Nuclear Treaty Verification at FOI

Annual report 2008

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Sammanfattning

Utveckling av verifikationstekniker för att detektera kärnvapenprov har varit ett huvudintresse för FOI i årtionden. Denna verksamhet har varit och är fortfarande huvudsakligen finansieratd av UD. Huvudsyftet är att förse regeringen och svenska myndigheter med teknisk expertis som kan användas i det internationella förhandlingsarbetetarbetet inom olika kontrollregimer för kärnvapen, samt att bidra till uppbyggandent av dessa regimer. Idag utför FOI forskning och utveckling huvudsakligen inom detektion av luftburna radionuklider (med tonvikt på radioaktivt xenon) och seismologi. En stor del av arbetet är integrerat i uppbyggnaden av verifikationssystemet för övervakning av det fullständiga provstoppsavtalet (CTBT). Denna rapport sammanfattar de aktiviteter som genomförts inom detta forskningsområde under 2008. Rapporten innehåller ocKå en kort beskrivning av den utrustning som används i forskningen.

Nyckelord: verifikation, CTBT, radionuklider, radioxenon, seismologi, IMS

Summary

At the Swedish Defence Research Agency (FOI), development of verification techniques for detecting nuclear weapon tests has been a main interest for decades. This work has been, and still is, mainly financed by the Swedish Ministry for Foreign Affairs. The main purpose is to provide national technical expertise for the Swedish authorities that can be used in international work conducted within different regimes covering nuclear weapon issues, and also to contribute to the build-up of these regimes. Today, FOI performs nuclear verification research, development and routine measurements mainly in the field of radionuclide detection (with emphasis on radioactive xenon) and seismology. A large part of the work is integrated with the build-up of the verification regime for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This report summarizes the activities performed in this research area during 2008 at FOI. The report also contains a brief description of research- and measurement facilities used in this research.

Keywords: verification, CTBT, radionuclides, radioxenon, seismology, IMS

Contents

1 Introduction

1.1 Nuclear treaty verification at FOI

In the area of international agreements, verification refers to procedures and tools used to monitor compliance with a treaty or other agreement. A treaty without verification is mostly regarded as weaker compared to a treaty with an extensive verification system. Today, a large variety of techniques are used to monitor compliance. The complexity of the methods varies over a wide range, from simple bookkeeping to sophisticated high-tech measurement techniques. A good illustration of this can be found in the area of the Non-Proliferation Treaty (NPT) where the classical safeguard techniques used by the IAEA now are complemented by methods allowed by the additional protocol including sophisticated environmental monitoring technologies. Besides being used as a formal instrument in an international treaty, the same technologies can also be used in a wider, or different, context, such as emergency preparedness. One example of this is routine measurements of airborne radionuclides used for monitoring of nuclear power plant accidents.

Another treaty that requires the development of new monitoring technologies is the Comprehensive Nuclear-Test-Ban Treaty (CTBT), opened for signature in 1996 and now signed by 180 states and ratified by 148[1]. The verification system of CTBT includes a network of over 300 measurement facilities (the International Monitoring System – IMS), an On-Site Inspection regime (OSI), an International Data Centre (IDC), and a Global Communication Infrastructure (GCI). The measurement technologies include seismic, hydroaucustic, infrasound as well as radioactive monitoring of both atmospheric particulates and noble gases.

At the Swedish Defence Research Agency (FOI), development of verification techniques for detecting nuclear weapon tests has been a main interest for decades. Sweden has been very active in different disarmament negotiation fora, and verification has always been a central part of the test ban discussions, and to support the government FOI (formerly FOA) got the task to carry out research and developments in this area. Today, FOI continues to be active in these fields, performing verification research, development and routine measurements mainly in the field of radionuclide detection and seismology. A large part of the work is integrated with the build-up of the CTBT verification regime conducted by the Provisional Technical Secretariat in Vienna, and is described in this report.

The main purpose for the research at FOI with regard to verification is to provide national technical expertise for the Swedish authorities that can be used in international work conducted within different regimes covering nuclear weapon issues. The research should be conducted in such a way that Sweden can provide a concrete contribution to the international efforts in this area. In this way, the advices and intelligence that FOI provides to the government will be of better quality compared to a passive monitoring of activities performed by other states.

To be able to do this, a certain amount of basic research within selected key areas is needed, providing new information and tools to the international scientific community, and creating an international network of contacts with Sweden as an active contributor. It is obvious that a country like Sweden, having very small resources compared to larger countries including the nuclear weapon states, only can perform such activities in a few specialised areas. In other scientific disciplines, a more general monitoring approach by necessity has to be applied. In the case of FOI, the last year's technical research in this field has been dominated by the development of measurement systems and analysis methods for detection of radioactive xenon. This field of research has regained momentum internationally the last decade due to the establishment of the international monitoring system for CTBT, starting in 1996. The detection technique is relatively new compared to for instance the well-established seismic monitoring technology, generally regarded as the back-bone of the CTBT verification system. Nevertheless, it has become clear to an increasing number of experts and decision makers that radioxenon monitoring could be crucial in order to verify whether an explosion was of nuclear nature or not. This was well illustrated in the activities following the first nuclear test

[1] Status on December 1, 2008. See also http://www.ctbto.org/.

conducted by the Democratic People's Republic of Korea (DPRK) in 2006. The research conducted by FOI in the area of radioxenon is described in section 4.

An important task for FOI with respect to CTBT is to be responsible for the Swedish National Data Centre (NDC). The NDCs are regarded as a part of the monitoring system in the sense that they act as national point of contact for evaluation of data collected by the IDC. In the case of a suspected nuclear test, it is not up to the CTBTO to challenge a state with the suspicion that a test could have been conducted (for instance by requesting an on-site inspection), this has to be done by a state party of the treaty. In order to be able to do that, the state parties need a technical capability of its own to evaluate the data from the verification system. The ambition level of the different NDCs is varying over a wide range. The nuclear weapon states and some other states have large NDCs acting more like independent IDCs, while others have medium sized NDCs performing some analysis of its own, and some states trust entirely the capability of the IDC in Vienna. Sweden and FOI, with its long history in the development of verification techniques, should be able to produce its own, independent judgement in the case of a suspected nuclear test. For this reason, FOI aims at developing a NDC with relatively high capability run by a limited number of staff. The activities within the Swedish NDC in the area of seismology and radionuclides are described in section 2.5 and 3.

Another crucial part of the monitoring system is of course the measurement stations. Through FOI, Sweden operates two CTBT stations, the Auxiliary Seismic station AS101 in Hagfors, and the radionuclide station RN63 in Kista, Stockholm. The station RN63 actually consists of two different systems, one measuring particulate radioactivity (SEP63), and one measuring radioxenon (SEX63). The operation and performance of these stations during 2008 is described in section 5.

In addition to the formal responsibilities with respect to CTBT, the verification group also wants to act as a general national competence in the field of radioactivity measurements. For this purpose, we try to maintain a general competence in the area of nuclear physics and metrology, as well as having knowledge of nuclear facilities like nuclear reactors. One way to achieve this is to involve ourselves and our equipment in studies and measurements related to these facilities. One example is measurements performed in the vicinity of nuclear reactors and isotope production facilities performed during 2008 and also planned for next year, described in section 4.2.

1.2 Organisation of the activities

Generally, all activities within FOI are organised in a project structure. In order to bring together several projects that naturally belong together with respect to competence, customers and overall strategy, an organisation described in Fig. 1 has been created for the research area described in this report. The projects are managed separately, but the activities are coordinated between the different projects by a project coordinator. The project coordinator is responsible for the overall strategy, and acts as a primary contact for the customers from the projects perspective. The project coordinator should also work actively to create new projects in the field. The project managers are responsible for the day-to-day activities within the project, as well as for budget and project plans, although these are prepared in close cooperation with the other project managers and the coordinator.

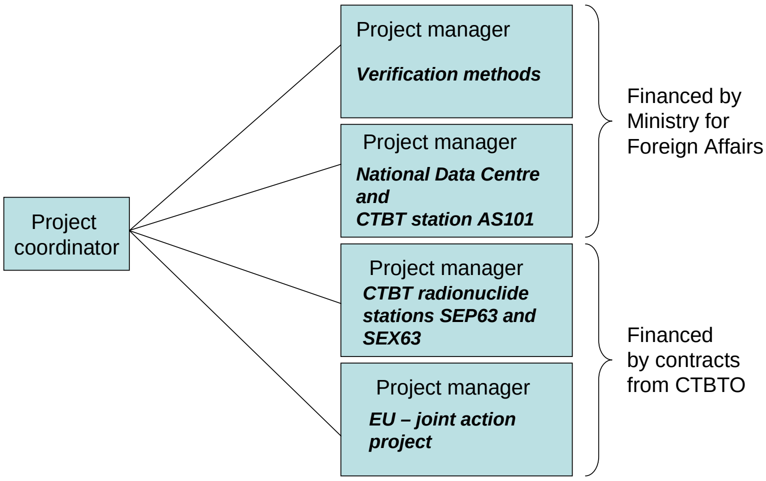

Fig. 1: Project organisation and customers for the FOI projects covered in this report.

The financial basis for the research described in this report comes from the Swedish Ministry for Foreign Affairs, which supports the projects “Verification methods”, and “National Data Centre and CTBT station AS 101”. The operation of the two radionuclide stations and the EU joint action project are performed under contracts with the CTBTO. In total, the projects cover about 5.5 person years of manpower and an infrastructure consisting of three monitoring stations, a National Data Centre and a Noble Gas laboratory. The infrastructure is briefly described in the next section.

2 Facilities

2.1 Introduction

A very important part of the activities within nuclear verification at FOI is the operation of the measurement stations for seismic activity as well as atmospheric radioactivity. We are currently operating one seismic station and two stations for atmospheric radioactivity. In addition, FOI also operates five particulate samplers for the Swedish radiation protection authorities, the main purpose being emergency preparedness. The latter stations are not a part of the projects included in this report, and are therefore not described here.

2.2 The Hagfors seismic array

The regional seismic array in Hagfors (60.14°N, 13.68°E) is situated about 250 km northwest of Stockholm. The station has been operating since the mid sixties. Ten years ago the station was upgraded, followed by certification by CTBTO in 2002. The station has 10 vaults (Fig. 2), each equipped with a seismometer (one three-component and nine one-component sensors) and a digitizer. The inter-array spacing's between the different elements are 300- 1800 m. Fibre optic cables connect the sensors to the central facility, where data acquisition and transmission is performed. Segmented data from the Hagfors array is transmitted on request to the IDC in Vienna via a satellite link. In addition a continuous data stream from the Hagfors station is transmitted first via a separate satellite link to Norway and then via internet to the Swedish NDC in Stockholm, where it is analysed on a daily basis. The station is characterised by low noise, and has a high sensitivity e.g. for the Semipalatinsk are and for regions in the Middle East. On average, about 5 regional and 10 teleseismic events are recorded every day.

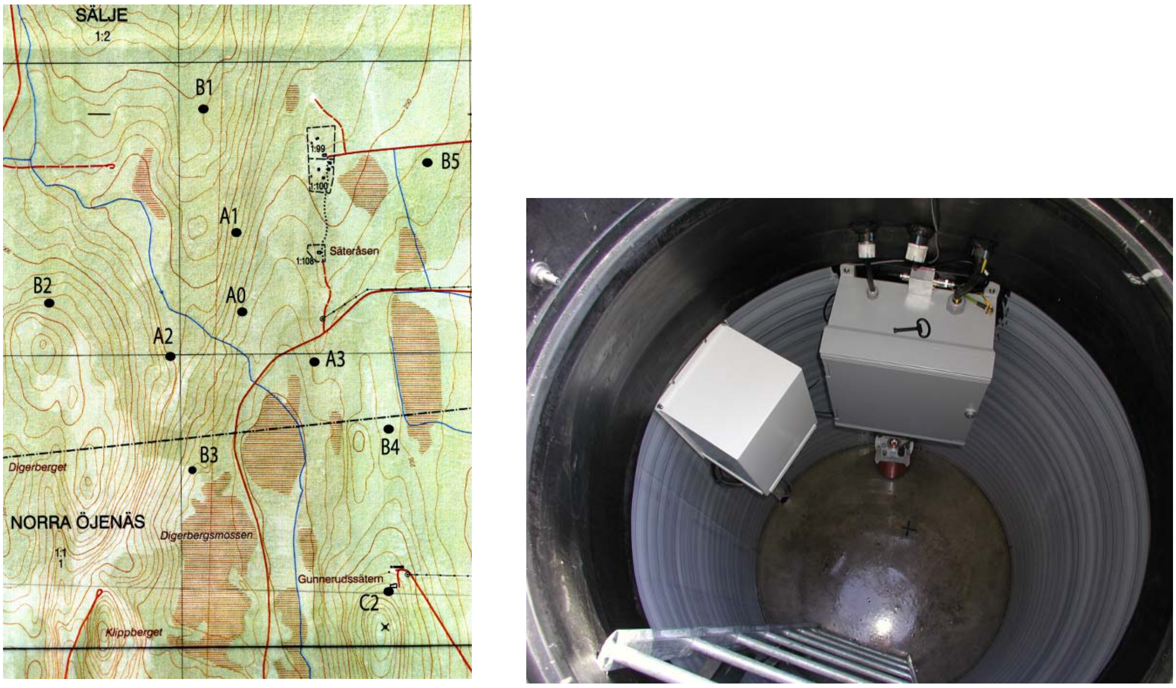

Fig. 2: The layout of the seismic array in Hagfors (left panel). The one-component seismometers are labelled A and B, and the three-component seismometer is located as C2. The photograph shows one of the vaults equipped with a seismometer and digitizer.

2.3 Particulate radioactivity

The nuclear verification projects operate an automatic particulate station for CTBT. The system (SEP63) is located in a container (59.40°N, 17.93°E) placed at the roof of the house opposite to FOI in Kista (Fig. 3), together with the radioxenon system (SEX63) and a national particulate filter station.

Fig. 3: The radionuclide measurement stations at FOI, Stockholm. The leftmost container holds the CTBT particulate station SEP63; the middle container is equipped with a CTBTO noble gas system (SEX63). The station to the right is a semi-automatic particulate sampler operated for the Swedish radiation authorities, and is not described in this report. The parabolic antenna to the left is the satellite link to the CTBTO International data Centre in Vienna.

The particulate station is based on the automatic particulate filter sampling system CINDERELLA, manufactured by Senya Oy in Finland. The system samples air at a rate of about 550 m^3/h through a filter. The filter is automatically cut in smaller pieces and put on top (after 24 hour radon decay) of a HPGe detector measuring for atmospheric particulate activity. The results are reported every 24 hour to the IDC in Vienna. The station has been operating in IMS since 2001 and is certified by the CTBTO.

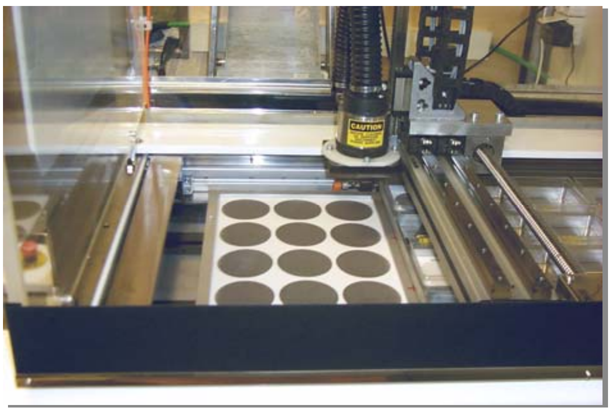

Fig. 4: The robot arm cutting and moving the filter pieces in the CINDERELLA system used in the CTBTO station SEP63.

2.4 Radioxenon

Research on radioxenon as a verification tool for nuclear weapons tests has been conducted for many years at FOI. The research has mainly been financed by the Swedish Ministry for Foreign Affairs. Today, the radioxenon laboratory at FOI consists of two fully automatic SAUNA II radioxenon systems, one mobile sampling system and one newly acquired radioxenon laboratory system. All systems are based on the SAUNA prototype system developed by FOI, ready in 1999. In 2003, a commercial partner, Gammadata AB, was found, and together with FOI, a commercial version – SAUNA II[2] - was designed, and the first unit was ready for delivery to FOI in 2004. The second unit was ready for installation in the following year. The latter system is the property of CTBTO and is used in the noble gas station SEX63 as part of the International Monitoring System. This station is operated by FOI under a CTBTO contract. All other equipment is the property of FOI, and is used in various measurement projects, ranging from basic R&D to targeted measurement campaigns.

The SAUNA II (Fig. 5) system is capable of automatic sampling, processing and activity measurement of atmospheric xenon. Results from the activity measurement of the four isotopes ^{133}Xe, ^{131m}Xe, ^{133m}Xe, and ^{135}Xe are recorded every 12th hour. The minimum detectable concentration for the most commonly detected ^{133}Xe is about 0.3 mBq/m^3, corresponding to two hundred atoms per m^3 of air.

Fig. 5: The automatic radioxenon system SAUNA II belonging to the International Monitoring System and operated by FOI.

Following the development of SAUNA II, a mobile xenon sampling system was developed by FOI in 2005 – 2006, also this in cooperation with Gammadata AB. This project was partly financed by CTBTO, in order to develop a system that can be used for On-Site Inspections. The system is mounted in seven boxes (Fig. 6) that easily can be transported to the desired location for collection of xenon samples. The xenon is trapped in charcoal columns that are sent to the laboratory where they are analysed in a SAUNA II system.

[2] See http://www.saunasystems.se/ for more information on the SAUNA II products as well as some history of the project.

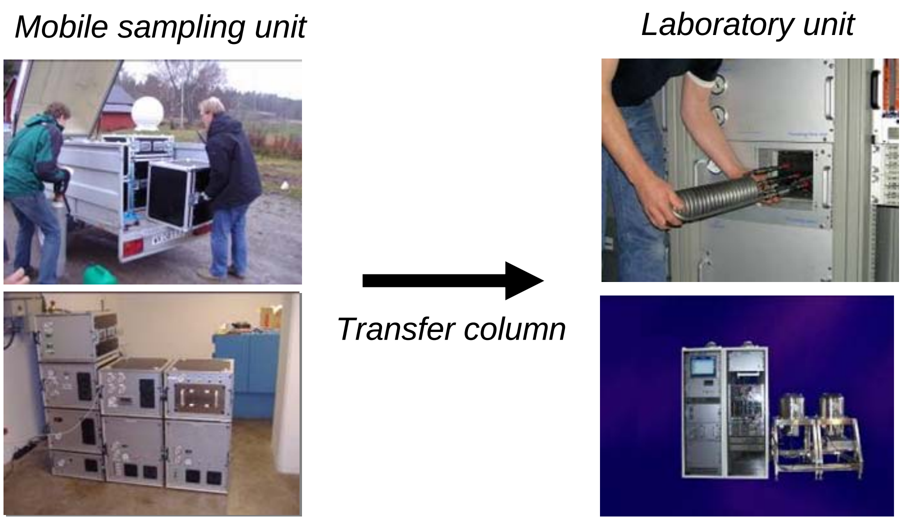

Fig. 6: The mobile xenon sampling system is used in combination with the ordinary SAUNA II system.

In order to increase the radioxenon analysis capability at FOI a third system has been acquired. This laboratory system has the capability to analyse xenon samples from the mobile unit and from archive bottles from SAUNA II. This system will be set in operation during 2009 (see also section 4.3).

2.5 The National Data Centre

The NDC facility, situated in Kista, Stockholm (Fig. 7), constitutes the combined radionuclide and seismic analysis resources at FOI. The primary goal for the NDC is to provide technical competence to the Swedish government in the area of nuclear verification, in particular in the area of nuclear testing. This requires access to relevant and up-to-date technical data as well as competence and tools for analysis and to put the results into context. The NDC subscribes to radionuclide and seismic raw sensor data as well as analysis results from the IDC in Vienna. In addition to the IDC analysis, FOI performs its own analysis. Furthermore, data from national measurement stations are collected. Data are automatically structured and stored in a database developed at FOI in cooperation with a consultant company. A software client (Fig. 8) is used to extract and compile information from the database. Data are analysed on a daily basis, and in the case something out of the normal is detected, data is tagged in the database for further study. The client facilitates different user profiles, or actors, such as alarm administrator, alarm analyst, station operator or NDC manager. The analysis is performed in several steps, where the result is passed on from one actor to the next. In the end, a NDC report can be produced by the NDC manager, potentially involving the results from several sources. Standard report templates are used, and every step is stored in the database. This ensures traceability and quality of the analysis and reporting procedure.

Fig. 7: The National Data Centre at FOI.

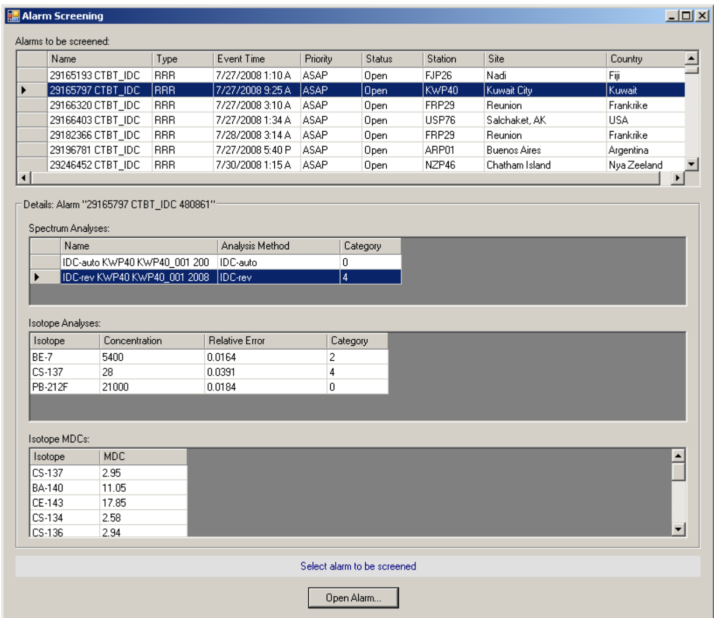

Fig. 8: A screenshot of the radionuclide alarm administrator view in the NDC client, used in the daily work monitoring the IMS radionuclide network.

Tools for data analysis are constantly developed within the NDC project as well as in the framework of other activities at FOI. In addition to the routine analysis intended to monitor compliance with CTBT, the NDC is used as a platform for scientific research, including development of new analysis techniques as well as focussed studies of particular data sets. The studies are often performed in cooperation with other scientific institutions and NDCs. Apart from the added scientific knowledge; these activities maintain and increase the general analysis competence of the NDC staff, and hence the capability to act professionally in the case of a real event.

3 Activities at the Swedish National Data Centre in 2008

3.1 Seismic data

In the identification of new events in the IMS seismic sub-network, reference events, or ground truth events, are of great importance. Ground truth events are well-documented events that can be compared with new events of unknown origin. At the Swedish NDC a data base of ground truth events from a number of selected regions of the world is constantly updated. Seismic event parameters such as location, depth, magnitudes, and screening results as well as a link to the wave forms in digital form from IMS stations defining the event are fed in to an information system. In 2008 seismic data from a total of 81 events world wide have been requested from the IDC, manually reviewed using the software GEOTOOL and stored in the data base. The main purpose of the review has been to confirm, or to refine if necessary, the analysis conducted at the IDC and to notify relevant characteristics of the observed wave forms. The Graphical User Interface (GUI) of the information system also facilitates event parameters from other Data Centres for example US Geological Survey (USGS) to be fed into the data base for each event. It is foreseen that this upgrade of the data base continues for several years in order to get a dense enough grid of reference events in the regions of most interest.

3.2 Radionuclide data

The NDC subscribes for raw spectral data as well as IDC analysis reports from all stations in the IMS radionuclide network. Detections classified as level 4 or level 5 events[3] in the IDC event categorisation scheme are classified as alarms and are routinely analysed by the radionuclide alarm administrator. The alarms are categorised according to an internal classification scheme (cosmic radiation, deviation of station functionality, naturally occurring radionuclide etc.) In addition to the routine monitoring of the earths atmosphere, this activity is performed to increase the experience of data produced by the different stations in the network, and to enhance the preparedness for a real event.

Another important activity performed during the year has been to continue the work to reformat and parse old radionuclide data into the database. Data produced at FOI exists in digital form from 1974 and onwards. Until now, data from 1974-1984 and 1995 -2009 has been parsed into the database.

[3] Level 4: one anomalous anthropogenic radionuclide measured; Level 5: multiple anomalous anthropogenic radionuclides including at least one fission product measured.

4 Radioxenon research and development in 2008

4.1 Work related to the build-up of the CTBT verification system

4.1.1 Radioxenon equipment

The radioxenon detection system SAUNA developed by FOI and now manufactured and sold commercially by the company Gammadata AB in Uppsala, Sweden, has until now (2008) been installed, or decided to be installed, at 12 sites in the International Monitoring System (IMS) for CTBT (see figure 9). This constitutes about 50% of the noble gas systems installed in IMS so far.

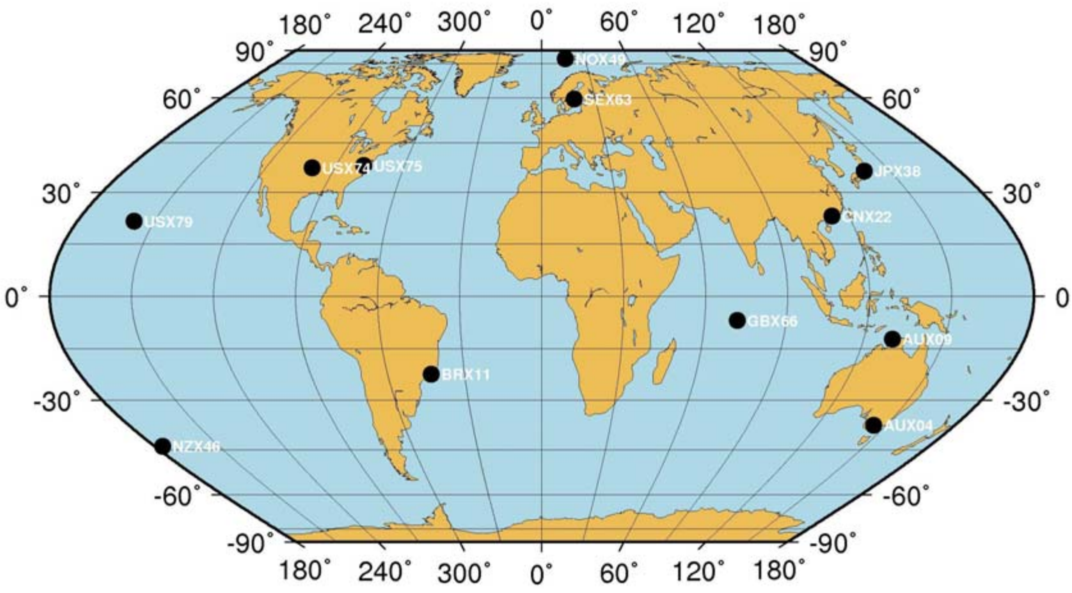

Fig. 9: Stations in the International Monitoring System for CTBT equipped, or soon to be equipped (as of 2008), with a Swedish SAUNA II system.

Ten of these systems transmit data daily (two are to be installed in 2009) to the International Data Centre in Vienna, and also to the Swedish NDC. According to a report at the 32:nd meeting of CTBTO Working Group B, 19 Noble Gas stations delivered data at the end of 2008. Meaningful performance statistics was reported for 17 stations. Out of these all SAUNA II systems performed well, with only minor problems. Although the manufacturing of these systems now is transferred to a private company, FOI still acts in close cooperation with the manufacturer on several issues regarding calibration, development and data interpretation. Even more importantly, FOIs detailed knowledge of the system of course gives Sweden a good position when it comes to data interpretation in the case of a real event detected by the SAUNA system, as well as radioxenon detection in general.

4.1.2 Radioxenon analysis algorithms and software

In parallel with the development of the SAUNA system at FOI, methods for analysis of data produced by the systems were developed in cooperation with PNNL, USA. This resulted in the so called "Stockholm algorithms", a set of equations used to analyse beta-gamma coincidence data from the detectors used in the systems. These algorithms were later used in the software now used for data analysis at the international data centre (IDC) in Vienna. More general analysis software for the same purpose has been developed at FOI, and will soon be published as “open source”, with the aim to be further developed by the radioxenon community. The software is used in the routine analysis of radioxenon samples at the NDC as a part of the database client.

4.1.3 The International Scientific Study of the CTBT verification regime (ISS)

In March 2008, CTBTO launched a global undertaking open to scientific experts involving a series of independent scientific studies of the verification regime. FOI has been asked to play an active roll in this study, and is coordinating the radioxenon part in cooperation with the radionuclide group coordinator. Work has also been conducted with the aim to produce several scientific contributions from FOI to the ISS workshop that will take place in June 2009. These contributions will include studies of the global radioxenon background as well as an assessment of the capability of the radioxenon network and a study of source terms from underground nuclear explosions.

4.2 The EU/JA field campaign

The operational activities related to detection of radioxenon have this year been focussed on preparing and conducting measurements within the framework of an international project aiming at mapping the global radioxenon background. The background of radioxenon is not well known at several locations around the world, and in an EU Joint Action (JA) program this will be further studied. The project is cooperation between the CTBTO, FOI and the Pacific Northwest National Laboratory (PNNL), Richland, WA, USA. The project was initiated by CTBTO, and FOI was contracted to perform the measurements using the FOI SAUNA II system and the mobile sampling unit. PNNL is participating as a subcontractor to FOI in performing the measurement campaigns together with FOI. In addition to the FOI SAUNA system, a SAUNA II system belonging to PNNL was used in one of the 2008 campaigns.

Measurements were this year performed in Belgium, Kuwait City, Kuwait and Mafikeng, South Africa. During 2009, campaigns in Chang Mai, Thailand, Cape Town, South Africa, and Germany, will be conducted. The results and conclusions of the project will be presented at a workshop in Vienna in June 2009.

4.2.1 Measurements in Belgium

The last few years it has been realised that some facilities producing radioactive isotopes for medical purposes (mainly ^{99}Mo/^{99m}Tc) have a major impact on the radioxenon content in the atmosphere. The first measurement campaign within the EU/JA project was focussed on such a plant, the Institute Nationales des Radioéléments (IRE) facility in Fleurus, Belgium. Mobile measurements were performed at 12 locations around Belgium in order to study radioxenon releases from the plant.

In May and June 2008, the mobile sampling system and the laboratory equipment were prepared for the measurement campaign. The mobile equipment was subject to a major service and upgrading. Field exercises were also performed with the mobile equipment to verify system function and to educate new personnel required to operate this system. The last week of June, FOI staff transported the system from Stockholm to Belgium, and on June 25, the mobile SAUNA system was assembled by lorry in order to start sampling (Fig. 10). The following three weeks 35 atmospheric samples were collected. Each sample contained xenon from 8-9 m^3 of air. Generally, two samples per day were collected, and shipped to FOI the following day.

Fig. 10: The lorry used to carry the mobile radioxenon sampling equipment parked during sampling (left). The right picture shows the interior of the lorry with the mobile sampling equipment.

Samples were collected at short (0-2 km, see Fig. 11), medium (10-20 km) and long distances (50-100 km) with respect to the plant. The directions of the sampling locations with respect to IRE were based on meteorological information provided by two different sources (SEK-SEN in Belgium and the PTS in Vienna). In addition to the atmospheric samples, gas from the stack at IRE was collected in evacuated bottles. In total, four such samples were collected, and sent to FOI for analysis**.**

Fig. 11: Short range sampling positions used in the vicinity of the IRE plant in Fleurus, Belgium. The sampling positions are indicated with black and white circles.

4.2.2 Measurements in Kuwait

Following the measurements in Belgium, the FOI SAUNA system was transported to Kuwait City, Kuwait, where it was installed and performed measurements from September to December 2008 (see Fig. 12). More than 100 xenon samples were collected and measured on-site. The results indicate a low xenon background, with the main contribution probably caused by radioxenon from European facilities.

Fig. 12: The SAUNA system arrives to Kuwait Institute for Scientific Research (KISR) which acted as hosts for the measurement campaign in Kuwait City (left). The right picture shows the system installed at the site.

4.2.3 Measurements in South Africa

At the end of the year, a second SAUNA system (belonging to PNNL, USA) was installed and set into operation in Mafikeng, South Africa (Fig. 13). The measurements will continue to the end of the year, followed by transport to Cape Town for further measurements.

Fig. 13: Physics students at the North-West University at Mafikeng are introduced to the SAUNA system.

4.3 Development of the radioxenon laboratory

With the goal of establishing a quality controlled radioxenon laboratory, FOI has in cooperation with Gammadata designed a system for sample preparation and activity measurements of xenon samples (Fig. 14). This system has already been sold internationally to a few laboratories, and FOI acquired one in 2008. The gas analysis system is able to analyse transport columns as well as archive bottles. New hard- and software for data acquisition will be used in the FOI version, and a new beta-gamma detector for sample analysis will be designed and tested. The system will be set in operation in 2009.

Fig. 14: The new radioxenon laboratory system acquired to the laboratory in Kista.

5 Performance of CTBT stations in Sweden during 2008

5.1 The auxiliary seismic station AS101

The seismic array station at Hagfors has been in full operation throughout the year. The reliable operation of the station and the communication links are reflected in the data availability estimates. For the time period 1 January – 31 October the data availability was 99.2 % at the IDC in Vienna and 99.9% at the NDC in Stockholm. The CTBTO requirement is 98 % data availability. For the same time period the seismic data sent to the IDC included 2071 seismic signals that were used as defining phases in the IDC event solutions. As an example of a detected event, the recordings from one of the instruments at the Hagfors station are shown in Fig. 15. The figure shows the detection of one of the largest earthquakes in 2008 that hit the region of eastern Sichuan in China on May 12. As reported by USGS more than 69000 people were killed and more than 45 million people were affected by the earthquake.

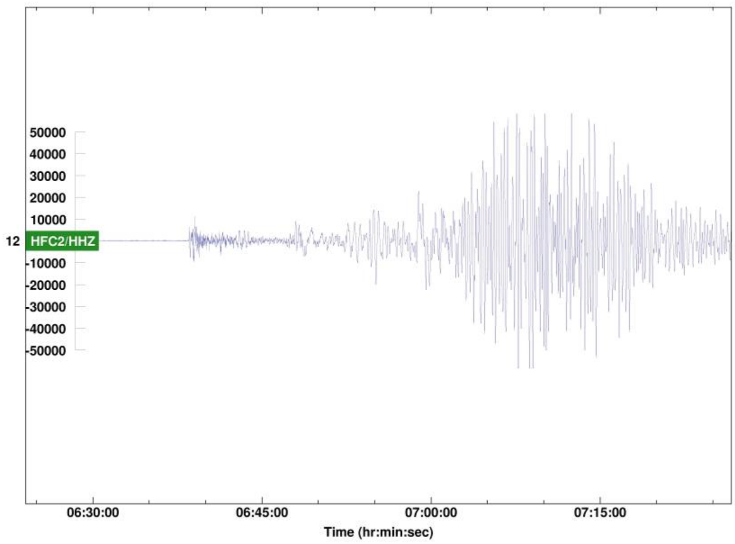

Fig. 15: Hagfors recording of the earthquake in Sichuan, China on May 12, 2008.

5.2 The radionuclide station SEP63

The station has been running without major disruptions during the year. Some upgrading of the infrastructure has been made such as installation of a new AC system. Data have been sent to IDC in Vienna according to plan and monthly reports have been produced. The data availability was 83% (defined as number of spectra possible to categorize versus the total number of expected spectra). Four samples during the year have been sent to CTBTO radionuclide laboratories after request for extra analysis.

The only anthropogenic radionuclide that is regularly measured at the station is ^{137}Cs. This isotope has been detected at about 35 occasions during 2008, the highest level is at about 5μBq/m^3 (Fig. 16).

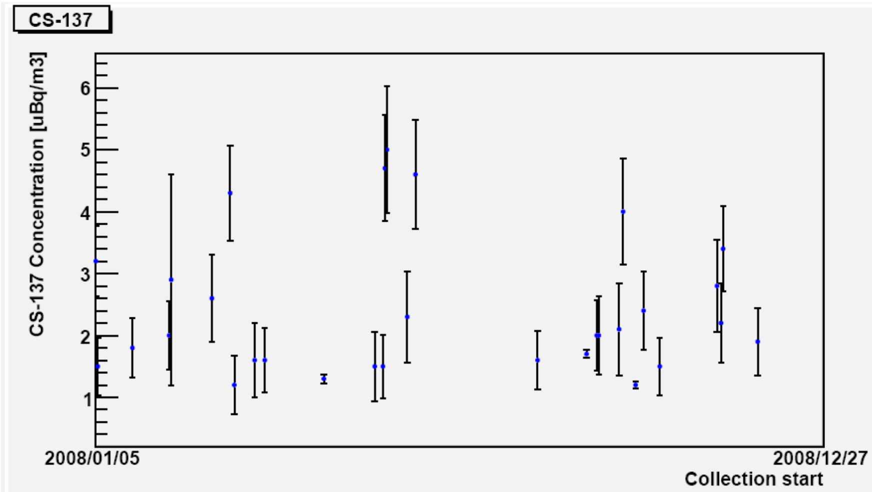

Fig. 16: Measured concentrations of ^{137}Cs during 2008 at CTBT station SEP63 in Stockholm.

5.3 The radioxenon station SEX63

5.3.1 System performance

During the year the station has delivered data most of the time, but it has experienced some disturbances which affected the performance. The interruptions are caused by various failing components, such as the evacuation pump and the gas chromatograph. During the year, the system delivered 527 “good” samples, containing at least 0.3 ml stable xenon. This corresponds to 72% yearly coverage. FOI and CTBTO have now signed a service contract for the station.

5.3.2 Measured radioxenon concentrations

Atmospheric concentrations of ^{133}Xe measured by the Stockholm station in 2008 are shown in Fig. 17. As can be seen, this isotope is detected on a regular basis, which normally is the case for European stations. Many of the higher peaks in Fig. 17 can be explained by releases from the isotopic production facility IRE in Belgium. This was well illustrated by the fact that a shutdown of the facility resulted with a clearly detectable decrease in the observed ^{133}Xe levels. The facility was shut down between August 25 and November 11, and during this period the average concentration went down to 1.05 mBq/m^3 compared to 2.21 mBq/m^3 for the period January 1 – August 24, when the IRE facility operated normally.

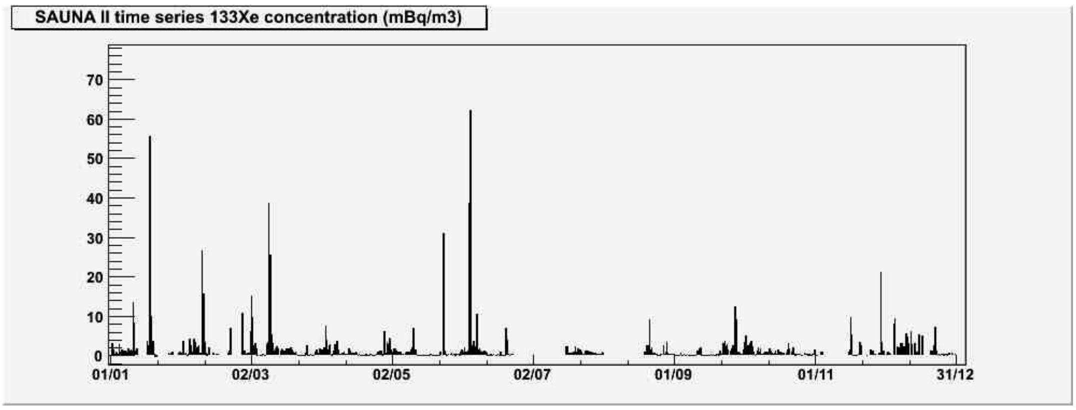

Fig. 17: Obtained atmospheric concentrations of ^{133}Xe at the station SEX63 in Stockholm during 2008.

On July 3 and 4 the SAUNA II system in Stockholm collected two samples containing ^{135}Xe. This isotope is, even globally, rarely observed in the atmosphere. Only ^{133}Xe is detected in Stockholm on a regular basis. The measured concentrations of the two isotopes for the two samples are listed in Table 1, and spectra from one of the samples are shown in Fig. 18.

Table 1: Measured ^{133}Xe and ^{135}Xe concentrations by the SAUNA II system at FOI in Stockholm.

Air collection times		Atmospheric activity	
Start	**Stop**	**^{133}Xe**	**^{135}Xe**
2008-06-03 14:12	2008-06-04 02:12	62.1 +/- 0.6	5.8 +/- 0.4
2008-06-04 02:12	2008-06-04 14:12	38.7 +/- 0.5	6.1 +/- 0.4

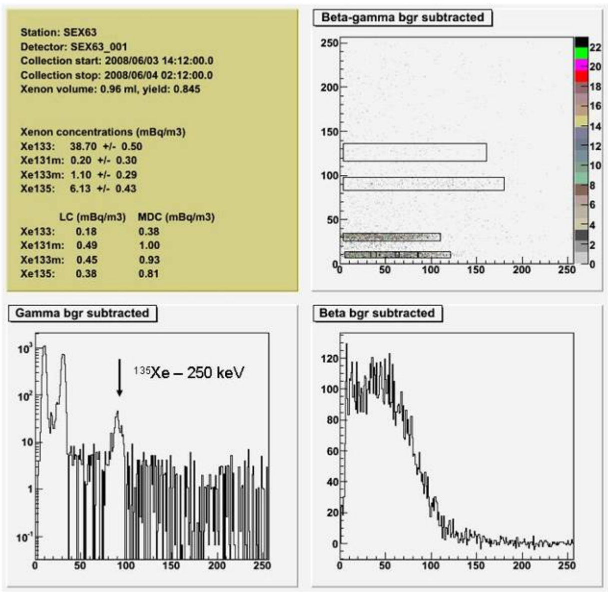

Fig. 18: Spectra from one of the samples in table 1, showing the presence of ^{135}Xe (visible as a peak in the gamma spectra in the lower left panel) and ^{133}Xe.

Meteorological backward trajectories indicated the nuclear power plant in Forsmark, located 110 km north of the sampling point, as a possible source of the release. This was confirmed by the power plant. Due to a valve leakage, a shutdown was started on June 2. Staff at the plant confirmed releases of noble gases during June 3 and 4, and the reported levels of ^{133}Xe and ^{135}Xe agrees with the measurements at SEX63. The plant also reported fuel damage. The fact that the normal delay lines used to reduce noble gas releases are bypassed during shut-down explains the elevated levels of the short lived isotope ^{135}Xe.

6 Publications and participation in conferences

The main part of the documentation produced within the activities described in this report comes in the form of customer reports or internal PMs (not listed here). In addition, we have the ambition to produce publications intended for a wider audience; although the customer has first priority. But in order to ensure the quality of the work performed, it is considered important to be able to publish relevant results in peer reviewed journals and to participate in conferences and workshops. The publications are to a large extent the products of different international scientific cooperation's.

Peer reviewed papers:

"Backtracking of noble gas measurements taken in the aftermath of the announced October 2006 event in North Korea by means of PTs methods in nuclear source estimation and reconstruction" – Andreas Becker, Gerhard Wotawa, Anders Ringbom and Paul R.J. Saey. Submitted to *Pure and Applied Geophysics.*

"Discrimination of nuclear explosions against civilian sources based on atmospheric xenon isotopic activity ratios"- Martin B. Kalinowski, Anders Axelsson, Marc Bean, Xavier Blanchard, Theodore W. Bowyer, Guy Brachet, Simon Hebel, Gilbert Le Petit, Justin I. McIntyre, Jana Peters, Christoph Pistner, Maria Raith, Anders Ringbom, Paul R.J. Saey, Clemens Schlosser, Trevor J. Stocki, Thomas Taffary, and R. Kurt Ungar. Submitted *to Journal of Environmental Radioactivity*

"Environmental Radioxenon Levels in Europe – a comprehensive overview" - Paul R.J. Saey, Clemens Schlosser, Matthias Auer, Anders Axelsson, Andreas Becker, Xavier Blanchard, Guy Brachet, Lars-Erik De Geer, Martin B. Kalinowski, Jenny Peterson, Vladimir Popov, Yuriy Popov, Anders Ringbom, Hartmut Sartorius, Thomas Taffary, and Matthias Zähringer. Submitted to *Pure and Applied Geophysics*.

Contributions to conferences and workshops

"Detection of nuclear weapons tests using radioxenon" – Anders Ringbom. Invited presentation at *"Svenskt Kärnfysikmöte XXVIII, Nov 11-12 2008"*

"Radioxenon detection – present status and ISS activities" – Anders Ringbom. Invited presentation at *CSIS/AAAS meeting on CTBT verification, Washington DC, Dec 11-12, 2008.*

"International Scientific Studies Project" – Anders Ringbom. Presentation at *Informal Noble Gas Workshop, St Petersburg, Oct 13-17.*

"Radioxenon measurements in the vicinity of a radioisotope production facility in Belgium" - Anders Ringbom, Paul Saey, Per Andersson, Stefan Ban, Lars-Erik De Geer, Klas Elmgren, Karin Lindh, Jenny Peterson, Catharina Söderström, Neda Tooloutalaie - Presentation at *Informal Noble Gas Workshop, St Petersburg, Oct 13-17.*