OPEN-SOURCE HARDWARE AND SOFTWARE AND WEB APPLICATION FOR GAMMA DOSE RATE NETWORK OPERATION

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The German Federal Office for Radiation Protection operates a network of about 1800 gamma dose rate stations as a part of the national emergency preparedness plan. Each of the six network centres is capable of operating the network alone. Most of the used hardware and software have been developed in-house under open-source license. Short development cycles and close cooperation between developers and users ensure robustness, transparency and fast maintenance procedures, thus avoiding unnecessary complex solutions. This also reduces the overall costs of the network operation. An easy-to-expand web interface has been developed to make the complete system available to other interested network operators in order to increase cooperation between different countries. The interface is also regularly in use for education during scholarships of trainees supported, e.g. by the ‘International Atomic Energy Agency’ to operate a local area dose rate monitoring test network.

INTRODUCTION

The German nationwide gamma dose rate monitoring network is operated by the Federal Office for Radiation Protection [Bundesamt für Strahlenschutz (BfS)]. It includes about 1800 probes uniformly distributed over the German territory with a typical distance of 20 km between neighbouring probes. The density is increased in the 25-km emergency planning zone around nuclear power plants.

The monitoring network is part of the German ‘Integrated Measuring and Information System for the Surveillance of Environmental Radioactivity’ (IMIS) (¹) and the German National Response Plan for dealing with the consequences of a large-scale radioactive contamination of the environment. This system also collects data from other federal networks, supervising, e.g. air, main rivers and open sea, from laboratory measurements as well as data from nuclear power plant monitoring networks which are operated by particular federal states (Bundesländer). It provides decision-makers with information on changes in radiation levels in Germany. Moreover, it enables to take appropriate precautionary protective measures and to inform the public(²).

DESIGN PRINCIPLES AND TECHNICAL IMPLEMENTATION

Each station in the gamma dose rate monitoring network is equipped with a probe located 1 m above ground, ideally on a flat meadow without larger plants or buildings in the direct vicinity(³). The probes are equipped with two Geiger–Müller tubes providing a dynamic range from 50 nSv h⁻¹ to 5 Sv h⁻¹. For readout, data handling and transfer, a data logger is installed at most sites inside a building in the vicinity of the probe. The data logger and the database servers use the open-source operating system Linux. Data are transmitted to one of the six network centres by fixed wired network, mobile network or the Internet. If one network centre is unavailable, the data logger automatically tries to contact another centre. Implemented protocols for data transfer are file transfer protocol (FTP), secure copy (SCP) and mail. Only a few commercial stand-alone probes of the Saphymo autonomous measuring XL2 gamma tracer type complete the network where no fixed line telephone or power network is available.

The current polling rate of the stations in routine operation is every 6 hours. The polling frequency can be increased to every 10 min in an emergency. This allows for almost real-time mapping of the footprint of a radioactive plume. The data logger generates spontaneous reports that are transferred to a data centre immediately, if a system malfunction is detected or if the measurements exceed a probe-specific threshold. The data centre analyses these reports and generates alerts to the officer on duty if a spatiotemporal coincidence of 1 hour and 30 km radius is detected.

The goal of the network design was to build a very robust and reliable system with a near 100 % data availability. Neither failure of network components nor damage of critical infrastructure, communication or power supply shall interrupt the baseline functionality. The network is operated from six network nodes located in Berlin, Bonn, Freiburg, Munich, Salzgitter and Rendsburg. Each of them is fully capable of polling and processing all network data. All software and hardware components are kept in a modular and simple structure. BfS data logger type ‘MWS3’ (German for Messwertsender Version 3), the BfS
gamma dose rate probe type ‘GS07’ and ‘GS08’ (German for ‘Gamma Sonde’ Version 7 or 8), database, data-interfaces, server procedures, programs and graphical user interface to data logger and database are in-house\cite{4, 5} developments provided by the BfS. Typically for BfS is that developers and users of the software and hardware work in the same unit, which enhances the exchange and feedback. All components are available as open source under GNU General Public License, Version 3 (GPL-3.0). This guarantees end users the freedom to use, study, share and modify the software. The GPL is a copyleft license, which means that derived works can only be distributed under the same license terms. In the following sections, the components are described in detail.

**GAMMA DOSE RATE PROBE DEVELOPMENT: GS07 AND GS08**

BfS started to develop its own ‘GS07’ dose rate probe hardware in 2007. The probe is comparable to the commercially available precursor GS05 from Techni Data, equipped with two Geiger–Müller tubes, for low and high dose rates. During the GS07 development, the high-voltage generation and probe housing have been redesigned (Figure 1). The counting unit delivers additional status parameters for quality assurance such as temperature, humidity, air pressure, high voltage and vertical probe orientation. Detection of atypically long signals and coincident counts in both tubes allow additional checks for proper detector operation. The detector high voltage is electronically stabilised in a temperature range between $-20^\circ C$ and $+60^\circ C$. The probes are assembled by an external provider according to the construction plans developed by BfS. Each probe is tested and calibrated in a radiation facility (Buchleranlage of Helmholtz Centre Neuherberg) with seven sources\cite{4} for final acceptance. Today about 800 probes of the GS07 type are in operation in the network, replacing the former GS05 probes.

The development of the GS08 probe type started in 2011. New features such as software-controlled high-voltage stabilisation and the option to transmit the actual voltage readings of the GM tubes to the database have further increased the quality of data and the capability to identify malfunctioning. Twenty prototypes of the new tube type GS08 have been put into operation in the network since mid-2013.

**LINUX DATA LOGGER MWS3**

BfS started in-house development of a new data logger in 2006, integrating over 30 years’ experience in ambient dose rate monitoring network operation. Main requirements were the following: support of standard data transfer methods, manufacturer-independent design, low-cost components, user friendliness and robustness.

The data logger consists of a main board equipped with an Axis ETRAX 100LX CPU with 100 MHz, 8 MB flash and 64 MB RAM and a backplane with most of the interfaces. It stores the measurements of the probe, calculates mean values and associated statistical values, and transfers data via the public telephone network, GSM or public authorities intranet to the respective measuring and service centre. Redundant modem–modem connections are used as a backup for telephone network or GSM. The hardware of the data logger is designed for a temperature range between $-20$ and $+55^\circ C$. The internal uninterrupted power supply guarantees 72 hour of stand-alone operation. The modem is switched off during power outages and is only used in short intervals when the data centre is contacted for receiving polling commands. The data logger supports standard Linux hardware and data communication protocols\cite{5, 6}.

The hardware of the MWS3 is designed in a way that various types of sensors (spectrometric or environmental) are supported. Some stations in the network are equipped with up to three different external sensors. Additional sensors can be placed in the tube housing (vibration detector, air moisture contents etc.) using the Inter-Integrated Circuit (I\textsuperscript{2}C)
data bus. A RS485 bus offers the option to connect even more sensors (soil humidity, solar radiation, air velocity etc.) at the site. Use of probes from other commercial manufacturers is also possible. The serial protocol supports the implementation of other modern tubes. A simple ASCII protocol with error detection based on the RS485 serial port allows for a distance of up to 1600 m between probe and data logger. The system is less sensitive to interference by electromagnetic noise compared with the old system with analogue data transmission.

DATA LOGGER SOFTWARE DEVELOPMENT

The data logger uses a Linux version adapted to the AXIS hardware. The software uses the standard multitasking library of C and is developed and tested on a standard Linux-PC and transferred after cross-compiling to the data logger. Four different tasks work together in the main data sampling program ‘controld’. One process handles communication with the tube and another process ‘displays’ the status of the system using an LED on the front side of the main board. The third process calculates the mean value and the standard deviation. The tasks of the fourth process are data transfer, error check and others. The data logger controls data acquisition and integrated hardware components and immediately notifies the data centre in case of suspicious measurements or hardware errors. An automatic message can be triggered:

- manually by a switch on the main board or in the web interface,
- by 1 hour of operation on battery,
- by long-term power outages (low battery),
- by battery error or no battery contact,
- in case of missing or too few counts from the high- or the low-dose tube,
- in case the count rate exceeds thresholds of high- or low-dose tube or
- 5 min after system start (status information).

Additional statistical values such as mean, max, min values, trend of time series etc. are calculated for each 1- and 10-min-interval data set for error detection and quality assurance. The alert threshold is calculated dynamically using the corrected (peak eliminated) mean value plus six times the standard deviation in a 7 days moving window. It is specific for the different environmental conditions and temporal changes in the background radiation (e.g. due to snow coverage). Data are transmitted to the data centre if this alert value is exceeded. The data are stored in the logger for several weeks as additional backup. Some error-reducing procedures have been implemented to avoid a storage space overrun or hang-up of external devices (probe, modem). This keeps the system running even in difficult situations.

Maintenance of the data logger in the field is achieved using a user interface with standard web documents (HTML) that supports the common gateway interface programs, a standard method used to generate dynamic content on web pages. Automatic and manual remote commands are supported submitted over the network. Even automatic generated orders such as network-wide intensive modes commands (data transfer every 10 min) are included. Thus, configurations and software updates can be performed locally by maintenance staff or remotely from the data centres.

The open modular design of the system allows the use of the logger for other standard sensors such as spectroscopic or semi-spectroscopic gamma sensors as well as for environmental sensors for air and ground humidity or temperature. The software, in general, can also be operated on a standard Linux laptop if needed.

DATABASE AND SERVER

The database of the network can be hosted on relatively low-level hardware. The minimum required hardware is a standard PC with at least a ‘Pentium 4’ CPU and 4 GB of RAM. The operating system is Linux; the software is tested using the distributions OpenSuse and Ubuntu. The database is developed by ‘MySQL AB’ (now Oracle). The operational database of the German network contains about 6 billion data sets (mid-2013) in 160 tables. About 2.6 million data sets are added per day. Interfacing to the database and supporting tools such as filters, validation tools and import and export programs are designed in a modular form, written in C, shell scripts, Perl and PHP. The graphical user interface is written for X Window systems and web browsers. Supported data flow protocols are FTP, SCP and mail, and the supported data flow media are the Internet, mobile and fixed network.

Each data centre is equipped with the same facilities, such as a data server, an FTP server, several modem servers for incoming data calls etc., to guarantee that each data centre is able to operate the network alone. The centres are interconnected via the redundant BfS network infrastructure. A spooling process immediately distributes incoming data to the five other database servers. If data cannot be delivered, the data are queued on the server until the problem is solved and missing data can be distributed. The incoming servers of an inoperable data centre are automatically switched off to avoid data storage on a malfunctioning system. Data loggers try to deliver data to the next data centre automatically, in case access to the first server fails. With this redundancy concept, practically no data set has been lost during the last 3 years.
Several processes on the main servers monitor the proper functioning of the network. An automatic early warning check is performed every 10 min. A network internal telephone alert to the officer on duty is automatically generated in case the spatio-temporal analysis of probe alert messages gives indications of an increase in dose rate. This procedure is based on the individual threshold calculation of the data loggers. Other procedures check database consistency and incoming dose rate data, identify and mark conspicuous data (Figure 2) for further checking, import meteorological data from the precipitation radar system operated by the German Meteorological Service (DWD), produce export data in other formats for external users, e.g. the EUropean Radiological Data Exchange Platform (EURDEP), calculate 2 hours or daily mean values and much more. Moreover, one procedure creates maps, time series and data tables every 6 hours for the Internet application of http://odlinfo.bfs.de.

BROWSER-BASED GRAPHICAL USER INTERFACE

The graphical user interface of the operational German network is based on the X Window system (X11). It is the product of many years of in-house development and has been specifically tailored to the needs of BfS, supporting data analysis and review of >2000 probes on a routine basis. An additional browser-based interface named ‘Cockpit’ has been developed to support smaller-sized networks with less complexity. The Cockpit allows network management and data review from all kinds of client systems, including smart phones. The interface to the database is written in PHP, i.e. an open-source, widely used general-purpose scripting language, especially suited for web development. The code can be embedded into normal HTML; the PHP framework is already included in standard Linux distributions. The goal of the language is to allow web developers to quickly write dynamically generated pages (8).

The X11 and the web interfaces for the BfS database consist of several modules. Maps, time series, station lists, master data, data quality assurance, data export, configurable network overview lists, station pictures and drawings are integrated. In addition, the web interface can easily be configured to support different network characteristics, including maps of the country where the network is implemented. For training purposes of, e.g. IAEA students, the web-based system has already been adopted to mock networks of the trainee’s home country. Additional modules can be added relatively easily to the system. Due to the chosen technique of a browser-based application, only minimal training is required to maintain small-sized networks with this tool. The application is written in English.

The main view of the web application (Figure 3) gives a general overview of the network, showing different types of maps, i.e. daily mean, 2-h mean, last measurement value and stations with suspicious measurements. The maps are produced automatically every 10 min by an external program. From the stations, pictured by coloured points on the maps, fast access to time series, station pictures and master data is possible. These overview maps allow a fast assessment of the area dose rate situation in the network.

Time series of the dose rate and other supported parameters from the probes allow fast access to current data and data history. Data points exceeding threshold values are earmarked automatically. Different colour symbols in the time-series graphs symbolise the status of each data value, i.e. illustrate whether they are valid, have to be checked or are inconsistent (Figure 2).

Figure 2. Time-series presentation of the gamma dose rate and the raw pulses from the low- and the high-dose tube. Due to probe malfunction originating from wind-induced strong vibrations of the research platform in the North Sea, some data points with values over the threshold are marked automatically. This marking is done automatically during insert into the database. The data needs to be checked manually during QA procedure.
A direct link to a plausibility check page offers the option to change status of the data sets.

Additional lists can be generated on-line to show all stations, optionally also including stations that are dismantled or out of order. Tables with dose rate values, count rates or temperatures are provided for selected time intervals. Data export functions support the comma-separated value tables supported by, e.g. MS Excel. Pictures and drawings of the probe site are displayed, if available. Master data of each station can be seen and modified. The configuration of the MWS3 data logger is displayed.

Figure 3. Main screen, different overview maps are displayed to give a comprehensive overview of the radiological situation in the country, text search allows the selection of single stations.
Finally, the status list (Figure 4) gives a comprehensive overview of the technical and radiological status of the stations in the network. Selection criteria allow the display of all operable stations or only those exhibiting malfunction or dose rate values above threshold values.

**Figure 4.** Status list showing only the stations with malfunctions such as batteries failure, no data and others to display a fast overall status of the network.

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**OTHER DATA SOURCES**
The data of the nationwide network are supplemented by several other fixed and mobile systems. Each nuclear power plant, including foreign near-border plants, is monitored by the federal state’s nuclear power plant monitoring system. Data from these...
stations are transmitted to the BfS within a narrow time frame.

Up to four helicopters operated by the Federal Police can be equipped with airborne measuring systems, including a high-purity germanium detector (HPGe) with an efficiency of about 50 % and four highly sensitive sodium iodide [NaI(Tl)] detectors of a volume of 4 l each. These systems deliver gamma spectrometry data and provide coordinates in 1-s intervals\(^9\). The data can be transferred to the network database immediately after the flight and local conversion, using modern mobile data transmitting systems.

Complementary to the network, the BfS operates six measurement vehicles equipped with mobile in situ germanium (HPGe) detectors. Spectra and nuclide information are transferred to the data centres immediately after measurement using a mobile phone network. Additionally plastic scintillator systems with an active volume of 5 liters, using the ‘natural background reduction’ technology is available. These systems support the usage of the global positioning system receivers for mobile ground contamination detection. This equipment is additionally available in the vehicles. These measurements are performed every second, and data blocks are transmitted in 1-min intervals. The Cockpit offers the option to see the mobile data from helicopters and for car measurement both as time series or on a map. Moreover, it supports export in CSV format for further work with the data using MS Excel or GIS programs. On-line data transfer during a campaign enables the officer on duty to obtain an overview of the local ground contamination combined with the position of the vehicles and in real time.

**SUMMARY AND OUTLOOK**

The German dose rate monitoring network is, to a great extent, technically based on in-house developments. Probes, data logger hardware and software, database and related software are developed efficiently whenever improvements are required. This reduces the investment cost significantly, helps keeping technical knowledge in-house and makes the network manufacturer independent. The software as well as the hardware design of the data logger and the GS07 probe are provided under open-source licence, available to partner peer institutions on request.

In addition to the X11-based graphical user interface, which is used and specifically designed to allow efficient data analysis and review of >2000 probes on a routine basis, the Cockpit, a new web-based interface, has been developed. It comprises basic functionalities and is particularly useful as a starting point for training and build-up of small-scale national networks. The interface has successfully been used during IAEA fellowship programmes at BfS.

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