system with pump (mostly supplied by operator).

GERMANIUM DETECTOR
- Size approximately 30% relative efficiency; preferably GX type, LabSOCS characterized.
- Cooling: Any type.
- Measurement chamber: Vol. ca. 18.5 L, aluminium, Marinelli type.
- Measurement chain: Lynx.

COMPUTER
- Server type computer, server operating system.
- Additional computers possible at any network place.
- Network switch for connection to other computers via network.

I/O BOX
Special interface for:
- 8 analogue inputs.
- 6 analogue outputs.
- 8 digital inputs.
- 24 digital outputs.
- Additional I/O on special request.

SOFTWARE
- Server OS.
- Suite of Genie programs, including LabSOCS.
- Special StackMonitor program package.
- Program languages: English, German, French (additional languages possible, if required).

DETECTION LIMITS
- Xe-133: $5 \times 10^2$ Bq/m$^3$ in 24 h.
- Kr-85: $1 \times 10^4$ Bq/m$^3$ in 24 h.
- Xe-133: $1 \times 10^4$ Bq/m$^3$ in 10 min.

The given values are the values as required by regulations. The actual achieved value for Xe-133 is much lower, but strongly depends on the local background conditions.

Please contact CANBERRA’s Application Support Group to learn more about implementing this stack monitoring system in your facility.