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Bulletin

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Editorial

Overview of this Issue

B. Autrusson
Chairman of the ESARDA Editorial Committee

When the Soviet Union (SU) collapsed, there were very serious concerns that scientists and engineers from the SU nuclear weapons programme who might have lost their jobs could be recruited by 'rogue' States or terrorist groups. The International Science and Technology Centre of Moscow (ISTC) and the Science and Technology Centre of Ukraine in Kiev (STCU) were established in the first half of the nineteen nineties, to provide alternative employment to former weapons scientists and engineers. Between November 2006 and September 2007, an evaluation of the non-proliferation activities of both these Centres was carried out on behalf of the European Commission. The authors' mission took place in the context of the end of the TACIS programme and the definition and implementation of a new European Foreign Policy Instrument, the 'Instrument for Stability (IfS)', in anticipation of the development of the European Neighbourhood Policy. The authors describe the objectives, the methodology, the findings and recommendations of the mission and give some thoughts and prospects on the current Commonwealth of Independent States context and the role of the Centres.

The current Bulletin also focuses on the proliferation resistance of actual and future facilities.

Nuclear energy can play an important role in the future of energy production, because it is an economic and non-greenhouse-gas-emitting way of producing electricity. To this end, it will be necessary to develop technically advanced solutions towards enhanced safety, sustainability, economic competitiveness, and proliferation resistance. The main idea is that the new generation of Nuclear Energy Systems will provide competitively priced and reliable energy production, whilst satisfactorily addressing concerns about nuclear safety, waste management, non-proliferation and public perception. Various studies are ongoing, to estimate the qualities and deficiencies of different concepts and designs. An essay in the present bulletin focuses on the most relevant characteristics of proliferation resistance and physical protection of the Generation IV Nuclear Energy Systems.

Another contribution deals with safeguards measures for Gas Centrifuge Enrichment Plants. A system for the detection of material diversion, based on real-time mass evaluation of the inputs and outputs, has been theoretically examined. The response of this Continuous Mass Measurement System (CMMS) to two specific diversion scenarios has been simulated and examined.

Equipment performance aims at the creation of relevant data. As Containment and Surveillance (C/S) is playing an ever-increasing role in safeguards systems, the issue of how to assess the performance of C/S equipment is being addressed by the ESARDA Working Group on C/S. The issue is important not only for the development of appropriate safeguards approaches, but also for the review of existing approaches with regard to the implementation of the Additional Protocol (AP) and Integrated Safeguards. It is expected that the selection process of appropriate equipment, especially for unattended operation, is facilitated by the availability of methods to determine the performance of such equipment. The authors describe a non-quantitative performance assessment methodology, with an application on a trial basis to a dry storage facility for spent nuclear fuel.

Following the practice of past years, each ESARDA working group presents its achievements of the year 2008. By reading their reports, you will have a demonstration of the excellent vitality of ESARDA. You are welcome to submit an article related to the field of safeguards to the Editorial Committee.

ESARDA News

The Changing Face of Springfields

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Abstract

The nuclear industry in the UK has changed beyond all recognition in the last few years. At Springfields, where commercial nuclear fuels are produced in the UK, this has been as a result of Government policy and multiple changes to ownership.

1. Organisation

Over the past few years many things have changed at Springfields.

British Nuclear Fuels plc (BNFL), a UK Government-owned company, owned and operated a large number of nuclear facilities throughout the UK and even in the USA from 1971. In 2001, Springfields was part of BNFL and the site and its products were branded under the Westinghouse name. Also within the BNFL group was British Nuclear Group, which controlled Sellafield operations, the Magnox reactors and project services. In addition, BNFL owned the research and development organisation Nexia Solutions. Westinghouse Electric Company UK Limited (WEC UK Limited) was set up, as a wholly owned subsidiary of Westinghouse Electric Company LLC, to run the Springfields Site and Uranium Asset Management Ltd (a nuclear transport and trading company). Springfields Fuels Limited was created, as a wholly owned subsidiary of WEC UK Limited, to be the Site Licence Company (SLC) to meet UK Health & Safety Regulation and the requirements of the Nuclear Site Licence.

In 2005, the Nuclear Decommissioning Authority (NDA) was formed by the UK Government in order to manage and decommission its nuclear assets. This led to a more complex structure being introduced. The existing structure of companies under BNFL, as described above, remained in place, but the NDA became the legal owner of all the sites' assets. The BNFL-owned companies then took on the Management and Operation contracts to manage the sites: in the case of Springfields, this meant the Site and its assets were owned by the NDA, the personnel were employed by Springfields Fuels Limited and the operations were managed under contract to Westinghouse Electric Company UK Limited. Under this structure Springfields Fuels Limited retains its responsibilities as the SLC.

Because ownership of all BNFL UK sites was transferred to the NDA, the regulatory interface also became more complex. The legal relationship, with regard to the Euratom Treaty, has remained between DG TREN and the responsible department within the UK Government (currently Department of Energy & Climate Change (DECC)) and between DG TREN and the SLC. Also unchanged are the direct links between DG TREN and the UK Safeguards Office and the SLC and the UK Safeguards Office. There is no direct link between Springfields and the IAEA, as all regulatory work is undertaken by Euratom. In addition to the above, the NDA has formed Contractual Links with the SLC and a Memorandum of Understanding with the UK Safeguards Office. The NDA also supports the UK Government's objectives and international initiatives both directly with DECC and the IAEA and indirectly via the SLC.

In October 2006, Westinghouse Electric Company UK Limited was included in the sale of Westinghouse Electric Company LLC by BNFL to Toshiba Corporation. This included the management and operations contract to run Springfields on the NDA's behalf. The resulting relationships between the various companies involved and the NDA looks like Figure 1.

Along with the sale of Westinghouse, BNFL has also sold off its Project Services business and has been divested of British Nuclear Group, Magnox Electric and Nexia Solutions. Indeed British Nuclear Fuels plc has now ceased to exist. A new Management & Operations Contractor has been appointed for Sellafield (Nuclear Management Partners Ltd), the Magnox business has been split into Magnox North & Magnox South and Nexia Solutions is being set up as a separate Government body under the name of National Nuclear Laboratory.

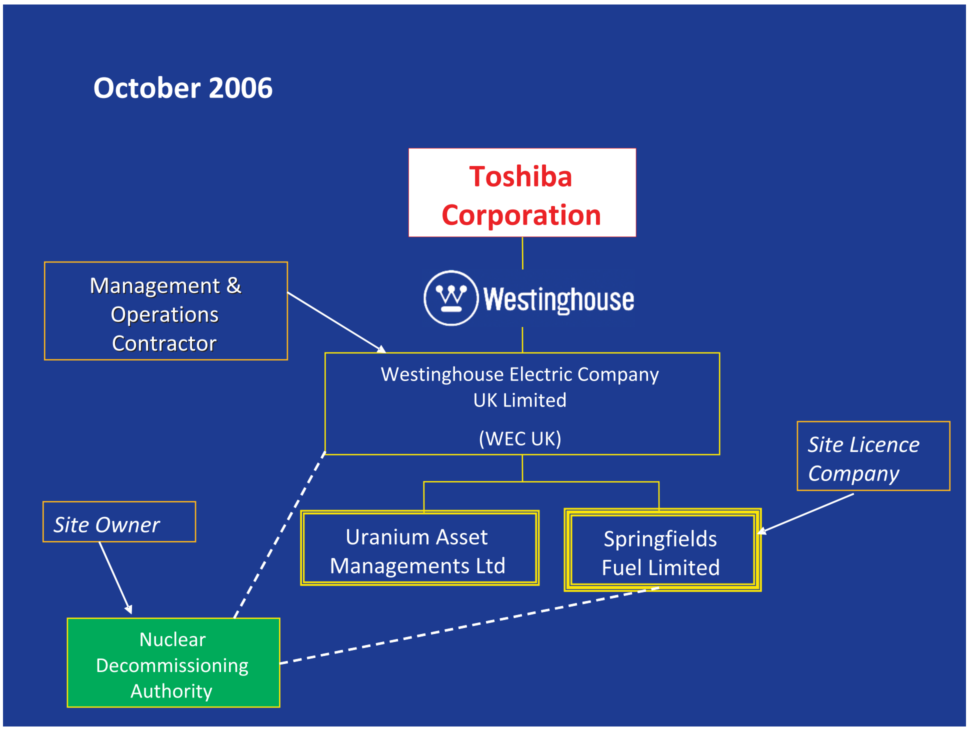

Figure 1

2. More about Springfields

The site occupies an area of about 80 hectares (200 acres). It currently employs about 1,400 people and is so named because of the number of natural springs that are on site.

A number of different operations are present on the site: Magnox Fuel Manufacture, AGR Fuel Manufacture, PWR Fuel Manufacture, Hex (Uranium Hexafluoride) Production, Enriched Powder Production, Residue Recovery and Decommissioning.

Magnox fuel has been produced on site since 1955. Since then, over five million elements have been supplied to reactors in the UK, Italy and Japan. Rod manufacture finished in 2008 and fuel manufacture is due to finish in 2009 with the final deliveries to station in 2010.

Figure 2

Advanced Gas Cooled Reactor fuel has been produced on site since 1969, and Springfields continues to supply all seven of the UK's AGR reactors under a Lifetime Contract with British Energy. The Oxide Fuels Complex (OFC) was opened in 1996 and produces up to 280teU of AGR fuel per annum.

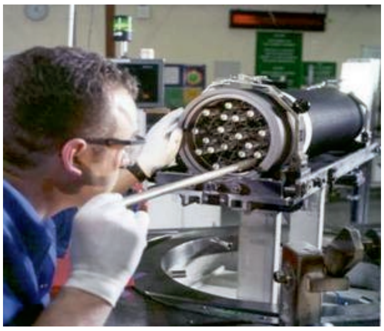

Figure 3

The OFC includes a 200teU capacity Light Water Reactor (LWR) fuel plant. This last produced fuel for Sizewell B in 1998, but has recently been refurbished with the intent to use it to produce fuel either for the new reactors built in the UK or worldwide as nuclear renaissance continues.

The OFC also produces about 300teU of Uranium Dioxide powder each year for export: mainly to Spain and Japan, but a contract has recently been signed to supply a trial quantity to Romania.

Uranium Hexafluoride has been produced on site since 1951, with the latest facility opening in 1994.

In 2006, a long-term contract was signed with a Canadian company to supply Hex.

The site operates Enriched Residue Recovery & Natural Residue Processing Plants. These aim to reduce the NDA's residue liability, as well as providing a service to external customers.

As plants come to the end of their life, decommissioning is required and old buildings are demolished. The current lifetime plan, as agreed with the NDA, takes the site from Figure 4 to Figure 5 by 2031. However, future plans might actually look completely different, as nuclear renaissance continues.

Figure 4

Figure 5

3. Safeguards Approach

The Safeguards approach at Springfields is to place the emphasis on Nuclear Material Control and Accountancy. The site has ten Material Balance Areas, which are split into 51 Works Accountancy Areas. These are then sub-divided into 106 Work Stations. All these areas are controlled by 14 Nuclear Material Custodians and nine Nuclear Material Accountants.

The Site Safeguards Office raises and issues all Safeguards- and Accountancy-related reports (e.g. ICR, MBR, PIL etc.), conducts quality checks on all site accounts, trains and approves all new Material Custodians, approves all changes to the site Accountancy system, checks all export and import advance notifications and coordinates contract notification and approval with Euratom. It also supplies a Nuclear Material Control and Accountancy service to Sellafield Limited (Capenhurst site) and is responsible for raising all Export & Import Licence applications for the site.

Currently, the only Safeguards Regulator for Springfields is Euratom. However, Springfields is involved in the UK Support Programme to provide: Training for IAEA Inspectors (Comprehensive Inspection Exercise & Design Information Verification) and new instrument testing.

4. Breaking News

Westinghouse Electric Company UK Limited has recently entered into discussions with the NDA on a sole basis for the long term management of the Springfields site.

Glossary

- **NDA** – Nuclear Decommissioning Authority: is a non-departmental public body, established under the Energy Act 2004. It is responsible for the decommissioning and clean-up of the UK's civil public sector nuclear sites. Its sponsoring Government department is the Department of Energy & Climate Change (DECC) which approves their strategy, plans and budget. The NDA owns the site, all assets and most of the nuclear material.
- **WEC UK** – Westinghouse Electric Company UK Limited: Wholly owned subsidary of Westinghouse Electric Company LLC.
- **SLC** – Site Licence Company i.e. the company responsible in law for meeting the requirements of the Site Licence e.g. Springfields Fuels Limited.
- **HSE UKSO** – Health & Safety Executive UK Safeguards Office: This is the government body that acts as the operational interface with DG TREN (Euratom). They also have a direct, but non-regulatory, interface with the Site Licence Company.
- **DG TREN (Euratom)** – European Regulator, with whom the Site Licence Company has a legal relationship.
- **DECC** – The UK Government's Department of Energy & Climate Change (formerly part of the Department for Business, Enterprise and Regulatory Reform (BERR).

Tribune and opinions

Status and Prospect of Non-proliferation Activities of ISTC and STCU

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Abstract

This article examines the role of the International Science and Technology Centre of Moscow (ISTC) and the Science and Technology Centre of Ukraine in Kiev (STCU) in preventing proliferation of the weapons of mass destruction (WMD) expertise and know-how of scientists and engineers from the Former Soviet Union countries. The Centres were created in the first half of the nineties, in the context of the collapse of the Soviet Union. This collapse raised very serious concerns: over the risk of former WMD scientists and engineers being recruited by States of concern or terrorist groups that wished to develop their own WMD capabilities and means of delivery; and the possibility that scientists and engineers would be driven to sell their knowledge, know-how or equipment in order to survive.

Since the Centres' inception, the regional and international context has changed dramatically at both economic and strategic levels, in particular regarding non-proliferation and global security. Changes of a political and strategic nature in the former Soviet Union required the European Union to review its relationship with Russia, to reassess the importance of Central Asian Countries and the future of Ukraine as it is pulled between Russia and Europe. The Centres have had to adapt to these changes. The article draws from an evaluation of the Centres' non-proliferation activities, carried out by the authors between November 2006 and September 2007 at the request of the European Commission. Moreover, since completion of the mission, many events, important for the strategic relationships between EU, Russia and other Commonwealth of Independent States (CIS) countries occurred as the affirmation of Russia's regional leadership: its rearmament along with the stiffening of its relationships with western countries and some neighbours and closure to visitors; the Georgia-Russia conflict; and the Russia-Ukraine gas crisis. As CIS countries are more affected by the current economical crisis, their situation could get worse and have a political impact in particular in Russia and Central Asian countries. These new developments, which had already been outlined in the mission's report, may have a major impact on the future of ISTC and STCU. The authors have attempted to take them into account in the article, which goes beyond the outcome of the evaluation, and to project the ISTC and STCU experience into the future. It describes the objectives, the methodology, the findings and recommendations of the mission, and gives some thoughts and prospects on the current CIS context and the role of the Centres.

The authors' mission took place in the context of the end of the programme of Technical Assistance to CIS countries ("TACIS programme") and the definition and implementation of a new European Foreign Policy Instrument, the "Instrument for Stability (IfS)", as the development of the European Neighbourhood Policy. The evaluation mission was carried out in Brussels, Paris, Russia, Kazakhstan, Ukraine and finally Georgia, through the audit of selected projects at the Centres and at the Institutes of the visited CIS countries. The evaluation drew also upon analysis of the answers to a questionnaire handed over to the Institutes and projects managers. IfS is now being implemented, and thoughts are ongoing on how to adapt the Centres to the new regional and international context, and how to draw from their experiences to manage other countries that raise proliferation concerns.

Keywords: ISTC, STCU; non proliferation; Former Soviet Union; CIS countries; redirection weapon scientists, weapons of mass destruction.

Disclaimer: The information and views set out in this report are those of the authors and do not necessarily reflect the official opinion of the European Communities, the Commissariat à l'Energie Atomique or the French Authorities. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained in the article therein and the evaluation report.

Evaluation Team and management: The evaluation mission on the non-proliferation activities of ISTC and STCU has been undertaken, to the benefit of the European Commission, by the French company BETURE, a subsidiary of the environment and energy group, PÖYRY ENERGY SAS, under a EuropAid TACIS contract. BETURE hired a team of three scientific experts in the fields targeted by the evaluation to carry out the work: Dr Isabelle Daoust-Maleval, biological scientific expert; Dr Philippe Louvet, chemical scientific expert and Dr Michel Richard, nuclear scientific expert and team leader.

Acknowledgements: The evaluation team is very grateful to the European Commission Officers, the European Commission/Directorate General for Research/International Cooperation unit headed by M. Robert Burmanger and M. Jürgen Sanders, the AIDCO task officers, the European Council representatives; the ISTC and STCU Secretariat staff, in particular, the EU Deputy Directors, MM. Waclaw Gudowsky and Michel Zayet, the State Parties Representatives, the CIS Institute managers and scientists who have organized the visits and warmly received them. Without the support of all these people, it would not have been possible to carry out the evaluation mission.

1. Introduction

This article draws principally from the mission report [1] on the evaluation of the non-proliferation activities of the International Science and Technology Centre (ISTC/Moscow) and the Science and Technology Centre of Ukraine (STCU/Kiev), carried out from November 2006 to September 2007 by the authors on behalf of the European Commission Directorate General EUROPAID [2]. The evaluation took place during a transition period. The former "*TACIS programme*" was terminated in December 2006. In 2007, it was replaced by a new EU external policy mechanism, the "*Instrument for Stability (IfS)*" [3, 4], designed to carry out the European global security strategy and to adapt it to the new international and regional context. The scope and appropriation of the IfS are quite different from those of TACIS, being geographically wider and dedicated to global security. As the redirection of former weapon scientists is a priority of the EU Strategy against proliferation of Weapons of Mass Destruction (WMD), this new context required the EU to reassess its policy on the support of ISTC and STCU. Then, the evaluation aimed at assessing the situation of the Centres non-proliferation activities and to provide the European Commission and the EU Members States with information and recommendations on the EU ISTC/STCU policy.

The objective of both centres is to provide scientists and engineers from Commonwealth of Independent States (CIS) countries: Russia; Eastern European countries; Caucasian countries and Central Asian countries, that possess knowledge and skills related to WMD or delivery systems, opportunities to redirect their talents to peaceful activities [5, 6, 7, 8]. Therefore, the main focus of the Centres' activities will concern the non-proliferation of expertise, and are mainly dedicated to WMD non-proliferation programmes and related areas (e.g. bio-security, Sensors, the integration of Former Soviet Union (FSU) science into the world scientific community, the creation of a high-technology research and development base in the FSU, and industrial partnerships).

The International context and CIS regional context have dramatically changed since the creation of the Centres, as have the EU security policy and the assistance policy to CIS countries. The article describes the background against which the evaluation has been carried out and how it has developed since that time. It summarizes the ISTC and STCU scope and mission, and the Centres' background and history, with an overview of their non-proliferation activities. The article sets out the contractual framework and objectives, as spelled out in the Terms of Reference. It describes the sources of information; the methods applied and the criteria developed as boundaries on the evaluation; and the programme of the expert team in-field at the ISTC and STCU Centres and at Institutes managing the selected projects in Russia, Kazakhstan and Ukraine. Finally, it provides an insight into the evaluation outcomes, main findings and recommendations, and comments on the operation of the Centres and their future.

Since the acceptance of the report by the European Commission in September 2007, many events have occurred. The Instrument for Stability is now being implemented. The first indicative programme covering two years, 2007 – 2008 [9], has been completed and the next, 2009 – 2011 [10], is getting underway. Through the IfS, the EU is revising its non-proliferation and security policy, the funding of the Centres has dramatically decreased and their programme has been revised to match the new CIS context. Based on the long-term objectives of the IfS to address the proliferation of WMD and counter global and trans-regional threats, thoughts are on-going on how to draw from the experiences and achievements of the Centres to manage other regions and countries of proliferation concern (i.e. the Middle East, Iraq, Libya and Syria). At the same time, the United States is considering broadening the CTR scope [11]. Above all, there are changes in the political and strategic context in the FSU. In particular, the stiffening and opaqueness of Russia, along with its closure and rearmament with the resurgence of regional ambition, are matters of concern. The Russia-Georgia conflict is an illustration of this trend. The United States and European Union are reconsidering their relations with Russia and their strategy to CIS countries. These new developments, which were outlined in the report, will have a major impact on the future of ISTC and STCU. The authors have attempted to take them into account and project the ISTC and STCU experience into the future.

During the study, the team has drawn from previous evaluation reports on the Centres: in particular, the report from FirstWatch which was quoted in the Terms of Reference, and also the other papers of the "Conference on Strengthening European Action on WMD" [12] including the documents mentioned therein.

2. Background of the evaluation

2.1. International context and CIS regional context

2.1.1. Evolution since the creation of the Centres

Since the birth of the CIS, as a consequence of the collapse and break up of the former Soviet Union in the early nineties, the international and regional contexts have dramatically changed at political, economical and global security levels. It has been a long time since the years of chaos in the aftermath of the disappearance of the USSR and the economic depression of the year 1998. Since the beginning of the century, Russia and the other CIS countries have recovered economically and, for some of them, become more open. But for Russia, Belarus and several Central Asian republics, democracy, human rights and openness are still a perspective out of reach.

In the early nineties, the strategic landscape of Eurasia also changed completely. Belarus, Kazakhstan and Ukraine inherited a sizeable nuclear weapon and WMD infrastructure. They gave up their nuclear status, decided to return their nuclear weapons and delivery systems to Russia, and then joined the Non-Proliferation Treaty (NPT) as denuclearized Non-Nuclear Weapon States. Russia remains as the only Nuclear Weapon State of the CIS. Russia, in common with the other CIS states, is involved in international disarmament and non-proliferation efforts: ratifying the Prohibition of Chemical Weapon Convention [13] and the Comprehensive Test Ban Treaty [14]; supporting the indefinite prorogation of the NPT (1995); and dismantling and destroying long-range missiles in the framework of the US-Russia Strategic Arms Reduction Treaty (START-I). Moreover, Russia declared itself in favour of the opening of negotiations for a treaty banning the production of fissile materials for nuclear weapons (the Fissile Material Cut-off Treaty, FMCT), and declared a fraction of its stock of high-enriched uranium (HEU – 500t) and weapons-grade plutonium (50t) as no longer needed for defence purposes. It is likely that, today, Russia will be less willing to participate in disarmament negotiations without any significant pay back.

2.1.2. Assistance to Russia and other CIS countries [15]

Since the end of the Cold War, the United States, the European Union, and others countries have been working with the successor states of the Soviet Union to account for, to secure and to dismantle nuclear and chemical weapons, ballistic missiles, toxic agents, dual use materials and infrastructures, as well as to help former weapon scientists and engineers to be reintegrated into civilian work. The most important part of the assistance has been provided by the United States to Russia. After the break up of the Soviet Union in 1991, Russia inherited one of the world's largest arsenals of nuclear and chemical weapons. In the early nineties, Russian economic and central controls deteriorated, making it difficult to maintain security at weapon sites. In 1992, the Congress established the Cooperative Threat Reduction (CTR) programme, known as the Nunn-Lugar Act, to help Ukraine, Kazakhstan, and Belarus to remove nuclear weapons from their soil. CTR also facilitated Russia's efforts to reduce its massive nuclear weapons arsenal and address its arms control commitments. The European Union and EU member states are engaged in international non-proliferation and disarmament assistance to Russia, bilaterally or through specific EU cooperation and assistance programmes such as the Northern Dimension Environmental Partnership (NDEP), TACIS, and the Council Join Action establishing a cooperation programme within the Russian Federation, which expired in June 2003. Since January 2007, the EU has provided assistance through several instruments of external policy, such as the Instrument for Stability (IfS), the Instrument for Nuclear Safety Co-operation (INSC), the European Neighbourhood Policy (ENP) and the Common Foreign and Security Policy (CFSP).

In June 2002, in the aftermath of September 11th, the Kananaskis G8 summit launched the Global Partnership against the spread of weapons and materials of mass destruction, which stressed the role of the Centres for the prevention of proliferation and terrorism [16]. Under this initiative, the G8 members committed to raise $20 billion in 10 years to support specific cooperation projects, initially in Russia, to address non-proliferation, disarmament, counter-terrorism and nuclear safety issues. In particular, the commitment addressed the destruction of chemical weapons, the dismantlement of decommissioned nuclear submarines, the disposition of fissile materials and the *redirection of former weapon scientists*. In the framework of the Global Partnership Initiative, some EU members and the EU have increased their assistance to Russia. The EU non-proliferation and disarmament assistance in CIS countries other than Russia aims at the conversion of former WMD production facilities (i.e. for Ukraine the ballistic and strategic missiles production complex), at the destruction of strategic armaments such as bombers, at securing sensible fissile materials and facilities including the Institute for Nuclear Research (Kiev) and in Kazakhstan, and upgrading of the safety of nuclear power plant.

2.2. Economic and political trends in the CIS [17]

Current CIS economic and strategic contexts are tightly linked, and have become a major determinant of the relationship of the EU with Russia and other CIS countries. Central Asian countries are becoming major suppliers of gas, oil and raw materials including uranium. Ukraine is now a strategic gas corridor between Russia and the EU.

2.2.1. Economic trends in the CIS

At their independence, Russian and other CIS governments inherited a dramatic legacy and had to reconstruct their own economies. Since the early 2000s,

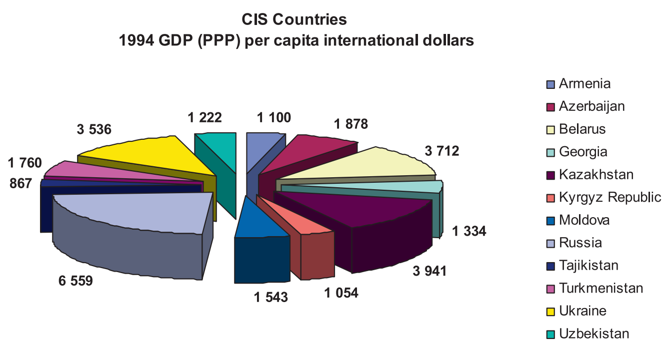

Chart 1: 1994 status of CIS economy.

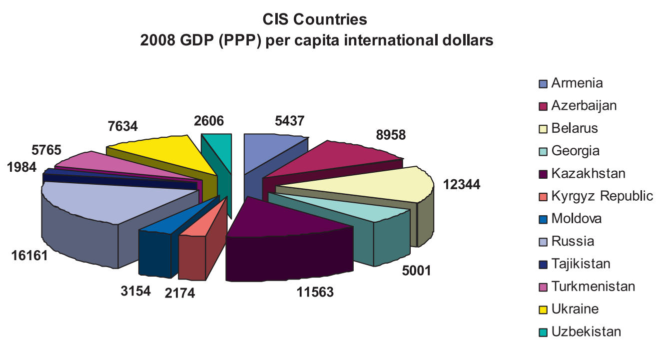

Chart 2: 2008 status of CIS economy.

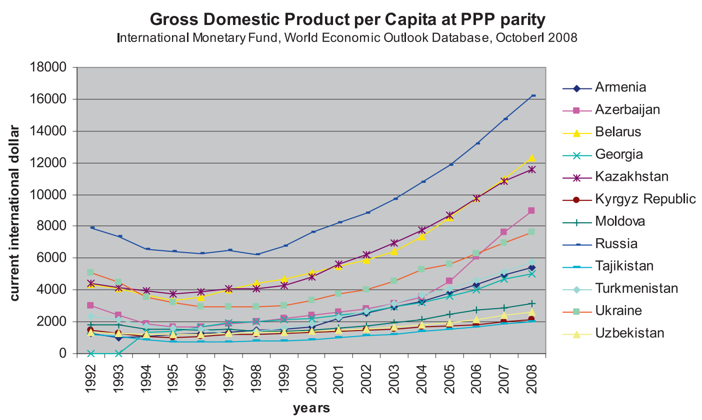

Chart 3: Compared trends of CIS economy.

Figure 1: Evolution of the economical situation of CIS countries from 1994 to 2008, GDP (PPP) per capita.

CIS countries developed very rapidly. By 2007, the economic CIS landscape was totally different, due mainly to soaring gas and oil prices. But the rates and the basis of economic development in Russia, Central Asian countries, East Europe and South Caucasus are quiet different, and depend mainly on their natural resources including oil, gas and uranium. These are illustrated by charts 1, 2 and 3 of Figure 1. Russia, Kazakhstan and Azerbaijan are becoming wealthier in terms of Gross Domestic Product PPP [18] (GDP), and Russia, now a major world oil and gas producer, ranks as the 9th richest economy in the world [19]. The other CIS countries rank far behind. Nevertheless, if Russia is becoming globally rich, the income per habitant is still very low and Russia is ranking only as 61st in terms of GDP per capita. Over the years, the performance of the Russian economy has exerted a strong influence on Russian policy towards foreign assistance. The economic and security needs, which prevailed in the nineties and drove the willingness of the Russian government to sign agreements; to accept assistance; to facilitate the projects funded through ISTC; and to open the institutes, has now tapered off. Among them is the 1992 agreement on the establishment of the ISTC, which is very profitable for both the institutes and the foreign collaborators. It is clear that the ISTC agreement could not have been concluded in its actual form if the negotiation would have to take place today. That means that any significant sign of loss of interest from the supporting parties, or any dismissal from Russia, may be used by the adversaries of ISTC and jeopardize the ISTC agreement.

Currently and in the near future CIS countries, in particular Russia and Central Asian countries which are more affected by the current financial and economical crisis as their economies rely mainly on the trade of raw material, are seeing the improvement of the last years somehow wiped out. One unknown is how this setback could impact significantly on the strategic and political balance of the region and arouse tensions with their neighbours and western countries?

2.2.2. Political trends in the CIS

The Russian government policy has become more inflexible and hard-line since the team experienced it during its stay in Moscow a couple of years ago. It seems that Russian policy is returning to the past: not to the former communist regime, but rather to a neo-tsarist expansionist policy as the manifestation of hegemonic renewed regional ambitions against a background of a wild market economy. Thus, President Putin is able to pledge 12 billions dollars for the preparation of the XXII Olympic Winter Games in Russia in 2014. Besides the development of oil and gas production, the Russian government has launched an ambitious nuclear programme, which plans to construct 25 nuclear power plants in Russia in the coming years, to export Russian nuclear power plants abroad (to China, India, Eastern European countries, the Middle East, etc.) and to develop new types of fast reactor. More disturbing is the rearmament of Russia and the strengthening of its defence policy. President Putin has announced that Russia could withdraw from both INF and CFE treaties and that the patrols of strategic bombers will resume. A re-energized Russia is drastically upping its military expenditure, and plans to double combat aircraft production by 2025. Plans for submarine-launched nuclear ballistic missiles (Bulava), with a 5,000-mile range and carrying up to 10 warheads each, are also being made, along with new, advanced anti-aircraft missiles and missile defense launchers. Russia's naval capability will also enjoy a massive upgrade. Russia's carrier fleet is expanding to include six brand-new nuclear-powered aircraft carriers, compared with only one currently in service. Russia is also planning to add eight new ballistic missile submarines and is developing new nuclear warheads. The warning message to the West is clear: "***The days of dismissing Russia as a spent force are over*** [20]". This trend has been confirmed since September 2007, further differentiating Russia from other CIS countries. What is happening now in Georgia is an illustration of Russia's campaign to reposition itself as a global actor, whom the international community will have difficulty to overrule in the future. At the same time, the events are a demonstration of Russia's weakness and lack of broader strategic thinking on many aspects of its foreign policy. Moscow has remained very ambivalent about the recognition of breakaway regions in the CIS in general, and is wondering how to deal with these regions in the future. CIS countries aggregate differently according to whether they stand by Russia or the EU. Central Asian countries stay in the Russian orbit, including Belarus. Ukraine, Moldova and Caucasian countries are balancing between Russia and the EU.

2.3. EU Security policy and assistance to CIS countries: a reassessment

Since the collapse of the former Soviet Union, assistance to Russia and other CIS countries in the areas of security and non-proliferation has been a concern for several EU members, and later for the European Union itself. The EU and EU Members support FSU disarmament and non-proliferation objectives and are involved in the elimination of chemical weapons; the disposition of weapon-grade plutonium from nuclear weapons; improvement of biological, chemical nuclear and radiological security and safety of sites and facilities; and prevention of the transfer of sensitive technologies and know-how to States of concern and terrorist groups. This has become an important part of the European Security Policy. The EU and EU Members are engaged in the International non-proliferation and disarmament assistance programmes to Russia and other CIS countries, either bilaterally or through specific EU cooperation and assistance programmes (cf.2.1.2).

Following the Thessaloniki summit joint declaration, the European strategy was spelt out in the document "A secure Europe in a better world" [21], The European Security Strategy and the EU Strategy against the WMD [22]. This was adopted by the Council in 2003, and new axes of action were defined in 2008, in particular, the EU assistance on non-proliferation and disarmament in CIS countries. Since 2003, the EU has redefined the instruments of foreign assistance and cooperation. ENP [23] sets objectives for enhanced co-operation between the EU and its eastern and southern neighbours in a broad number of areas, based on clear commitments to share values and provide effective political, economical and institutional implementation. The ENP Action Plan aims to share the benefits of EU enlargement with the EU's eastern and southern neighbours. The IfS promotes enhancement of security at the Border of the European Union and beyond, to prevent conflicts and terrorism through crisis management and proliferation prevention.

As the ISTC & STCU contribute to the achievement of that goal by stabilizing the former weapon scientists and engineers within peaceful activities and preventing the transfer of sensitive know-how and expertise to States of concern or terrorist groups at the edge of the European Union territory, they are one of the tools to implement the EU security policy. One of the project areas of the IfS is directed to the evolution of the ISTC and STCU. As stated in the first IfS Indicative Programme, covering the two year period 2007-2008 [24] and Priority 1 non-proliferation of weapons of mass destruction "*Project area 1 – Support for the retraining and alternative employment of former weapons scientists and engineers*", the Governing Boards of ISTC/STCU acknowledged the need to adjust to a new environment. In March 2006, they initiated a strategic reassessment of the strengths and possible improvements in order to decide on the future direction of the ISTC and SCTU. Within the indicative Programme 2009-2011 [25] Priority 1, Non-proliferation of WMD "*Project area 5 – Support for the retraining and alternative employment of former weapons scientists and engineers*" the Commission recognized the radical changes in the economic and political scene in the FSU since the Centres were established. They commissioned an expert study in 2007 and undertook an assessment mission to the ISTC in 2008. The assessment concluded that the proliferation threat from Russia itself was now limited, especially in the nuclear field, but that there was a real risk of biological proliferation, particularly from other parts of the former Soviet Union. Furthermore, that ISTC/STCU could continue to play an important role as a funding mechanism, that Russia should be encouraged to play a more active role in the ISTC, including contributing to its funding, and that the Commission should focus a considerable part of its funding on partner projects.

From this assessment, the Commission recognized that the Centres have dual objectives. Not only do they pursue the non-proliferation goal of providing alternative peaceful employment opportunities to former weapon scientists and engineers, but also they have broader objectives of reinforcing the transition to market-based economies. They do this by supporting basic and applied research and technology development and promoting the further integration of scientists of the FSU into the international scientific community. This activity should be funded by an instrument other than IfS. As the risk of proliferation of expertise from outside the former Soviet Union has increased, particularly in the context of undeclared WMD programmes established or suspected (e.g. Iraq, Libya, Syria, and DPRK), G8 members have agreed to respond to this new threat by placing greater emphasis on non-proliferation outside the FSU. The US and the United Kingdom are already actively supporting redirection actions in the Middle East. The EU has, so far, not supported any redirection actions outside the FSU. In the IfS indicative programme 2009 – 2011, the EU proposes to extend the scope of assistance beyond the FSU to other countries, in particular in the Middle East and North East Asia and Africa.

Therefore, the budget devoted to ISTC and STCU reflects the change in the regional and international context and the new stand of the EU. Until 2007, in the framework of the TACIS programme, the overall Centre budget was around €25M: €20M for ISTC and €5M for STCU. Since the implementation of the IfS and the shift in priority, the Centre's budget is continually decreasing and, over the period 2009-2011, the Centres will be granted €30M.

A difficult issue for the EU and other parties is to find a balance between the necessary adaptation to the actual and future international and regional context and the appropriate level of resource to allow the Centres to fulfil their missions effectively for the benefit of the EU and the international community other than in minimalistic mode.

Security-related research is an important building block for supporting European freedom, security and justice. It will also contribute developing technologies and capabilities in support of other European Community policies. The required security technologies and knowledge [26] are developed in the Framework of the European Security Research Programme of the 7th Framework Programme. On these themes, former weapon scientists and engineers of CIS countries have, from their past experiences, all the competences and skills necessary to bring additional support to the Security Research through the ISTC & STCU project within a strategic partnership with CIS countries, and to use the ISTC & STCU as a platform for research in Security.

Remarks from the trend of the strategic, political and economic posture of Russia in particular towards other CIS countries, one could wonder to what extent the scientific and technological cooperation programme for the redirection of former weapon scientists conducted in the framework of the ISTC projects provided Russia with a basis for the resumption of military programmes, by maintaining know-how and preserving capabilities. No one can answer that question, because no one knows what would have happened in the chaos of the early nineties without the prevention of the transfer of dangerous know-how and technology to rogue countries or non-State actors. These pessimistic views should be appreciated in the light of the scientific accomplishments of the ISTC, which has succeeded in establishing the base of a scientific and technological network of excellence involving Russian, CIS and western institutes.

However, taking into account this international and regional context it seems important that the ISTC and STCU governors and management establish improved monitoring of projects. In particular, that the emphasis on Russia should be decreased in favour of the other CIS countries, principally to address remaining proliferation concerns in Central Asian, and that the balance in favour of the STCU be readjusted to match the European Neighbourhood Policy.

2.4. ISTC & STCU background

2.4.1. History of the Centres [27]

During the cold war, the Soviet Union maintained several hundred research institutes that were dedicated to research, development and production of WMD and their means of delivery. The exact number of scientists is not known, either by the post-Soviet CIS governments or by the Western intelligence agencies. A June 2005 study by the RAND Corporation [28] estimated that 200,000 – 220,000 people worked on the nuclear weapons programme; 60,000 – 70,000 worked on the biological weapons programme; and between 5,000 and 8,000 worked on

Figure 2: ISCT & STCU Governing Board parties and CIS parties.

the chemical weapons programme. These figures do not include the thousands of less-experienced junior scientists and technicians, who either worked on these programmes or supported their efforts through pure science and engineering activities (physics, chemistry, biology, electrical engineering, advanced materials, etc.), or the administrative and support staff. During the Soviet period, over 97 per cent of the support for the sciences came from the State, which amounted to about 10.9 billion roubles in the year 1990 alone.

The centres were created in the early nineties, when the rapid collapse of the Soviet Union raised very serious concerns about the risk of an exodus of senior scientists to work for, or to sell sensitive knowledge to, States of concern that might wish to develop their own WMD. The idea of establishing an international fund to help employ former Soviet weapon scientists was raised in late 1991. ISTC & STCU are intergovernmental organizations (Figure 2). Since their inception, the ISTC and STCU have funded over 81,000 scientists and engineers in the FSU, and over 3,250 projects to a total value of $1,000 million. Annually, the two science centres provide grants for over 4,000 research and technology projects. They also assist in various aspects of business development, such as patent and commercialisation, and through the sponsoring of workshops and visits of industry experts.

The **ISTC** is the larger Centre in terms of financial contributions and number of projects funded. On November 27th 1992, the United States, Japan, the EU and the Russian Federation signed the ISTC agreement, which formally established the institution. The EU membership is represented by the Presidency and the European Commission. The ISTC began operations on October 15th 1993, after President Boris Yeltsin signed a presidential decree ordering provisional operation of the Centre. It has functioned successfully with this status, with all Member States having ratified the agreement except Russia. The Eurasian CIS countries began to join from 1992. These included Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, and Tajikistan but not Turkmenistan. Other supporting countries include Canada, South Korea and Norway. Until December 2008, the 97,397 scientists and engineers from Armenia, Belarus, Georgia, Kazakhstan, Kirgizstan, Russia and Tajikistan received ISTC funding to participate in 2,646 projects totalling US$814.6 million [29].

The **STCU** was established in Kiev, in 1992, at the request of the Ukrainian Government. Representatives from the four founding parties – Canada, Sweden, Ukraine and the United States – signed the agreement that established the STCU. The agreement was brought into force in May 1994. Later, in 1998, the European Commission jointly with EURATOM replaced Sweden. Japan channelled some financial support for a limited number of projects (1 MUSD). The STCU is reputed to operate more effectively than the ISTC – possibly because its host agency, which contributes to and funds its operation, is the Ukrainian Academy of Sciences but perhaps also because it is smaller, less bureaucratic and its area of jurisdiction is just Ukraine. All the STCU staff have undergone a training programme that emphasizes the Centre's philosophy of service. Unlike the ISTC, there is also less governmental oversight of staffing of the Centre. The STCU helped over 13,200 scientists from Azerbaijan, Georgia, Moldova, Ukraine, and Uzbekistan and funded 887 projects for over $136 million.

2.4.2. Scope and mission of the Centres

The objective of both centres is to provide CIS scientists and engineers that possess knowledge and skills related to WMD or missile delivery systems with opportunities to redirect their talents to peaceful activities. Therefore, the ISTC and STCU are dedicated to WMD non-proliferation programmes. According to their unique statutes and agreements, the ISTC and STCU should coordinate the efforts of several governments, international organisations and private industry sectors, providing opportunities in international partnerships to former WMD scientists from CIS countries. **The ISTC and STCU are central to the management of these science partnerships.** Through their political, legal and financial framework, the ISTC and STCU may contribute to the international effort on fundamental research programmes concerning non-proliferation and programmes on global security. They may also contribute to innovation and commercialisation programmes by establishing commercial and industrial links between the demand of international markets and the pool of scientific skills available in CIS institutes. The aims of the Centres are:

- ***Non-proliferation of expertise:*** The Centres activities will focus on supporting projects and activities that create potentially useful high-value scientific employment for WMD scientists of the CIS and durably lower the risk of a brain-drain to potentially dangerous countries and organisations. This objective was reaffirmed by the 2002 Kananaskis G8 declaration on Global Partnership.
- ***Integrating the FSU science into the world scientific community:*** The Centres will be ac-

tive sponsors of workshops, conferences and symposia and will support the participation of their scientists in international scientific and business gatherings.

- ***Creating High Tech R&D Base in the FSU:*** The Centres training and technology development activities will be used to facilitate the structural adjustment of institutes willing to demonstrate their ability to conduct cost-effective research and the development of self-supporting innovative structures in NIS countries.
- ***Creating Industrial Partnerships:*** The Centres will establish themselves as reliable match makers that create scientific and technical partnerships.

2.4.3. ISTC and STCU non-proliferation activities

Assessment of the non-proliferation activities. The assessment of the non-proliferation activities of ISTC & STCU, as stated in article II (A) and article III of their respective agreements, constitutes the core of the evaluation conducted on behalf of the European Commission. According to their statutes and agreements, the ISTC and STCU should coordinate the efforts of several governments, international organisations and private industry sectors, providing opportunities in international partnerships to former WMD scientists from Russia and CIS countries. ISTC and STCU are central in the management of these science partnerships. Through their political legal and financial framework, the ISTC and STCU contribute to the international effort on fundamental research on non-proliferation and global security programmes including G8 and PERS. They contribute to innovation and commercialisation programmes by establishing commercial and industrial links between the demand of international markets and the pool of scientific skills available in Russia and CIS institutes. All these activities should prevent former WMD scientists from Russia and the CIS countries being involved in research that could benefit States of concern or terrorist groups, and should also contribute to fulfil the mission assigned to the Centres by the international community.

ISTC & STCU project selection mechanism. On the basis of the programmatic approach of the Centres, the institutes issue a project proposal: either a regular or a partner one. The proposal is reviewed through the institute's government concurrence on the basis of national security criteria, including the statute of former WMD scientists of the project team and scientific or technical quality requirements. Then projects are submitted to the Board of Governors and the funding parties, which choose the projects they wish to support and also to the partner. As a member of the board, the EU selects projects according to the European Commission DG RTD criteria, which include non-proliferation value and scientific and commercial value of the proposal. For example, they consider whether the project fills a scientific or technical gap; the outcomes of the project in terms of innovation; if there are European collaborators involved in the project and the potential for exchange with them; whether the outcome of the project may be used in the development of WMD, or whether the project prevents proliferation through alternative employment of former weapon scientists; and how the indigenous and international network build up impacts upon the scientists and their institutes. Finally, how the project could be implemented. The authors' assessment mission highlighted the considerable effort that is spent on the approval of projects, compared with follow-up and evaluation of the outcome (at least for the regular projects).

For the purpose of evaluation, the expert team reviewed the ISTC data base, research project proposals and outcomes of Governor Board Meetings (GBM), to identify the most representative institutes (based for example on their involvement in ISTC projects and former weapon-related programmes including weapons, protection, counter-measures and expertise) and the projects most relevant to the objectives of the evaluation. For project selection, the expert team also took into account other constraints, including budgetary, political and information ones, and limited time frame.

Overview of the Centres activities. To improve their effectiveness and better focus on the shared needs of the parties, ISTC and STCU have adopted new approaches for the definition of project proposals: the programmatic approaches for STCU and the targeted research and development initiative for the STCU. The September 11th attack and followings emphasized the urgent needs of the international community in the area of security research and development to defeat these new threats. Drawing from the high scientific and technical level of institutes and laboratories of CIS countries as from their experience acquired in the development of WMD, the two Centres could contribute to fulfil these needs. That is why their programmes, agreed by their board of Governors have been targeted to this type of research: forensics science, bio safety and security, CBRN threat detection and response, explosive detection, then supporting the G8 Global Partnership orientations [30]…Both ISTC and STCU are tightening their links with the European Union Framework Programme of Research and Development, which will help to improve the integration of the former weapon scientists in the world scientific community and benefit from the high expertise of these scientists in specific areas like security research.

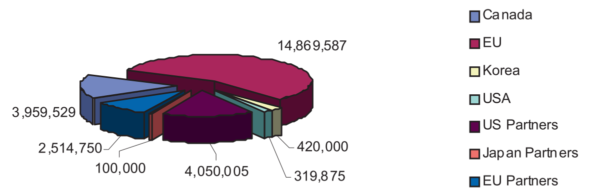

Figure 3a: Total new ISTC project funding ($) in 2008 by Source.

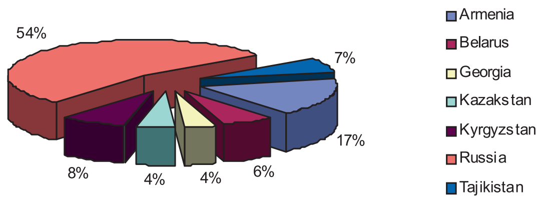

Figure 3b: 2008 ISTC project funding received by beneficiary country total: 26,233,746 $.

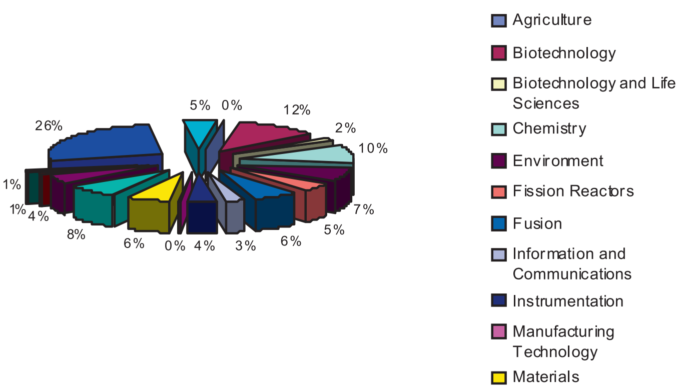

Figure 3c: 2008 ISTC project funding ($) by technology area.

a) **ISTC 2007 & 2008 activities [31]**

Currently, the ISTC staff comprises approximately 180 people, representing a streamlining over recent years to adapt the Centre to budgetary constraints (Figure 3). In 2007, the ISTC accomplished new project funding for 147 projects, to the value of $49.2 million, of which ISTC Partners provided $21.8 million for 74 projects. Since the inception of the programme, and with the addition of 44 new Partner organizations to the existing 335 Partners, a total of $235.2 million has been provided in project funding. As of December 2007: 2,578 funded proposals received ISTC funding totalling $785.2M, involving 69,218 participants from 980 institutes in Russia and CIS. In 2007, ISTC grant payments to participants were equivalent to 1,571,701 person-days, including a full range of supporting programmes in commercialization and innovation; travel support; communication; intellectual property; and competency building.

The ISTC's priorities have been reviewed according to objective expressed previously and spelt out according to the needs expressed by the funding and recipient parties in two groups: Group 1 (first priority) encompasses Counter Terrorism and Global Security, Biotechnology, Public Health and Agriculture, Advanced Nuclear Energy Technology, Nuclear Fuel Cycle and Nuclear Safety. Environmental Remediation and Climate Change Mitigation and Renewable and Environmental Friendly Energy Technologies (Non-nuclear energy technologies) and Group 2 (second priority) including High Energy Physics based on Advanced Accelerator Technology (also called Particle Physics).

b) **STCU 2007 activities [32]**

The staff of STCU comprises 70 people. The activities of the STCU cover regular scientific projects, marketing projects (Institute Sustainability projects), partner projects, and projects based on joint initiatives with co-financing from CIS institutions through the "Targeted initiative", scientist training, and their promotion through seminars and conferences with the aim to develop links with foreign scientists in the area of peaceful research (Figure 4). STCU has also retargeted its programme to encourage and support research and development in security as nuclear forensics, bio safety and security supported by seminars to develop exchanges with the western laboratories and institutions.

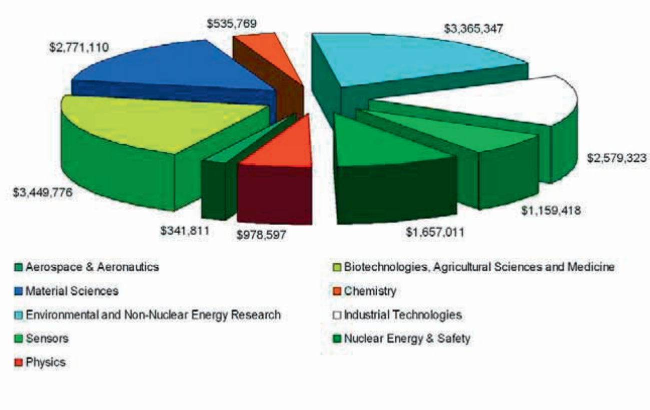

Figure 4a: New project funding in 2007 by primary technical area.

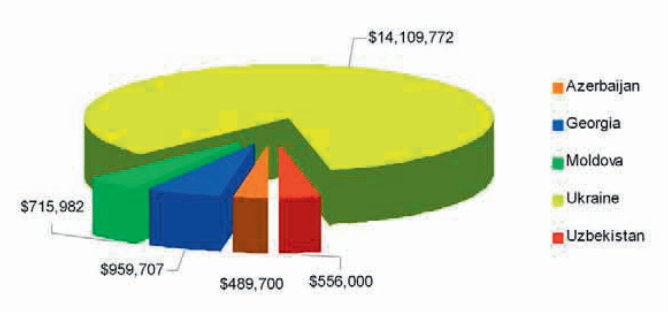

Figure 4b: New project funding in 2007 by location of recipient organisation.

3. Objectives of the mission and Terms of References

3.1. Incentives

As pointed out in paragraph 2.3, the initial concerns that led to the founding of the centres have tapered off, and it is widely recognized that the balance between the objectives of the centres and the manner in which they conduct their activities need to be reevaluated in light of the changing nature of the scientific community in the FSU – in particular, Russia. Over time, the scale and coherence of what was, in Soviet times, a more closely-integrated science sector have been changed by natural processes, with important implications for the science centres. That is, the size of the science community in Russia (and probably in other former Soviet countries as well) has been greatly reduced through a combination of emigration and the decisions of individual scientists to seek alternative employment outside science. As the risk of proliferation has changed, a technical reassessment of the activities of the Centres to prevent proliferation of WMD and their means of delivery was deemed necessary by the European Commission.

3.2. Objectives

The evaluation mission objectives, scope and framework and expected results were spelled out in the terms of reference. **The Global Objective is the** Improvement of the operation of ISTC and STCU as well as the programmes that they finance in the NIS states. **The Specific Objective is the** Analysis of the functioning, adequateness, and appropriateness of the ISTC and STCU, as well as the programmes that they finance in the NIS states.

3.3. Expected results

The expected results of the evaluation are the following:

1. Analysis of the current need in the former Soviet Union for organisations such as the ISTC and STCU, in terms of helping WMD scientists to find civilian employment: *It entails establishing what the demographic situation of WMD specialists in the former Soviet Union is today. Relevant questions include: How many WMD specialists are still active professionally? How has this changed since the inception of the centres? What are the needs in the FSU from the ISTC and STCU with regards to this new demographic? A methodological approach could be to look at age structures and demographic shifts over time, as well as how education programmes in the region will affect the total number of scientists in WMD relevant fields.*
2. Analysis of the background of the scientists supported by the ISTC and STCU, both currently and in the past: *It means establishing the general profiles (specializations and qualifications) of the scientists currently and previously cooperating with the ISTC and STCU. How are/were their profiles related to WMD research? If possible, how have the profiles of the associated scientists shifted over time (is there an increase over time in scientists not related to WMD associated with the centres?)*
3. Analysis of the goals and work of EU-sponsored research projects in the NIS region, and whether these projects are, or could be, related to WMD research: *It means looking into EU funded research projects in the region, both those linked to ISTC and STCU, and those financed by other projects. The goal in this case will be to establish whether there could be any possible links between those projects and WMD research of any kind. Besides contacting the ISTC and STCU, the consultant will also establish contact with DG RTD in Brussels, to identify other projects relevant to non-proliferation.*
4. Analysis of whether the ISTC and STCU have been successful in fulfilling their mission of finding sustainable civilian employment for WMD scientists working with them: *It means analysing the effectiveness of employment creation with these programmes – how many scientists have found civilian jobs? What job creation measures do the ISTC and STCU take? How long do scientists continue to depend on funding from the ISTC and STCU and why do they stop applying for new grants? The consultant will also provide a detailed report of what is lacking in the centres' employment creation strategies, and proposals of what must be done to improve this.*

3.4. Critical Results

As the original Terms of Reference were rather ambitious for the allotted resources, the expected results has been prioritized to identify the results critical to the mission:

1. Are the ISTC/STCU projects financed by CE actual non-proliferating and non-proliferation projects?
2. Are the weapon scientists engaged in these projects real weapon scientists, and how should this be verified?

3.5. Limitation of the evaluation

The mission to evaluate the non-proliferation activities of the ISTC and STCU was a first for the EC, reaching beyond the usual scope of financial or management audit. Consequently, the Terms of Reference were rather flawed. The resources granted by the Terms were too limited to meet their objectives. Funding and duration fell short of the scope of the study, even after the objectives had been streamlined and refocused. The budgetary and time constraints had impacted and in some ways hampered the course of the mission. This mismatching had some consequences on the progress of the mission. The time schedule was too short to carry out the entire programme, and several visits to institutes were cancelled including Vector, GosNIIOKhT in Russia and Lyv in Ukraine. No visits to other CIS countries, other than Russia, Kazakhstan and Ukraine, were possible. The lack of time did not permit analysis in depth and integration of the important mass of information collected during the mission. Major emphasis was put on the nuclear evaluation duration in Moscow and Kiev, compared to the chemical and especially the biological ones, despite the breakdown of projects and funding by technology areas showing that biology and life sciences concentrated the highest number of projects (and in some respects, the most sensitive). Technology areas such as means of delivery, sensors and material and "other field" category (lasers, accelerators), were not adequately covered by the expertise. Nevertheless these difficulties did not undermine the solidity of the findings and the recommendations.

4. Evaluation methodology and criteria

4.1. Information sources

The main information sources and instruments used for the evaluation were:

- The Terms of Reference as a framework of the evaluation.
- The Analysis of documentation: UE, ISTC & STCU, articles and reports. Thanks to the DG Research and AIDCO officers, the team gained access to a large range of documents on international non-proliferation programmes in Russia and CIS countries; the policy and programme documents of the European Commission with regard to General Directorates including the Boards of Governors; ISTC/STCU, CIS countries' documents as well as party policy and think-tank documents.
- Interviews with EU and Member States' representatives on the context, European Policy, challenges, and project selection mechanisms.
- Study and analysis of EU-funded projects and other projects according to the second and third expected results as given by the Terms of Reference, specifically non-proliferation:
  - Projects selection mechanism
  - Follow-up of projects selected by the Board and EU-funded
  - Over 200 ISTC projects and 100 STCU projects analysed for each area: nuclear, chemical and biological
  - Selection of typical projects and Institutes for the evaluation in the framework of allotted resources and agenda and clearance constraints.
- The conduct of interviews on the basis of a "***questionnaire***" with selected CIS scientists and institutes, laboratories and project managers in various fields including: basic sciences, physics, materials, manufacturing, information technologies, nuclear fission and fusion technologies, non-nuclear energy, environment and monitoring, chemistry, life sciences and biotechnologies, aerospace and surface transportation, non-nuclear energy.

4.2. Methodology

The methodology implemented for the evaluation is based on the analysis of sources as above and:

- The working out of criteria for the identification of proliferating or dual-use activities for each field: nuclear, chemical and biological.
- The analysis of the projects and activities on the basis ***of criteria developed by the team to***

identify proliferating or dual-use research and activities.

- The selection of projects to be evaluated.
- The redaction of a "***questionnaire***" to conduct the interviews with main stakeholders, with EC representatives and States Parties' representatives, ISTC and STCU officials and project managers.
- The analysis of the answers to the questionnaire and interviews on the base of the Terms of Reference and the 5 EU criteria: *Relevance, Effectiveness, Impact, Efficiency and Sustainability.*

4.3. Project selection

4.3.1. ISTC project selection

As regards to ISTC: more than 200 projects were analyzed in the nuclear field, 224 projects in the biological field and more than 200 projects in the chemical field. Out of these projects, 31 projects from 11 nuclear institutes in Russia, 33 projects from 12 biological institutes in Russia and Kazakhstan, 18 projects from 9 chemical institutes in Russia, were selected.

4.3.2. STCU project selection

More than 100 projects were analysed in the nuclear field and more than 100 projects in the chemical field. Out of them, 11 projects from 8 nuclear institutes in Ukraine and 8 projects out of 6 chemical institutes in Ukraine were selected. The mission of the bio expert was cancelled due to security issues.

5. Evaluation agenda and programme

The mission extended over 1 year, from October 2006 to September 2007, and was carried out in three phases:

- **A desk phase:** The inception meeting took place in Brussels on October 23rd 2006. The desk phase in Brussels from November 20th to mid January 2007 encompassed both analytical and preparatory work: interviews; information and data collection; basic information analysis; study of the strategy of the EU for the ISTC and STCU; EC project selection for funding and management mechanism analysis; review of research project proposals and the outcome of Governor Board Meetings (GBM) and Scientific Advisory Committee meetings; selection of representative projects for evaluation; preparation of the evaluation at ISTC and in Russia and Kazakhstan, and STCU and Ukraine and possibly other CIS countries.
- **A field phase:** The field phase started at ISTC, Moscow and in Russia and Kazakhstan, from February 18th 2007 to March 17th. The second part of the evaluation field took place at STCU, Ukraine without the bio expert, the mission of whom was cancelled, from March 26th to April 3th for Chemical and April 6th for Nuclear.
- **An analysis phase:** A preliminary report was presented to the Commission, Brussels on June 20th 2007. The final report was provided to the EC on September 6th, 2007. A presentation of the findings & recommendations was delivered to the Committee for the implementation of the Instrument for Stability (IfS) on February 22th 2008.

6. Field Phase operation at ISTC & STCU

The field phase of evaluation was conducted first in Moscow (ISTC) (despite some troubles) and in institutions in Russia and Kazakhstan, then in Kiev (STCU) and in Ukraine [33]. An STCU biological seminar held in Georgia allowed the team to get some information on the activities carried out in the country.

6.1. Evaluation in Russia

See Figure 5.

6.1.1. Nuclear evaluation

11 institutes were visited: 5 in the Moscow region (MIPhI, Kurchatov Research Centre, IPPE Obninsk, FEI, VNIINM Boshvar, ITEP) 3 in the St Petersburg region (KRI Khlopin Radium Institute, NIIEFA EFREMOV, Research Institute of Technology, Sosnovy Bor) 1 at Sarov (VNIIEF),1 at Snezhinsk (VNIITF), 1 at Novosibirsk / Akademgorodok (CO RAN, Institute of Laser Physics), and 31 projects were evaluated.

6.1.2. Chemical evaluation

7 institutes were visited: 3 in the Moscow region (GITOS State Institute of Technology of Organic Synthesis/Saratov, MSU Moscow State University Department of Chemistry, MIFCT Lomonosov Academy of Fine Chemical Technologies, GosNIIOKhT State Research Institute of Organic Chemistry and Technology, IPAC Institute of Physiologically Active Compounds) 3 in the St Petersburg region (KRI Khlopin Radium Institute, RSC "Applied Chemistry" Russian Scientific Centre of Applied Chemistry, RIHOPHE Research Institute of Hygiene, Occupational Pathology and Human Ecology) 1 at Vol-

vograd (RIHTOP Research Institute of Hygiene, Toxicology and Occupational Pathology), and 18 projects were evaluated.

6.1.3. Biological evaluation

12 institutes were visited: 4 in the Moscow region (Institute of Mathematical Modelling, Mendeleev Chemical Technological University, Shemyakin-Ovchinnikov Institute of Bioorganic Chemistry, Institute of Toxicology and Hygienic Regulations of Biopreparations/ Serpukhov, IPAC: Institute of Physiological Active Compounds/Chernogolovka) 3 in the St Petersburg region (Khlopin Radium Institute, Institute of highly pure biopreparations, Research Institute of Hygiene,Occupational Pathology and Human Ecology), 1 at Obolensk (State Research Centre for Applied Microbiology and Biotechnology), 1 at Pushino (Institute of Biochemistry and Physiology of Microorganisms), 1 at Lyubuchany (Institute of Immunological Engineering), and 33 projects were evaluated.

Figure 5 : Evaluation of ISTC non-proliferation activities in Russia.

Figure 5a: VNIIEF (Sarov) Commercialization project #3140.

Figure 5b: Research Institute of Technology (Sosnovy Bor, Leningrad reg) projects #1950.2, # 833.2, #3592, #3345.

6.2. Biological evaluation in Kazakhstan

In the framework of allotted budget and resources, the evaluation team was not able to carry out the evaluation in other CIS countries, excepted one biological mission in Kazakhstan where one institute was visited (Kazakh Scientific Centre for quarantine and zoonotic diseases, Almaty) and 5 projects were evaluated. Nevertheless, thanks to cooperation and openness of the staff of the institute, the evaluation was productive (Figure 6).

6.3. Evaluation in Ukraine

6.3.1. Nuclear evaluation

8 institutes were visited: 5 in the Kiev region (Institute of Macromolecular Chemistry of National Academy of Science of Ukraine, IOCh NASU Institute of Organic Chemistry of National Academy of Science of Ukraine, ISP NASU V.E. Lashkaryov Institute of Semiconductor Physics of National Academy of Science of Ukraine, M.D.Strajesko Institute of Cardiology of National Academy of Science of Ukraine, Institute for Nuclear Research), 2 at Kharkov (National Science Centre KIPT, Kharkiv National University),1 at Dniepropetrovsk (Dnipropetrovsk / Yuzhnoe KB "Pivdenne" State Design Office), and 11 projects were evaluated (Figure 7).

6.3.2. Chemical evaluation

6 institutes were visited in the Kiev region, the first four above jointly with the nuclear expert (M.M. Gryshko National Botanical Garden Of COSCOMATOM of Ukraine of National Academy of Science of Ukraine, Institute of Molecular Biology and

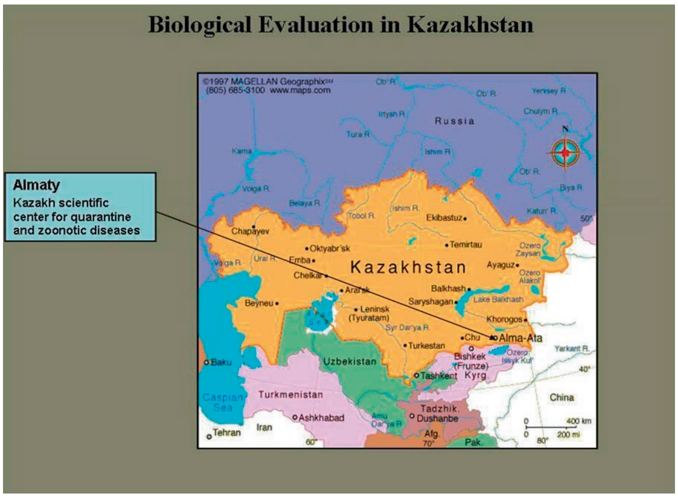

Figure 6: Evaluation of ISTC non-proliferation biological activities in Kazakhstan.

Figure 7: Evaluation of STCU non-proliferation activities in Ukraine.

Figure 6a: Kazakh scientific centre for quarantine and zoonotic diseases, Almaty. Projects #K-573, #K-1346, #K-847, #K-788.2, #K-1347.

Figure 7a: Visit to the Yuzhnoe KB "Pivdenne" space museum.

Genetics), with the visit to institutes in the Lviv region cancelled (Department of Physical-chemistry of Institute for Physical-Organic Chemistry and Coal Chemistry), and 11 projects were evaluated.

6.3.3. Biological evaluation

The mission of the bio expert was cancelled.

6.4. Biological mission in Georgia

On the invitation of STCU, the biological expert participated in a scientific workshop in Tbilisi, Georgia, 2–5 July 2007, sponsored by STCU along with the Durmishidze Institute of Biochemistry & Biotechnology, and titled "Plant & Microbial Enzymes – Isolation, Characterization and Biotechnology Applications". This participation enabled the team to gain some insight into the Georgian biological institutes and the non-proliferation activities of ISTC and STCU in this country (Figure 8).

Figure 8: STCU biological seminar in Georgia.

Figure 8a: Biological workshop in Tbilisi, Georgia 2–5 July 2007.

7. Finding and recommendations

7.1. Outcomes

1. ***Analysis of the current needs in the former Soviet Union for organisations such as the ISTC and STCU in terms of helping WMD scientists to find civilian employment:***

   Organisations like the ISTC and the STCU are still needed and important because the risk of proliferation and transfer of sensitive knowledge and technology has not disappeared, even if the nature of the proliferation has changed. They play an important role as a technological and scientific cooperation network. The situation is different from one region to another and from one CIS country to another. It varies according to the scientific and technological field and the region of interest. In Russia, the risk of proliferation is more important for chemical and biological areas than for nuclear. The risk of proliferation is much more important in Central Asian, especially in biological proliferation, than in Ukraine and Russia. To ensure a sustainable stabilization of WMD experts, in particular in countries other than Russia, specific measures should be set up such as the increase of the daily rates which should be brought up to the cost of living. Even now, reinforced by the effects of the global economic crisis, too low daily rates create vulnerabilities and open the door for selling sensitive knowledge, materials and technologies on the black market.

2. ***Analysis of the background of the scientists supported by the ISTC and STCU, both currently and in the past; are the WMD experts involved in EU funded projects founded by the EU real former WMD experts and how could this be verified?***

   The bulk of audited projects involve more than 50% of former WMD scientists. How has this been verified? It is unrealistic to ask CIS countries' governments for detailed biographies of scientists and engineers to be attached to a project, as the information in the biographies are national security sensitive and likely to be of proliferation value. The only relevant method is to assess the skills and background of projects' participants through interviews in the institutes and laboratories, carried out by an evaluator with similar background, and through the analysis of the project summaries and work plans.

The evaluation team analyzed the selected projects through the documentation handed over by DG/RTD and interviews at the ISTC and STCU and in the institutes. It appears clear that the bulk of evaluated projects could not be carried out if the majority of involved scientists were not former WMD experts. The ratio of former weapon scientists is still over 50%. ***That is why the set up of a European expert network in non-proliferation and WMD is a strategic objective, as provided for in the IfS.***

3. ***Analysis of the goals and work of EU-sponsored research projects in the NIS region, and whether these projects are, or could be, related to WMD research.***

   The projects funded by the EU were analysed according to both the non-proliferating and non-proliferation characteristics of:

   - ***Non-proliferating projects:*** The content of analyzed research projects is not proliferating. Nevertheless, very few projects could present some potential for dual use. This is neither abnormal nor dangerous if the process is controlled. This kind of sensitive project needs to be identified early on, and requires a careful follow-up of its implementation. It could be explained by the fact that these projects are developed by high-level former weapon-related scientists drawing upon the best of their past knowledge in the field.
   - ***Non-proliferation projects:*** Analyzed EU-funded projects are non-proliferation projects! They enable the redirection of former weapon scientists to peaceful research, in particular when the institutes were in the core of the former weapon-related programmes (weapons, means of delivery, protection, counter-measures, expertise…). Moreover, the sensitive projects previously mentioned present great interest to enhance the broad field of global security. The competencies of the related institutes constitute a basis for building a real partnership on global security between FSU laboratories and facilities, and the EU ones, as the ISTC & STCU plan to achieve (cf. 4).

4. ***Analysis of whether the ISTC and STCU have been successful in fulfilling their mission of finding sustainable civilian employment for WMD scientists working with them.***

   The answer is balanced: Many institutes, especially in biological and chemical fields and even in Russia, are still not ready to become self-sufficient in terms of sustainable employment. They remain vulnerable as regards proliferation, especially in a context where the Russian Federation and some CIS countries are becoming closer, richer, and engaged in a rearmament process. These vulnerable institutes could sell their knowledge, know-how or harmful materials to States of concern or non-state terrorist groups. For these reasons, it is quite essential to "**keep a foot in the door**" in order to maintain the knowledge of activities and the technological development. Moreover, the open web site of ISTC & STCU should be reviewed, so as not to offer a shopping list of the institutes' capacities on sensitive knowledge.

7.2. International context and evolution of CIS countries

The evolution of the economic, political and strategic status of Russia and some other CIS countries raise some questions reinforced by the negative impact of the global economic crisis. How should the assistance and cooperation change to match this new situation? The answer should be given in the light of what may have happened without any programme to prevent transfer of sensitive technologies and knowledge to States of concern or terrorist groups, and be assessed in regard of the ISTC and STCU accomplishment as they succeeded in establishing the base of a technical cooperation network including the institutes of the Russian Federation, institutes of the other CIS countries and western institutes.

To deal with that issue, Parties to the ISTC should maintain the action but differentiate it. It seems important, to establish a better follow-up of the projects through a network of European experts, to decrease and adjust the emphasis on Russia to the benefit of the other CIS countries and, in particular, to deal with remaining proliferation risks in Central Asian. Also, to reset the balance between ISTC and STCU to the benefit of STCU, to be consistent with the European Neighbourhood Policy and the relation with countries like Ukraine.

Visibility. There is a call from the EU industries and laboratories to have a better vision of CIS laboratories and institutes. How to convey the wish of CIS laboratories to develop the cooperation with the EU ones? To set up a mapping of competences to have an efficient management of project outcomes and follow-up of projects, in particular during the final phase of the project, and after to take advantage of their outcomes. In the chemical and biological fields it would be worthwhile to create new "CEG-like" (Contact Expert Groups) as the nuclear ones which are useful and efficient. These new CEG would achieve a better coordination of projects and definition in the field of global security, with the objective to promote CIS laboratories to international standards.

Kazakhstan. The situation of laboratories in Kazakhstan is bad, with regard to bio safety and bio security, and the strains are not well protected. Kazakhstan for the biological field is in a difficult and threatening situation. *The situation is the same or worse in other Central Asian countries, Kirghizstan, Tajikistan and Uzbekistan. The institutes retain highly virulent strains (plague, anthrax,…) some of which are resistant to antibiotics.* The level of salaries is still very low. New projects are proposed without a preliminary risk analysis (avian flu project) and the risks are multiform. A risk analysis should be carried out before any acceptance of projects. New positions ought to be created in the institutes and in the ISTC: a quality assurance manager, a bio security expert and a bio safety expert and ultimately creation of an expert network with the other CIS institutes and their European counterparts.

8. Conclusions and perspectives

During more than a decade ISTC and STCU have successfully operated in redirecting former WMD scientists of the FSU countries towards peaceful activities through the support to project and activities integrating the technological and scientific communities of CIS countries to the world scientific communities, the creation of a high level R & D base in the CIS and the creation of industrial and scientific partnerships. The international and regional context has dramatically changed since the creation of the Centres and particularly over the last couple of years. ***ISTC and STCU are now at a crossroads. They have to change, but they constitute for the EU an exceptional asset which should be preserved and used to deal with Russia and other CIS countries:***

- With their specific and exceptional status, the legal and financial dispositions of which allow them to act more directly and more efficiently with the former weapon scientists of the CIS scientific world;
- With their in-depth knowledge of the CIS industrial and scientific communities and the relation they have established with the institutes and industry;
- With their contribution to combat against proliferation and global security;
- With their experience in matters of scientific and technological cooperation, the basis of which should be preserved and adapted to the new regional and international context.

ISTC and STCU should evolve to promote a strategic and scientific relation with the CIS Countries in the field of global security and become a platform for the research on security in a real partnership. The Russian Federation, as the other CIS governments, should contribute to the founding of these activities as does the Ukrainian Academy of Science for STCU projects. The fate of ISTC, and to a lesser extend STCU, is very dependent upon Russia's attitude and how Russia wishes to take advantage of the ISTC. If Russia wished to terminate the ISTC operations, or if the political situation lead to the closure of the ISTC, then the operations of other ISTC CIS parties would have to be transferred to the STCU. How the current economical crisis may impact on these developments is still unknown but would probably delay the progresses.

New directions. To fulfil the urgent needs of the international community in the area of security research and development emphasized by the September 11th attack and followings, the Centres should as they have already started to do, retarget their programmes to become two effective and efficient platforms for security research and development involving Russia and the other CIS in a real partnership with the funding parties, drawing from the high scientific and technical level of institutes and laboratories of CIS countries as from their experience acquired in the development of WMD.

The risk of proliferation has globally decreased and changed its nature, but it has not disappeared. Then, the implementation of the core mission of the Centres is still relevant. The proliferation risk is different from one region to another and from one CIS country to another, according to the scientific and technological field and the region of interest. In Russia, the risk of proliferation is still more important for chemical and biological areas than for the nuclear one. In Kazakhstan and other Central Asian countries, the risk of biological proliferation is still a deep concern.

Could the ISTC & STCU experience be used as a model for other countries, such as Libya, Iraq, Syria, DPRK and others, as it is foreseen in the IfS 2009 – 2001 indicative programme [34] and as already started under the umbrella of the new Cooperative Threat Reduction Programme, CTR 2 [35]? As pointed out above, ISTC and STCU constitute an invaluable asset and could be used as a model to enhance global security in countries and regions that relinquish WMD programmes, as provided for in UNSCR 1540 and 1810 and other international initiatives such as G8, GTRI,..). Nevertheless, there are deep differences with FSU countries, scientific and cultural, which should be taken into account in any though on that issue. In particular should be noted, the existence in those countries of highly skilled scientific and engineers working in a long lasting high-level network of scientific and technological institutes, laboratories and fabrication facilities which constituted the stage of ISTC & STCU operations which does not exist in the targeted countries.

Assistance to the former weapons scientist programme in Russia and other CIS countries has been criticized as inefficient and too expensive [36]. This is both true and incorrect. Some programmes had been a waste of resources. But concerning the ISTC and STCU operations, the assertions put forward do not seem to rely on the solid ground of in-depth field evaluation, and the evaluation team does not agree with the overall conclusions of the report in reference. The team is of the view that ISTC & STCU remain an irreplaceable asset for non-proliferation and global security, which should be adapted to the new regional and international context, used as a platform for a new cooperation framework and as a model for new initiatives (cf. supra).

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Peer reviewed section

Proliferation Resistance Attributes of Advanced Plutonium Processing

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Abstract

To obtain public acceptance for future use of Pu, new concepts must overcome the present concerns about environmental compliance as well as concerns about misusing plutonium of the civil nuclear fuel cycle for nuclear explosives e.g. by terrorists. In future the preferable remedy is the multi-recycling of all transuranium elements in fast neutron reactors. In such a partitioning and transmutation scheme, P&T, Pu becomes proliferation resistant, when mixed with self-generated actinides. This strategy will also reduce the long-term radio-toxicity, the radiogenic heat production and the Pu content of the nuclear waste per GWe produced in the geological repositories, which otherwise could be regarded as future Pu-mines.

The development of advanced spent fuel reprocessing should aim at technologies with intrinsic barriers that – under normal operation – exclude the production of weapon useable fissile material at all stages of the process. Complementary institutional, extrinsic measures would then have to verify the declared operation and the absence of weapon useable material, instead of presently verifying the declared mass of weapon useable Pu.

1. The present role of fissile plutonium

The public opinion has strong concern about plutonium because of its radio-toxicity and use as nuclear explosives. Present nuclear energy generation is mainly based on the light water reactor, LWR technology using low enriched U-235 fuel. However, one third of the energy produced stems from fission of built-up plutonium.

Being a carbon free energy source nuclear fission does not contribute to the climate change. Contrary to most of the new alternative energy concepts nuclear energy generation by LWR is a mature technology, which at least could bridge the time gap between the phasing out of energy production by fossil fuel and the deployment of alternative energy technologies. The known resources to mine uranium at reasonable cost extend at least to 2050 [1]. Out of these reasons several states decided to continue or to start with nuclear energy generation. Despite the fact, that on the public's mind is still the nuclear waste disposal question. The ca.1% of plutonium built-up in discharged spent fuel amounts up until now from ca.1500t [2] to 2500t [3] Pu metal. Spent fuel is regarded by some states as waste and will be disposed of directly in permanent geological repositories. Others consider Pu in spent fuel still as a valuable, potential resource, which they recover or they "wait and see". The retrieval geological disposal seems a potential alternative.

Pu stemming from the civil fuel cycle has been and is still separated and remade into mixed U-Pu oxide fuel, MOX to be reused mainly for LWR – being at loss for keeping the fast breeder option open. According to a recent Harvard study the uranium price must rise at least to 360$/KG before it becomes economically competitive, when MOX fuel is compared with LWR U-fuel. However, the fuel cost contributes only about 10% to 20% of the consumer electricity price. The expected cost increase of a Pu based nuclear energy generation therefore has to be seen in context of energy cost increase by new alternative energy concepts being introduced in many states – to reduce carbon-dioxide emissions.

There are other good reasons to develop a plutonium economy now.

2. Possible role of fissile plutonium in the future

To reduce dependence on U supply Japan and France opted for a future symbiosis of light water – fast reactors, LWR-FR, which will make about 80% use of U resources compared to less than 1% in U fueled LWR. India follows the same route, but will produce U-233 in FR to kindle Th- breeder reactors.

The direct final geological disposal of spent nuclear fuel is considered by the public a risk to coming generations. Presently the decay heat of the actinides in the directly disposed spent LWR fuel limits the capacity of a geological disposal site e.g. Yucca Mountain to 70.000 t HM. (The present US power stations will fill the repository already by 2015.)The separation of Pu and possibly of all actinides from the spent fuel reduces significantly the long-term heat generation and radio toxicity of the remaining waste (Figure 1).

However, long-living radiotoxic actinides could migrate out of the repository and endanger future generations. In groundwater saturated repositories the uranium oxide matrix of directly disposed spent fuel seems more resistant to leaching of actinides than from high level waste in borosilicate glass, which is not the case for repositories in clay or rock salt [4] as long as they stay dry. Nevertheless, in the future disposed spent fuel might be mined to separate fissile Pu for nuclear bombs (one should bear in mind that for this application the quality of the discharged Pu isotope mixture is improving due to the 3 times faster decay of Pu-240). The present recovery of only Pu from spent fuels by the PUREX process does not solve the possible proliferation of Pu based nuclear explosives. We must recall: a first use of plutonium was as a nuclear bomb, called "fat man" and exploded in 1945 over Nagasaky. The Pu was produced by a dedicated PUREX process, which use is claimed by some non-nuclear weapon states as an "inalienable right". Earlier the peaceful development and use of nuclear energy (as guaranteed by Article IV of the Non-Proliferation Treaty, NPT) gave access to genuine nuclear weapons technologies: plutonium production by the PUREX process. NPT did not prevent that some states intended or achieved to extract Pu for non peaceful purposes. Presently PUREX or any separation of Pu out of spent fuel is regarded a sensitive technology.

Soon after the discovery of Pu, Fermi expressed its doubts: [5] "It is not certain that the public will accept an energy source that produces vast amounts of radioactivity as well as fissile material that might be used by terrorists."

Would an advocated Pu separation moratorium be the solution? Looking back in history, an emerging technology always found its way by introducing new technological solutions to overcome shortcomings. Only a "better" technology could replace the present Pu economy. A role the alternative energy generation may play in the future – or Partitioning and Transmutation, P&T of all actinides. Therefore to gain public acceptance for future use of Pu in civil nuclear fuel technology, new concepts must overcome the present concerns about environmental compliance as well as nuclear proliferation and security worries about misusing plutonium of the civil nuclear fuel cycle for nuclear explosives by states or terrorists.

A partitioning and transmutation, P&T of all actinides from the discharged nuclear waste will increase the geological repository capacity proportional to the degree of actinide removal from waste. Fewer needed repositories for the same amount of nuclear energy produced would certainly ease the opening of new repositories and quieten down the public concern about present nuclear energy use that may becoming a hazard to future generations.

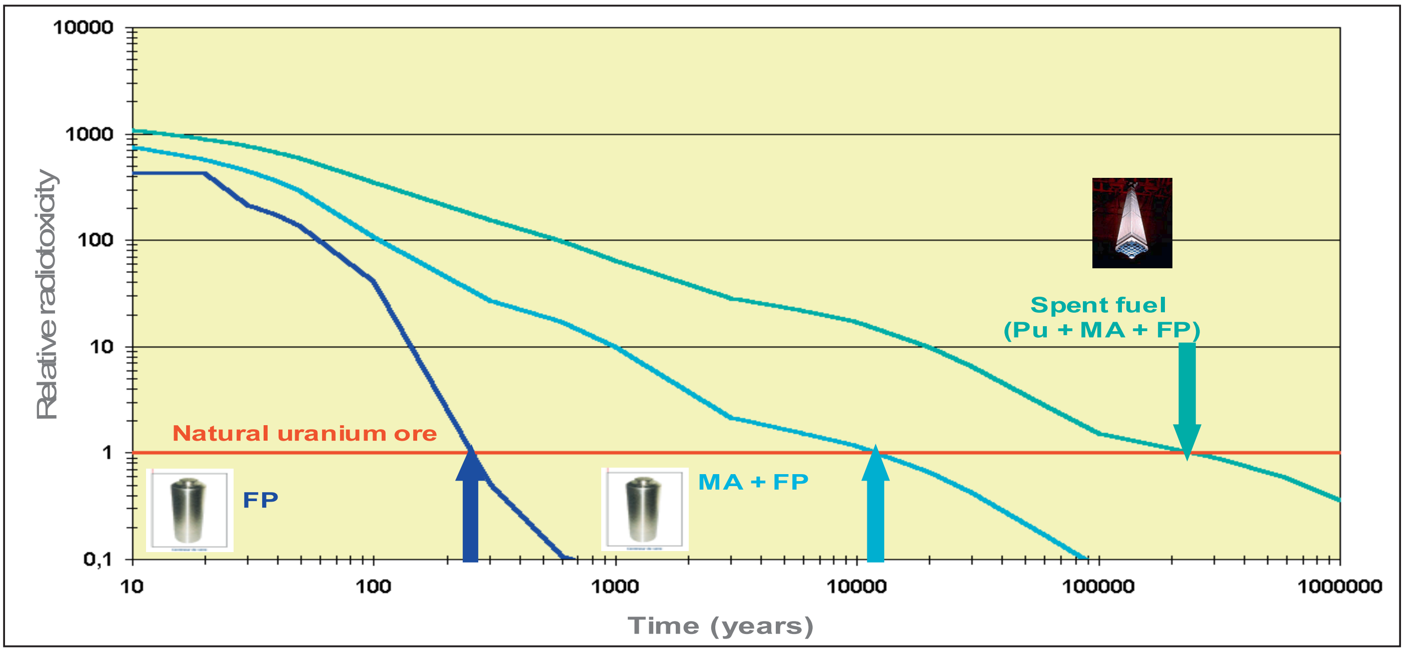

Figure 1: Time dependence of relative radio toxicity of uranium ore and from that produced spent LWR fuel: directly stored without reprocessing (Pu + MA + FP), HAW after PUREX reprocessing (MA+FP) and remaining waste (FP) after partitioning for transmutation. [9]

The partitioned actinides, when recycled in Fast Neutron Reactors, will be transmuted to short-living or stable fission products. In a multi-recycling strategy about 99% of the actinides can be destroyed, if the partitioning and fuel make-up step in-between each cycle have loses of about 0.2%.

3. Advanced reprocessing: partitioning of actinides

The partitioning approaches can be grouped into aqueous- (hydrometallurgical) and pyro-processes. Earlier developed aqueous processes sequentially separate the actinides from spent nuclear fuel [6]. The existence of an intermediate pure Pu product disqualifies the processes as proliferation prone. Preferable is a P&T scheme with a group separation of all actinides together; such as the aqueous multi-stage extraction GANEX process as being conceived by CEA, France and the batch type pyro-chemical partitioning under test by CRIEPI, Japan [7].

Activities in this field have started, but not yet achieved the maturity of the earlier developed processes. Nevertheless the results of the new approaches are promising. Their present status is discussed in detail elsewhere [8]. In particular they show the potential to separate the actinide group from spent nuclear fuel with high yield. Accordingly large scale plants could be designed and operated to release only very small amounts of actinides to the waste streams as required for a meaningful reduction of radio toxicity and of fissile material release to the environment.

4. Intrinsic attributes of non-proliferation

According to IAEA TEC-DOC-1575 proliferation resistance criteria should meet two "basic principles: proliferation features and measures shall be implemented throughout the full life for innovative nuclear energy systems. Both intrinsic features and extrinsic measures are essential, and shall neither be considered sufficient by itself." However we should note that intrinsic features are not subject to malevolent human interventions. Intrinsic proliferation resistance attributes of processes and their products inter alia are:

1. The process has intermediate or final products emitting a fatal radiation dose for significant quantities.
2. Actinide mix of significant quantities with high thermal output and neutron generation inhibits effective nuclear explosion.
3. Difficulty to separate out fissile material (Pu, Np) from final or intermediate products.
4. Change of an existing plant must be more complex than building a clandestine PUREX type facility.
5. Integrated design features facilitating C&S measures

How can we denaturise Pu that it is no longer for military use?

An actinide mixture – as self-generated in a civil fuel cycle – would effect twofold the manufacture and performance of a nuclear explosive device. Fast Neutron Reactors can accommodate a lower fission product decontamination of the mixed actinide product (without significant neutron poisoning like in LWR).The actinide mix obtained by pyro-chemical partitioning exhibits properties not very different from spent fuel, that will make its handling much more difficult and dangerous (Table 1). Normally a disadvantage turns here into a merit. Radiation and ingestion hazard by the TU mix form an inherent barrier and will deter a diverter. Fanatic terrorists would probably not be deterred by the lethal dose (external radiation and incorporation) they will receive in handling the TU mix contaminated with about 5% lanthanide fission products – the less so since the death will occur only some weeks later.

Radiation and decay heat will decompose or melt the chemical explosive lenses needed to compress

Radiation type	Per g of An mixture	Per g of LWR Pu	Per g of weapon-grade Pu
Alpha-activity (Ci)	1.53	0.85	0.09
n-activity (n/sec)	8.8E+04	1.4E+03	1.3E+02
photons/sec	1.1E+10	5.0E+09	2.9E+08
MeV/sec	2.3E+08	5.1E+07	3.1E+06

Table 1: Comparison of radiation emitted by the pyro-chemically produced actinide mix, An with LWR Pu and weapon-grade Pu. [9]

the Pu- material to a critical mass in a bomb. If the spent fuel is processed in due time, then we can expect a decay heat of 300 W in a nuclear device made of the actinide-mix (Table 2), enough to have the detonator melting and phase transitions changing the shape of the fissile material sphere; if not sophisticated cooling conducts the heat out of the bomb, if not the compaction is achieved by other means or if not the material is stored for a few years to have the Cm-242 decay.

More effective is the increased spontaneous fission neutron rate in the fissile material leading to a pre-detonation of the bomb (a fizzle). The probability of a pre-detonation occurrence rises with the number of spontaneous fission neutrons starting a fission chain reaction already during the compaction period, Figure 2. An excess criticality, C can not build up. Contrary to U-235 this was the difficulty, which bomb designer had to overcome, to cope with Pu-240 generated neutrons. With an acceleration of the compaction to 5E-6 sec an increase of Pu-240 to 20% – as observed in Pu from spent LWR fuel – will still most probably release energy (E in Figure 2) in the ton range of TNT. Pu diluted with U as for MOX -fuel is not directly useable for nuclear explosives, since its critical mass will rise to become unpractical. However a U/Pu separation is not a difficult task. The proposal [10] to increase the Pu-238 isotopic content enhances also the probability of pre-detonation – but 20% Pu-238 addition will still most probably allow a release of energy in the range of about 100 KG TNT. During compaction with a spherical shock wave period of the assumed 5 E-6 sec – not easily achievable for terrorists – 5 KG actinide mix with Cm-242 and 244 (as specifies Table 3) will yield about 1000 neutrons compared to 0.1 neutrons in weapon grade Pu. Already at begin of the compaction the actinide mix will fizzle caused by premature fission chain reactions, because neu-

Nuclides	Weight (g)	N neutrons (n/s)	Heat (Watt)
Np-237	248		
Pu-238	91	2 E5	50
Pu-239	2540		4
Pu-240	1130	1 E6	8
Pu-242	280	5 E5	
Am-241	46		5
Cm-242	1.5	3 E7	183
Cm-244	18	2 E8	53
Cm-246	0.8	7 E6	
Total	5000	2.5E8	300

Table 2: Weight, spontaneous fission neutrons and heat of a 5Kg metal actinide mix as obtained from spent LWR fuel with 40.000 MWd burn-up after 1 a cooling.

	20%Pu-240	20%Pu-240 + 20% Pu-238	Actinide-mix PWR	Actinide-mix equilibrium
N/sec	1 E6	3.5E6	2.5E8	5.5E8
N/sec x t	7 E-3	2.5E-2	2	4
Energy release according Seyfritz	1 t TNT	150 Kg TNT	Ca. 270 g TNT	Ca. 2 g TNT
Energy release according Mark	1.7 t TNT	250 Kg TNT	—	—

Table 3: Spontaneous fission neutron rates and most probable fission energy releases for different actinide mixtures.

trons from spontaneous fission are present in excess to their reciprocal lifetime t of approximately E-8 sec within a 5 KG actinide mix sphere. The observations are an extrapolation according to Seyfritz [11] and Mark [12].

US Attractiveness Level [13] rate the actinide mix to fall into category C to D, High to Low Grade Materials following an approach, which is based on the critical mass, the heat content and radiation dose [14]. The evaluation does not consider spontaneous fissions causing a pre-detonation of the so-called "High to Low Grade Material". However the pre-detonation will release only a neutron/gamma shower – typically for a criticality accident – and no significant energy, but rather disperse the radiotoxic actinide mix to the environment. Why should a diverter of an actinide mix material undertake all the effort to construct a complicate nuclear explosion device, if he could achieve the same or worse effect by a Radiation Dispersion Device, RDD? Such a device consisting of actinide mix and TNT would be similar in its effect to the dispersion of MOX fuel [15].

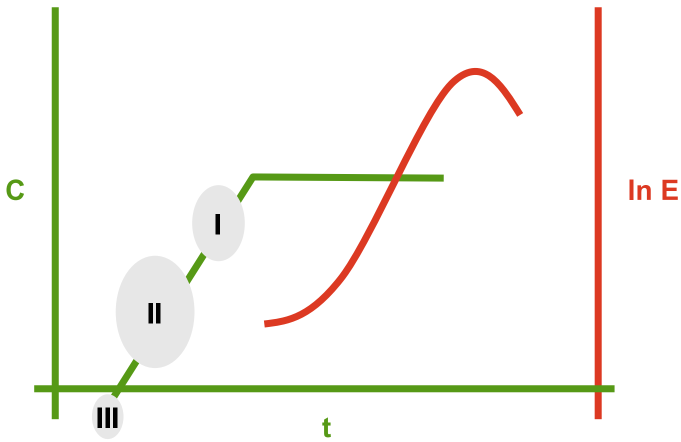

Figure 2: Schematic time dependence of excess criticality, C and released energy, E. Arbitrary units. (Predicted range of high probability of predetonation caused by Pu-240, I, by Pu- 240+238, II, by actinide mix, III).

5. Extrinsic proliferation attributes

Proliferation resistance of a spent fuel treatment option is defined "*as that characteristic that impedes the diversion or undeclared production of fissile material or misuse of its technology by states intend on acquiring nuclear weapon or other nuclear explosive devices*". Furthermore, under diversion we understand also theft by sub-national groups and define fissile material as weapon useable Pu, Np-237 and Am-241. From non-proliferation point of view, any fuel cycle option ought to be advocated, which from its design stage on should already meet world wide public concern of diversion of fissile material and its misuse e.g. by terrorist groups. Therefore the development of advanced spent fuel reprocessing should exclude the production of weapon useable fissile material at all stages of the process. In this respect a group separation of all actinides without intermediate pure products of Pu, Np or Am is advantageous compared to the present PUREX processes. The diverted material cannot be used directly by proliferating states or terrorist groups.

Complementary institutional measures would aim to verify the declared operation and detect any alteration of the licensed process for a clandestine production of weapon useable fissile material. Technical barriers must hamper a change of the licensed process to such an extent, that for proliferators the clandestine setting up of a separate PUREX type process could be much easier achieved. The detection of clandestine operations is subject to IAEA safeguards under the "additional protocol". Hence for such a scenario the role of IAEA international safeguards would be to verify the absence of weapon useable fissile material rather than of verifying a declared mass of weapon useable fissile material. The proposed continuous aqueous processes can be modified more easily to separate out a Pu or Np stream, than the batch – type metal-refining processes. The safeguards objective to detect the diversion of declared nuclear material will remain unchanged for both of the reprocessing approaches. A containment and surveillance, C&S is required e.g. to observe that blanket fuel is processed together with the driver fuel (Pu bred in the uranium blanket has weapon grade quality and the associated minor actinide are scarce).

The integration of a pyro-partitioning process facility into the nuclear reactor containment (as shown for the integrated fast rector, IFR or the molten salt breeder reactor, MSBR previously operated in Idaho and Oak Ridge, both USA) eases nuclear material safeguards. Since for an integrated plant there is no need of transport on public roads (which would require longer cooling time of the spent fuel), an immediate reprocessing and fuel make-up becomes possible. The out of pile fissile material is lower and due to shorter cooling the intrinsic non-proliferation barrier (by Cm-242) is high. The same containment houses power station and fuel make-up, which eases the implementation of C&S measures. No shipper receiver – difference has to be established.

A possible scheme for nuclear material safeguards of a pyro-processing plant as proposed by CRIEPI is shown in Figure 3. C&S measures are applied in all three Material-Balance-Areas, MBA. The transfer

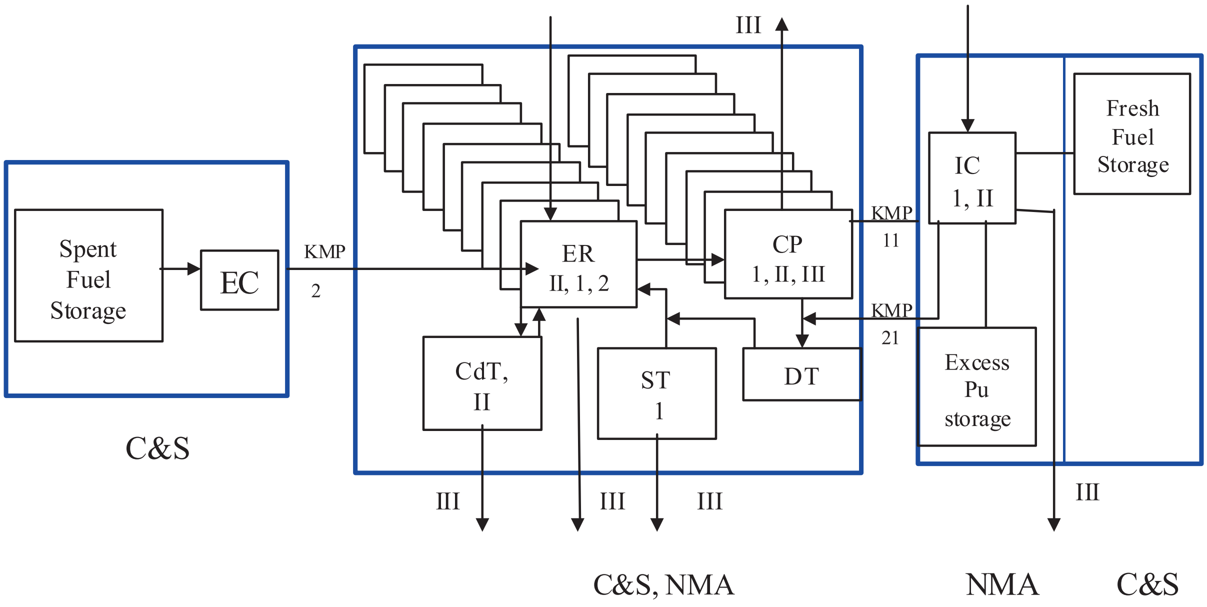

Figure 3: A possible scheme for nuclear material safeguards of a pyro-processing plant as proposed by CRIEPI (Abbreviations explained in text).

in-between MBA is accounted for at KPM, Key-Measurement-Points. C&S measures are sufficient for the EC, element chopper. In the two other zones C&S measures are complemented by near real time Nuclear-Material-Accountancy, NMA for the ER, electro refiner and CP, cathode processor batteries, the supporting CdT, cadmium- , ST salt- and DT, dross-treatment and the IC, injection casting of the fuel pins. [16]

6. Conclusion

At present we see a renaissance of energy generation by fission. However the waste of the LWR once-through fuel strategies is regarded as an environmental and proliferation hazard to coming generations by the release of radio toxicity to the environment from the geological repositories and due to a possible recovery of fissile Pu for nuclear explosives. The envisaged P&T scheme would destroy the mass of fissile and long-living radio toxic actinides by two orders of magnitude and accordingly reduce the number of needed repositories. In a P&T scheme there will be neither needed any weapon technology as PUREX or U-235 enrichment nor is produced directly useable fissile material for nuclear explosives at any stage of the civil fuel cycle.

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Safeguards Analysis of Material Flows in a Gas Centrifuge Enrichment Plant

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Abstract

A system for the detection of material diversion in a Gas Centrifuge Enrichment Plant (GCEP) producing enriched uranium based on real-time mass evaluation of the inputs and outputs has been theoretically examined. The response of this Continuous Mass Measurement System (CMMS) to two specific diversion scenarios has been simulated and in each case, the diversion could be detected. As a result of these basic simulations, the CMMS could prove to be a promising technique for use in safeguards verification of GCEP's. There is no experimental verification of the approach so far.

Keywords: Non-proliferation, gas centrifuge, uranium enrichment, diversion, CMMS.

1. Introduction

Under the terms of the Non-Proliferation Treaty, the International Atomic Energy Agency (IAEA) carries out inspections of nuclear industry facilities in all countries that have signed the treaty. In particular, facilities where weapons-grade uranium or plutonium can be produced require a lot of attention to ensure that there are no undeclared activities with specific regard to nuclear materials. Under the terms of Chapter VII of the Euratom Treaty, the European Commission (EC) carries out similar inspections in European countries.

At the moment, there are 3 main possible diversion scenarios that can occur at a GCEP which normally produces declared amounts of Low Enriched Uranium (LEU, 235U content < 20%) which concern the IAEA, namely [1]:

1. The production of quantities of undeclared Highly Enriched Uranium (HEU, ^{235}U content ≥ 20%)
2. The diversion of a significant amount of LEU
3. The production and diversion of undeclared LEU from undeclared feed

In order to prevent these from occurring, the IAEA (together with the European Commission in EU countries) conducts inspections both inside and outside the halls containing the enrichment centrifuges. These inspections involve Limited Frequency Unannounced Access (LFUA) visits to the interior of the cascade hall to ensure that the internal arrangement of centrifuges and piping networks is unchanged [1]. They also involve activities outside the cascade hall, such as examination of records and reports, non-destructive assay of UF_6 in containers, sample taking for destructive analysis, high precision trace analysis of environmental swipe samples, and check weighing of containers, along with the use of containment and surveillance devices [1].

In addition, equipment is employed by inspectors for monitoring the enrichment of UF_6 in process pipes, using gamma spectrometry. ^{235}U nuclei emit gamma rays with a characteristic energy of 186keV and these photons can be registered by a detector attached to pipes containing UF_6. These detectors are used as part of Continuous Enrichment Monitors (CEMO's), which are usually placed on product header pipes and send a regular state-of-health message or – in case of production of enrichments higher than normal – an enrichment alert to the IAEA and EC office. Based on the 186keV peak intensity obtained, the CEMO gives a go/no-go signal, referenced to 20% enrichment [2].

Although these methods of detection of enriched uranium diversion exist for a number of years, they are not considered to be perfect, and are applied in a very limited number of installations only. Indeed, the reliability of the current instrument is doubtful, as there are many problems with regard to temperature stability and interferences by deposits on inner surface of the pipework. Moreover, the LFUA principle is intrusive and generally operators of GCEP's are reluctant to provide access to the cascade hall interior. There is also an additional inconvenience with the CEMO system because the low pressure of the UF_6 gas in the cascade means that the sample geometry cannot be considered infinitely thick. Corrections for the gas pressure have to be made with the use of radioactive ^{109}Cd measurements but even these have considerable uncertainty and only lead to an approximate assay. This source has the major drawback of a relatively short half life (462.6days) requesting regular reconfigurations and source replacement.

A new approach to diversion detection has been put forward by J. Delbeke, J. Howell et al. at the European Commission Joint Research Centre (JRC) in Ispra, Italy which is based on continuous mass measurement of the feed, product and tails [3, 4]. By measuring the mass of these cylinders against time, the flow rates of each can be calculated. In normal steady-state operation, the feed rate should equal exactly the sum of the product and tails flow rates. Changes in these flow rates should indicate a new set of operational characteristics and will show up in the cumulative mass balance (explained further in the next section). This technique could become an attractive way to monitor a GCEP with minimal intrusion. The JRC team examined 3 specific diversion scenarios, which are as follows:

1. The protracted diversion of LEU from a cascade by increasing the feed flow and skimming off the excess product flow.
2. Increasing the product assay by means of increasing the separative capacity of the centrifuges (and hence the cascade) while maintaining a constant feed rate.
3. Increasing the product assay above 20% (i.e. HEU) by maintaining the separative capacity but decreasing the feed rate.

In all 3 cases, their proposed Real Time Mass Evaluation System (RTMES) had a specific response which indicated the undeclared activity.

This method of continuously measuring the feed, product and tails weights could be used to detect further diversion scenarios, albeit not necessarily via the cumulative mass balance. Instead of determining the latter, it is proposed that for 2 more important scenarios outlined below, the flow data is used to detect diversions using other calculations:

1. Reconfiguration of the entire plant to produce HEU efficiently, i.e. an ideal cascade.
2. Initially using the cascade to produce LEU as per normal operation but then using batch recycling of the product to produce higher enrichments.

2. Theory and background

In any isotope separation plant, like most chemical engineering processes, there are always 3 main streams: the feed, the product and the tails (also called waste, somewhat euphemistic). In this report, the following labeling is used for the properties of these 3 quantities:

F = feed cylinder mass

f = feed flow rate

N_F = feed concentration of ^{235}U

P = product cylinder mass

p = product flow rate

N_P = product concentration of ^{235}U

W = tails cylinder mass

w = tails flow rate

N_w = tails concentration of ^{235}U

Graphs of a typical cylinder mass history can be seen below in Figures 1 and 2 in a theoretical ideal case (commercial enrichment plants are fed from several feed stations, and it is vital to guarantee a flexibility in feed chests to maintain a continuous flow). In the case of the feed cylinder, the mass decreases from its maximum value to the empty value (normally tare) of the empty cylinder, whereas for the product and tails cylinders, the mass increases from the start value (normally tare) upwards until the cylinders are full.

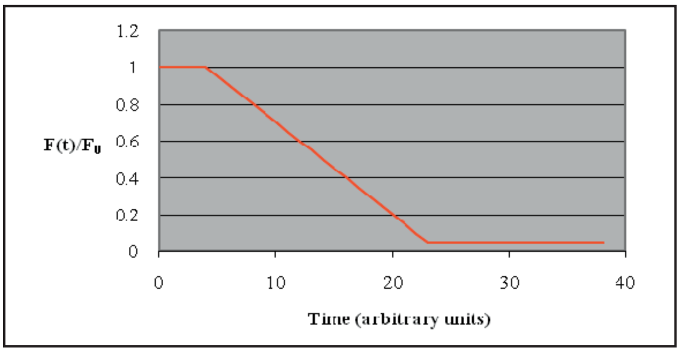

Figure 1: Typical feed cylinder history.

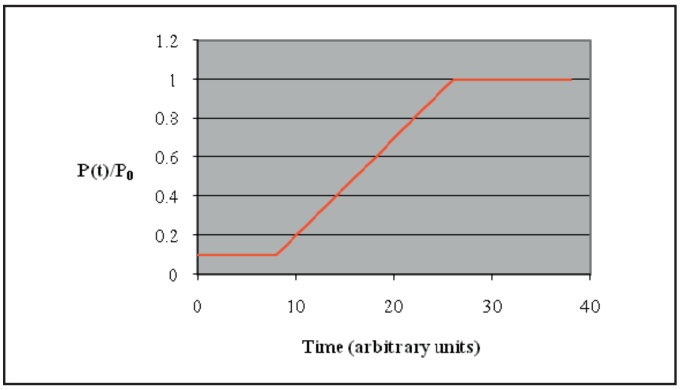

Figure 2: Typical product cylinder history.

The graph for the waste (tails) cylinder against time would be very similar to that of the product cylinder, although the actual quantity of material in the tails flow will normally be greater. Using these plots, the feed rates can be calculated from the slopes:

$f = -dF/dt$ $\quad$ $p = dP/dt$

$w = dW/dt$

In this paper, NU refers to natural uranium and thus contains 0.72% ^{235}U.

3. CMMS Detection of Diversion

As proposed by J. Delbeke et al., the RTMES is in principle able to detect 3 diversion scenarios (outlined in the Introduction). The reason it is able to do this is because it is capable of registering changes in the inventory of a plant, via calculating the cumulative mass balance [3, 4].

In this paper, the authors propose analyzing the data for f, p and w in situations for which the cumulative mass balance is inappropriate.

3.1. Cascade Reconfiguration

For the cascade reconfigurations, two distinct options are explored. The first option is to measure the equilibrium time of the cascade and the second is to continuously measure the cut (ratio of product to feed).

3.1.1. Equilibrium time

At the beginning of the operation of a GCEP, the cascade is filled with feed at a constant rate. The system is then run in total reflux, which means that there are no inputs or outputs. Then, once the concentrations at the top and bottom of the cascade reach the desired level at t_2 and t_1 respectively, tails and product are withdrawn slowly. The feed, product and tails rates are then gradually increased to the full steady state rates. The exact equations that govern the start-up procedure are complex and beyond the scope of this study [5]. However, Figures 3 to 5 offer a reasonably fair portrayal of the feed, tails and product flow rates at the start [6].

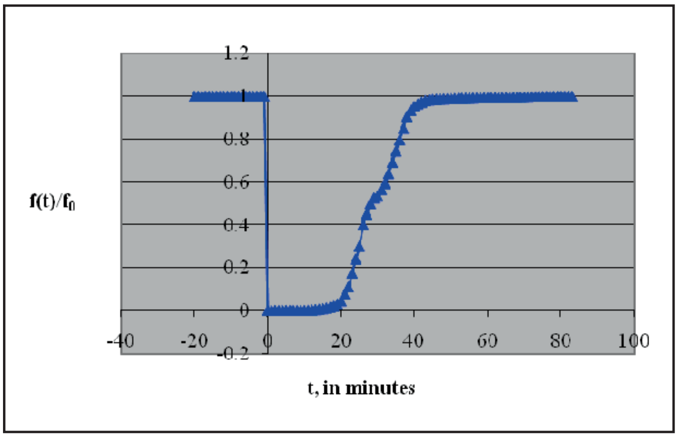

Figure 3: Start-up history for feed flow.

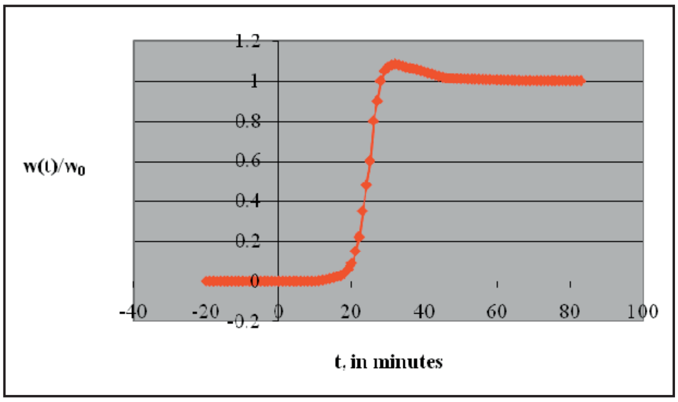

Figure 4: Start-up history for tails flow.

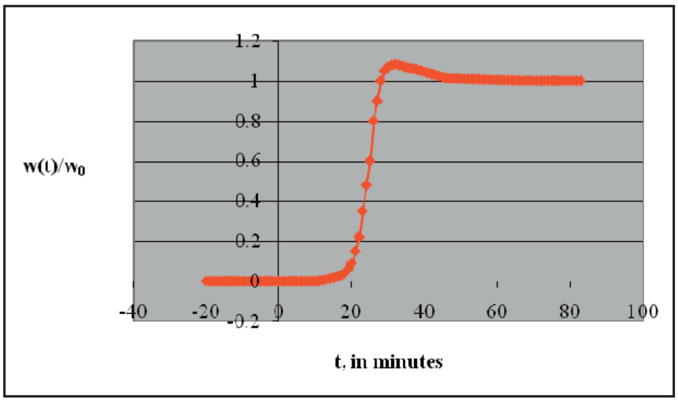

Figure 5: Start-up history for product flow.

The definition of the equilibrium time, t_p, is the time from the initial start-up to the point at which the product flow reaches half its asymptotic value. If it is assumed that the cessation of initial feed flow marks the exact start-up point in time (i.e. t=0), then the equilibrium time can be measured by noting p_0, the steady-state product flow, and determining the time when $p(t)=p_0/2$.

It can be proven that the equilibrium time can be calculated quite accurately using equation (1) [5, 6].

$$t_p = [(\beta+1)t_h/((\beta-1)\ln\beta)]\ E(N_P,N_F) \quad (1)$$

where β is the enrichment factor ($= R_{s+1}/R_s$)

with $R = N/(1-N)$

t_h is the hold-up time of centrifuge

and

$$E(N_P,N_F) = [-2 + (N_P - 2N_PN_F + N_F)\ln(R_P/R_F)/(N_P-N_F)]$$

Table 1 gives a list of equilibrium times calculated using this formula, together with the uncertainty in t_p due to the need to estimate β and t_h independently of the operator. This uncertainty was calculated using differentials.

	β	t_h	δβ	$δt_h$
	1.26	13	0.05	1
N_F	**N_P**	**$E(N_P,N_F)$**	**t_p (min)**	**$δt_p$(min)**
0.0072	0.03	0.34	3	1
0.0072	0.05	0.62	5	2
0.0072	0.25	2.00	16	6
0.0072	0.5	3.00	24	10
0.0072	0.9	5.14	40	17

Table 1: Equilibrium times t_p for various enrichments using NU as feedstock

3.1.2. Overall process cut

The second option for detection of reconfiguration would be to simply measure the overall cut θ of the process. This quantity is dependent on all 3 assays of the inputs and outputs, as given in equation (2) [7].

$θ = p/f = (N_F-N_W)/(N_P-N_W)$ (2)

Despite the fact that θ is dependent on the tails assay, such is the difference between that for a GCEP producing LEU from NU and that for one producing HEU from NU, that it would be almost impossible for the operator to fully hide the effect on θ by adapting the tails assay.

N_F	N_P	N_W	θ
0.0072	0.03	0.001	0.21
0.0072	0.03	0.002	0.19
0.0072	0.03	0.003	0.16
0.0072	0.03	0.004	0.12
0.0072	0.03	0.005	0.09
0.0072	0.03	0.006	0.05
0.0072	0.05	0.001	0.13
0.0072	0.05	0.002	0.11
0.0072	0.05	0.003	0.09
0.0072	0.05	0.004	0.07
0.0072	0.05	0.005	0.05
0.0072	0.05	0.006	0.03

N_F	N_P	N_W	θ
0.0072	0.9	0.001	0.007
0.0072	0.9	0.002	0.006
0.0072	0.9	0.003	0.005
0.0072	0.9	0.004	0.004
0.0072	0.9	0.005	0.002
0.0072	0.9	0.006	0.001

Table 2: Cuts for various enrichments using NU as feedstock.

As Table 2 demonstrates, θ is a value that can vary considerably with the value of the tails enrichment. However, it must be remembered that usually the tails enrichment is kept to roughly 0.2% or 0.3% [7]. Even by changing the tails enrichment, there is still a marked difference between θ for a NU→LEU GCEP compared to a NU→HEU GCEP.

3.2. Batch Recycling

If batch recycling occurs in an unchanged plant originally designed to produce only LEU from NU, then it can be shown that the ratios of R_P/R_F and R_W/R_F must remain constant in order to ensure that the number of stages in the stripper and enricher stay the same, where $R = N/(1-N)$ [7]. This can be used to predict the number of cycles that would be required to eventually produce high-grade HEU. Table 3 gives the various ^{235}U concentrations of the feed, product and tails for each of the 4 cycles in the batch recycling scheme which uses a plant designed to produce 4.2% LEU from NU.

	N_F	N_P	N_W	θ
Cycle 1	0.0072	0.042	0.002	0.13
Cycle 2	0.0042	0.209	0.012	0.152
Cycle 3	0.209	0.616	0.068	0.257
Cycle 4	0.616	0.906	0.307	0.516

Table 3: Cut and concentration in each cycle.

Thus, the final product has a concentration of 90.6% ^{235}U. As the product is always less than the feed in a given cycle, the amount of feed material available for the next cycle decreases. There are 2 main strategies that the operator could adopt: operation of the plant for fixed periods of time, or by maintaining constant flow rates for each cycle. Each of them are explored in detail.

3.2.1. Plant operation for fixed period of time

If the plant produces 4.2% LEU from NU with a tails assay of 0.2% and has a separative capacity of about 1000tSWU/yr, it should be able to process about 1200t of feed per year. This is equivalent to 38.03g/s. Table 4 shows the feed, product and tails flow rates for each of the 4 cycles, mentioned in Table 3.

	f (g/s)	p (g/s)	w (g/s)
Cycle 1	38.03	4.94	33.09
Cycle 2	4.94	0.75	4.19
Cycle 3	0.75	0.193	0.557
Cycle 4	0.193	0.10	0.093

Table 4: Flow rates per cycle.

In other words, the flow rates are reduced after each successive cycle to keep the plant running for constant time periods. If f_0' p_0' w_0' refer to the initial flow rates, then the use of batch recycling should be apparent in a long-term history of these rates.

	$f(t)/f_0$'	$p(t)/p_0$'	$w(t)/w_0$'
Cycle 1	1	1	1
Cycle 2	0.13	0.152	0.127
Cycle 3	0.02	0.039	0.017
Cycle 4	0.005	0.02	0.003

Table 5: Ratios of flow per cycle to initial flow.

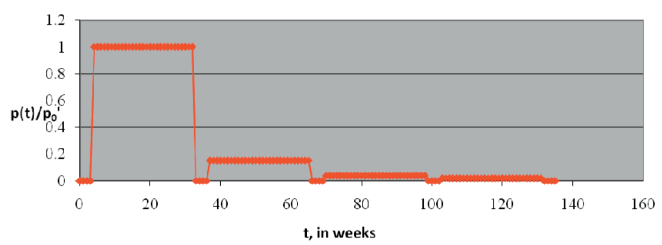

Figure 6: Batch recycling of nuclear material with constant operational periods.

Figure 6 shows a graph of the product flow for each cycle divided by the initial product flow, and it clearly shows that the plant is being used for batch recycling. It assumes that the plant would run for 26 weeks at a time, with 4 weeks in between to allow for emptying out and cleaning the centrifuges. However, if the plant was not being used for batch recycling and was only being shut down for practical reasons, for instance maintenance or malfunctions, then the history of the product should show something like the picture shown in Figure 7.

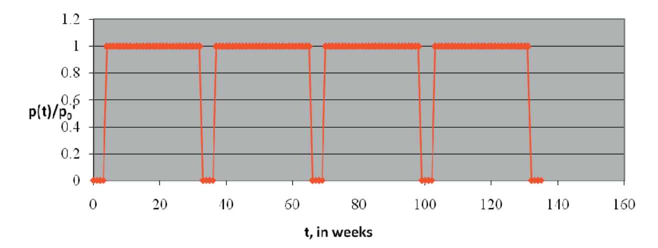

Figure 7: Normal plant operation with regular shutdowns for maintenance or repair.

The only way to make the fixed-period strategy work would be to divide the plant into a number of separate cascades. In the first step, all of the cascades would be used to process the initial feedstock while in the successive steps, less cascades would be required.

3.2.2. Plant operation with constant flow rates for each cycle

The previous strategy has a number of disadvantages, most notably the fact that the full capacity of the plant is not being used in the second, third and fourth cycles. An alternative batch recycling system to the one above is to use the entire plant in each cycle which would imply maintaining a constant feed rate but would mean that the plant would operate for successively shorter periods of time. The product and tails rates change gradually in each step because θ slowly increases.

	Operational time
Cycle 1	52 weeks
Cycle 2	6.76 weeks
Cycle 3	1.03 weeks
Cycle 4	1.85 days

Table 6: Operation of plant with constant feed rate.

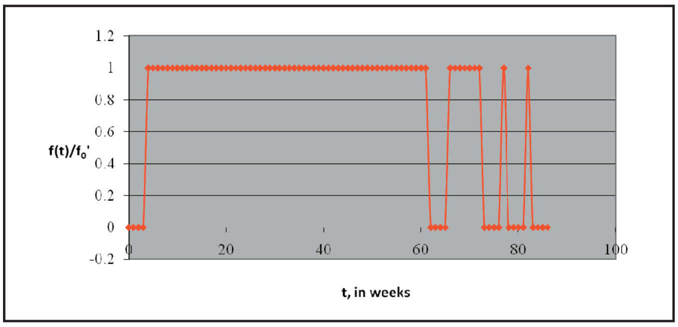

Figure 8: Batch recycling with constant feed rate.

Table 6 shows the operational time of the plant while Figure 8 shows a graph of the long term history of the feed flow. Once more, the CMMS is able to detect the batch recycling of material.

4. Conclusions

The purpose of this study is to extend the potential use of the ideas behind the RTMES and to simulate the response of such a system to diversion scenarios that have not been considered up to now.

To summarize, the response of the CMMS to two main types of diversion scenarios has been simulated using simple material-flow-based models of GCEP's.

For the case of the cascade reconfiguration, there are 2 ways in which the CMMS can detect the new state of affairs. The first is based on measuring the equilibrium time of the cascade. If the cascade is performing the operation NU→LEU(3 to 5%), t_p should be within the range of 4 ± 3 mins or less. If it is enriching to higher levels, t_p will be longer and in the case of NU→HEU(90%), t_p will be of the order of 40 ± 17 mins. Advantages of this method include the calculations' independence from the tails assay, the ability to know that the cascade is reconfigured before any major levels of product have been obtained and the fact that the number of centrifuges in the plant does not need to be known. One major disadvantage of this technique is the need to estimate the hold-up time and separation factor of the centrifuges, as these values have to be determined independent from the operator; this estimation leads to a large percentage error in the equilibrium time. Two other downsides to this method are the fact that it can only be used when the plant is starting up and also, the assumption that the cascade is ideal (probably it can work also in continuous operation, looking at the delay of the output signal following a change in input, but to detect a cascade reconfiguration, there will be necessarily a stop/restart). The latter could be an issue if non-ideal, energy-inefficient cascades were used, for which the equilibrium time is always larger than that of an ideal cascade. Nevertheless, even though a plant works in non-ideal conditions, we will have a sort of historical record of "normal" operation and also when this does not match with theoretical ideal values, it will be some plant fingerprint. Any change in the equilibrium time could be a hint of change of operating conditions.

An alternative method to ascertain whether or not the cascade has been altered is to continuously measure the cut θ, i.e. the ratio of product rate p to feed rate f. If the plant is working in the mode NU→LEU(3 to 5%) with a reasonable tails assay, θ should be inside the range: ($0.07 \leq \theta \leq 0.20$). If the configuration is in the NU→HEU(90%) mode, θ should be within: ($0.002 \leq \theta \leq 0.007$), but many more stages would be needed to reach 90% in one go, leading to a major reconfiguration, like the serial connection of cascades. Among the benefits of this method is its ability to show up the reconfiguration without needing to have the CMMS installed before the reconfigured cascade has begun operation. Another important advantage is the fact that no assumptions about ideality are made so this method of detection is still valid regardless of the efficiency of the plant. One disadvantage is the relatively large uncertainty due to the potential variation in the tails assay by the operator. A final point that ought to be made is that it is a complimentary detection technique to the equilibrium time measurement. Thus, if there is a long equilibrium time and a low value for the cut, these 2 pieces of information would provide a strong indication that HEU is being produced directly from NU.

With regard to the batch recycling scenario, the CMMS should have no difficulty in showing up the diversion via long-term monitoring of the product, tails and feed rates. One possible way to circumvent the CMMS would be to avoid emptying the plant out after each cycle. Although there is nothing to stop the operator from doing this, it is a questionable situation as the dilution of highly-enriched feed with much less-enriched feed would flagrantly waste the large amounts of time and energy put into the production of the former. However, the quantity of material "damaged" due to the mixing of different enrichments will only be during the transient required to reach the new equilibrium (maximum hours). This loss is fully justified by the fact of avoiding a "suspect" operation such as emptying the plant.

In addition to using the CMMS for calculating the flow rates, the fact that it measures the absolute mass of the cylinders at the entry and exit points would also be useful in ensuring that only certain canisters are used at specific points. For instance, 48Y containers should usually be found at the feed points only, and if the tare mass of a cylinder in a feed station was less than that of a 48Y, this would suggest that NU is not being used as the feedstock. This could be supplemented by camera surveillance of the feed, product and tails areas. However, cheating would not be too difficult, by adding extra weights.

In terms of practical implementation, the CMMS would consist of a set of calibrated mass balances located at each feed and take-off station, with knowledge as to whether or not they are feed, product or tails points. The mass at each station would be measured at regular intervals (as weighing by load cell is not accurate, the interval has to be chosen in such a way that the weight changes are not hidden by random weighing errors) and this information sent to a central tamper-resistant computer on site via a secure communication system (large weighing errors will be a problem in general if accurate flows over small time intervals need to be established). This computer could then store this data (relaying data to a safeguards office is almost certainly no option at European plants because of the confidentiality of data issues involved). The computer could then perform the analysis itself using defined algorithms and only alert inspectors in the event of undeclared operations occurring.

The use of the CMMS has only been examined in principle and could encounter various complications. Thus, experimental validation of the technique may be required before it is considered suitable for employment in commercial GCEP's.

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Working Groups activities

Report by the Working Group on Standards and Techniques for Destructive Analysis (WGDA)

K. Mayer
Chairperson

The events of September, 11 date back more than seven years. The threat of international terrorism, however, is still very present and has led to significant changes in security culture. This changing environment is also reflected in the nuclear world. In the recent years, we experienced a shift in emphasis from nuclear safeguards towards nuclear security. In consequence, also the role of destructive analysis (DA) has changed. In traditional nuclear safeguards applications, DA methods essentially served for highly accurate element and isotope assay of nuclear material. In strengthened safeguards, highly sensitive analytical techniques have been developed, aiming at the detection of undeclared nuclear material or undeclared activities (e.g. through particle analysis). In a nuclear security context, a comprehensive and thorough analysis of samples of nuclear material can reveal important information on the history of the material. Such investigative radioanalytical techniques (often called nuclear forensics) are increasingly applied, not only to nuclear material intercepted from illicit trafficking, but also to samples taken during safeguards inspections. Information inherent to the material may then be used to check consistency with declared operations and processes.

The activities of the WGDA in 2008 reflect these new challenges. Nuclear safeguards and non-proliferation, however, remain at the heart of the working group. One of the main achievements of the group had been the promotion of the concept of target values for measurement uncertainties, initially conceived in the late 1970's. In its meeting in Luxembourg (May 2008), the group evaluated the need for a review of latest edition of the International Target Values for Measurement Uncertainties (2003). The discussions highlighted several points:

- For a number of method/material combinations, lowering the target values should be considered.
- Target Values are currently presented as "random" and "systematic" components. Analytical laboratories evaluate their uncertainties according to the GUM (ISO Guide for the expression of Uncertainty in Measurement). The compatibility of the two concepts should be examined.
- Include also target values for the minor abundant uranium isotopes (^{234}U and ^{236}U).
- Consider target values for measuring chemical impurities.
- Consider defining target values for isotope analysis in individual particles.

The group furthermore reviewed the current status of interlaboratory measurement evaluation programs (EQRAIN, REIMEP, IMEP and SME).

With regard to training and education in the specific area of destructive analysis, the group finalized three "Technical Sheets" on quality control in nuclear sample measurement, on nuclear reference materials and on uranium assay by titration methods. The group contributed two lectures on "nuclear forensics" and on "destructive analysis" to the training course on Nuclear Safeguards and Non-Proliferation organized by the ESARDA WG on Training and Knowledge Management (March 2008).

In a dedicated workshop (April 2008), the group addressed the problem of minor isotopes measurements in uranium. Experts from different scientific communities (earth sciences, environmental science, safeguards and nuclear forensics) exchanged their experience in the field and elaborated recommendations for bulk and particle analysis. They underlined the importance on minor isotope measurements as relevant source of information on the nuclear material. The findings of the workshop were published in an elaborate report in ESARDA Bulletin No.40.

As stated in the Action Plan and Success Indicators, the group undertakes to keep abreast of "nuclear forensics". A report on the application of nuclear forensics techniques in safeguards was published in Bulletin No.38.

Overall, the WGDA has progressed very well along the lines defined in the latest update of its Action Plan (2007) and released the deliverables as indicated in the success indicators. With respect to 2009 a workshop on chemical impurities in uranium will be held at JRC-ITU, the respective announcement was published in ESARDA Bulletin N.40.

Report by the Working Group on Non Destructive Analysis (WG-NDA)

P. Peerani
Chairperson

During 2008 the NDA working group has practically completed two ongoing projects:

- the second part of the ESARDA Multiplicity Benchmark;
- the Good Practice Guide for the use of modelling codes in Non Destructive Assay.

Another important event was the launch of the Int'l Working Group on Gamma Spectrometry Techniques (IWG-GST).

The ESARDA Multiplicity Benchmark started few years ago with the double purpose to validate Monte Carlo simulation codes and to test hardware/software solutions for LIST mode data acquisition in neutron multiplicity counting.

The first part of the benchmark (labelled as phase I and II) was dedicated to analyse some theoretical cases and was completed in 2006. The final report was published on the Special Issue of the ESARDA Bulletin number 34 (June 2006).

The second part (labelled as phase III and IV) was launched in 2007 as follow-up of the previous benchmark. The main difference with respect to the first part was that now it deals with experimental data. The measurements serving as reference to the benchmark were done at the PERLA laboratory by a joint team gathering the JRC, IRSN and LANL in February 2007. They consist of six cases, where six samples (a low- and high-intensity californium source, a metal plutonium source, a small and a large mass plutonium oxide samples and a mixed oxide sample) have been measured using an AWCC in passive configuration with a multiplicity shift register and a LIST mode acquisition card.

Phase III of the benchmark has the goal of validating the Monte Carlo codes for simulation of neutron counters: the entire experimental setup has been modelled by the participants and fully simulated. Computed count rates (Singles, Doubles and Triples) have been compared to measured ones.

Phase IV was dedicated to testing and validating the software for LIST mode data processing. Pulse trains acquired using a time-stamping data acquisition card have been distributed to the participants who have processed them by computing the count rates, which have been compared to the reference values acquired using a multiplicity shift register.

5 participants provided results for phase III and 10 for phase IV. All the results have been gathered during 2008 and a final report has been drafted. Currently it is under internal review and it is planned to be published in one of the next issues of this Bulletin, whereas a summary paper has been submitted at the 31st ESARDA Conference in Vilnius (Lithuania), in May 2009.

The "Good Practice Guide for the use of modelling codes in Non Destructive Assay" is a document, produced by the ESARDA NDA-WG under request of the IAEA with the purpose to document the accepted best practice principles for the use of radiometric modelling codes, in the Non Destructive Assay (NDA) field of the nuclear industry. These include various code types, from discrete ordinate and Monte Carlo codes, to reactor physics "burnup codes". The intention of this guide, by documenting best practice, is to both provide confidence for technical, management and regulatory staff, in the validity of the results of modelling codes, and provide a convenient knowledge base for technical staff in this highly specialist field.

After an overview of the codes available for the different types of application, the guide develops the main principles that should be followed in the different phases of conception, development, use and validation of computational modelling:

- Problem Definition
- Benchmarking / Validation
- Training / Competency
- Quality Assurance
- Nuclear Data
- Physics Treatments
- Treatment of Uncertainties

The first version of the document has been issued in June 2008 and is currently under internal revision. It will be also published on one of the next issues of this Bulletin.

Another important activity concerns the participation and support that ESARDA NDA-wg members provide to the IWG-GST. This working group, co-sponsored by ESARDA and INMM, gathers gamma spectrometry specialists both from Europe and America with the purpose to jointly undertake problems related to isotopic measurements of U and Pu with special emphasis on code sustainability, standardisation and validation issues. The Terms of Reference of the IWG-GST have been agreed and are published on the ESARDA Bulletin number 40 (December 2008). In November 2008 the first meeting of the working group was held together with an International Workshop in Oak Ridge. One of the major achievements expected by this IWG is the development of a testing and validation platform for gamma spectra evaluation codes.

Report by the Working Group on Containment and Surveillance (WG-CS)

B. Richter
Chairperson

In 2008, the working group had 18 **members and observers** from R&D establishments, safeguards equipment manufacturers, safeguards inspectorates, plant operators, regulatory agencies, and ministries. They represented the ESARDA organisations: European Commission (Euratom/DG TREN, DG JRC), Finnish and Swedish nuclear regulatory authorities, French Institute for Radiation Protection, Safety and Security, and AREVA, German nuclear operators (GNS, VGB) and Jülich Research Centre, United Kingdom Safeguards Organisation and Sellafield Safeguards Department. Observers from outside ESARDA represented the International Atomic Energy Agency, Argentine-Brazilian safeguards authority ABACC, Canadian Nuclear Safety Commission CNSC, and US Sandia National Laboratories.

The working group **addressed** the following **issues**: performance assessment of containment and surveillance (C/S) instrumentation, interface between safeguards and security, wireless in-plant data transmission, guidelines for developing sealing systems, Audit Group guidelines and C/S development, safeguards design and simulation tool for surveillance and remote monitoring, laser item identification system, remote-monitored sealing array, and IAEA's Next Generation Surveillance System.

Recurrent activities are: information exchange and discussions on R & D within the working group, maintaining a compendium on C/S instrumentation, and support of the ESARDA Editorial Committee.

Achievements of the working group as a whole and of individual working group members and observers were published in the ESARDA Bulletin (5) and in conference proceedings (2008 ESARDA Annual Meeting (1), 2008 INMM Annual Meeting (6), 2008 INMM-ESARDA Workshop (2)), and contributed to the ESARDA web site, such as the compendium on C/S instrumentation. A technical sheet on the application of mailboxes was published in ESARDA Bulletin No. 40.

One of the working group's major efforts was still to develop a **methodology for determining the performance and assurance of C/S instrumentation**. After having previously established a conceptual approach for performance assessment (Proc. 29th ESARDA Symposium, 2007), the working group was provided, early in 2008, with information about a specific dry storage facility for spent fuel and high-level radioactive waste, its safeguards approach and diversion assumptions, proposed requirements for task profiles that specify the functionality of C/S instrumentation, and specifications of several C/S instruments making up their individual performance profiles.

The working group started to apply the assessment methodology, on a trial basis, to this facility by familiarising itself with the layout and operation of the facility, with the characteristics of the transport and storage casks, and with the other information mentioned before. The following applications were considered: (1) camera system in the reception area with an overlook of the storage area, (2) seal on secondary lid of cask, (3) seal on protective lid, and (4) seal on group of casks.

An extended discussion and revision of the task requirements took place during the two working group meetings of 2008, and additional requirements were conceived. For instance, the requirement "ability [of the camera] to focus on short distances of a few meters up to long distances of about 200 meters" was further specified to account for the minimum size of an object to be identified at 200 meters distance, i.e., 6m by 2.5m corresponding to a spent fuel cask. In addition, the request emerged that surveillance at 200m distance would require two cameras "looking at each other", and that this should be reflected in the list of requirements. Another example was "system reliability [of the camera]" which could be answered, e.g., by the statement "approved by IAEA for 150 months MTBF". Such a statement is intended to draw the attention to a possible impact on the maintenance and replacement strategy to be implemented for the camera system in the specific application. Furthermore, the life-cycle of the IAEA's current camera system is anticipated to end in 2018.

With regard to requirement levels, the term "mandatory" raised some discussion, and the working group unanimously concluded that a failure to meet this requirement level would immediately exclude the instrument under evaluation from the application under consideration. For instance, for the application of seals to the cask one of the "mandatory" requirements was: "seal wire diameter less than 7mm". In this case, the working group's conclusion was definitely final. However, the working group identified other "mandatory" requirements which would not necessarily lead to exclusion of instrumentation. This would be the case under the following preconditions: (1) no alternative C/S instrument was available that met the requirement, and (2) otherwise applicable C/S instruments could be implemented on the basis of a viable replacement strategy. Finally, it was proposed to include costs and assurance of supply in the task profile.

As a preliminary result the working group came up with four tables for the above mentioned applications for camera and seals. Each table contained between 15 and 25 requirements. As the IAEA's only camera system technology is the DCM14, no alternative was taken into account. DCM14 did not fail in any mandatory requirement. Three types of seals were assessed: metal cap, COBRA fibre optic, and VACOSS electronic. Sealing of the secondary lid with the protective lid in place could only be done with the metal cap seal, whereas for sealing of the protective lid and of a group of casks all of the three seals could be used, with a preference for an electronic seal, as it would enable remote interrogation from outside the storage hall and, thus, keep the inspector's radiation exposure as low as possible.

Interface between safeguards and security: The working group stated that safeguards and security clearly had different objectives. Furthermore, security was a national responsibility, whereas the re-sponsibility for safeguards lay with an international organisation. Nevertheless, the working group con-ceded a concern on the part of the international community about security issues, e.g., expressed in IAEA INFCIRC/225. A comparison of requirements for safeguards and security yielded major differ-ences in timeliness criteria and response elements. The main questions to be addressed would be: Can safeguards and security measures be applied simultaneously? How do they interfere with each other? Which of them outranges the other? In the discussion, it was stated that there may be synergies; e.g., a common image reviewing technique may be leading to a higher cost effectiveness, or there may be a potential to transfer security measures to safeguards applications. An assumption was that there could be synergies in geological repositories, a new facility type which has not yet been safeguarded. Furthermore, it was stated that security had a strong human component in addition to instrumentation, and, last but not least, the safety issue should not be neglected. In concluding, the working group stated an increasing overlap between safeguards and security with different concerns, i.e., international versus national, open versus confidential, different timeliness criteria, and different requirements such as authentication and detection in safeguards versus prevention in security. A common concern was deterrence. The working group recommended to focus on technological issues and to avoid political issues. As the security market was larger than the safeguards market, there could be a cost benefit for safeguards, if security instrumentation could be applied in safeguards. In the follow-up discussion the perspective arose to integrate also safety aspects, so that a paper on safeguards, safety and security could evolve for publication in the Bulletin.

Wireless in-plant data transmission: The working group intended to discuss and issue a statement on the use of wireless in-plant data transmission. The result was a publication in the ESARDA Bulletin. The first part was published in ESARDA Bulletin No. 36, providing specific arguments for considering the use of wireless communications as a complement to fixed cable installations, presenting an overview of state-of-the-art wireless technologies, and making a projection on capabilities that are likely to be reached in the near future. The second part, published in ESARDA Bulletin No. 38, was dedicated to RF technologies in a safeguards concept, to information security considerations, and to the integration of wireless technologies into existing and new facilities.

Guidelines for developing sealing systems: Following the publication of the Guidelines for Developing Unattended Remote Monitoring and Measurement Systems (URMMS) by the ESARDA Working Groups on C/S and NDA, the Working Group on C/S was requested to draft also guidelines for developing sealing systems. A first approach was presented to and discussed by the working group. The main aspects were related to (1) the development of new seals (including mechanical interface, tool for seal operation, control equipment, inspector's interface, management interface, seal handling procedure, and data security), (2) environmental constraints with reference to the Common IAEA-Euratom Test Procedures, (3) constraints imposed by facility operators, (4) inspectorates' requirements, and (5) planning (including maintenance, user-friendliness, and disposal of removed seals). Furthermore, it was stated that aspects of equipment authorisation and testing would have to be taken into account.

The working group concluded that, for further revision and extension, the existing URMMS Guidelines should be taken into account, and envisaged to develop guidelines not only for sealing, but to include identification and containment verification systems. As radiation tolerance could be a difficult issue, it would be helpful, if reference could be made to common IAEA/Euratom irradiation test procedures (pending under the German Support Programme to the IAEA) and criteria. Chemicals and salt could be included under "corrosive environment". In the future, there may be limitations in the transportation of lithium batteries. The working group found itself at the very beginning of this project. Also, a connection was seen to the development of a performance assessment methodology for C/S instrumentation; however, a discussion of this aspect was postponed.

Audit Group guidelines and C/S development: In 2007, the then ESARDA NMAC Audit Focus Working Group provided guidelines for plant operator's nuclear materials accounting and control (NMAC) systems drawing upon performance criteria reflecting the spirit of ISO 9000. With regard to the development of C/S instrumentation, it was discussed that implementation of appropriate C/S instrumentation by a plant operator could play a role in ISO quality management of timely material tracking to meet the operator's NMAC needs. Therefore, the ESARDA Working Group on C/S might use NMAC criteria to identify potential functions of operator-owned C/S instrumentation. Elaborating such a role for C/S instrumentation might help defining NMAC approaches for future facilities (specified by, e.g., Generation IV International Forum, Global Nuclear Energy Partnership, Next Generation Safeguards Initiative). The newly established ESARDA NMAC Audit Working Group would be developing specific auditing concepts for each type of nuclear facility such as fuel fabrication, power reactor, and reprocessing. The working group concurred that it would be easier to implement a quality management system in item facilities than in bulk handling facilities.

If Euratom would be auditing an operator's quality management system, the priority would be to focus on facility-specific risk analysis of undetected concealment compared to probability analysis. Appropriate, i.e., tamper indicating and authenticated, C/S instrumentation could reduce the risk. With reference to the terms *monitoring* and *tracking* that were used instead of *safeguards*, it was stated that the underlying legal basis for auditing was EU Commission Regulation No. 302/2005. However, plant operators were aware that, from a technical point of view, audit could go beyond the regulations, whereas from a political point of view, audit would result from the discussion process between opera-tors and regulators.

While the Working Group on C/S assumed that the presented approach suggested tight connections between safeguards and physical protection, it was stated that the Audit Working Group would address continuity-of-knowledge but not physical protection. Finally, the conclusion was drawn that the subject deserved future cooperation between the two working groups.

Safeguards design and simulation tool for surveillance and remote monitoring: The tool which was still under development, was designed for 3D-modelling and simulation of facilities as well as set-up of C/S devices such as camera positioning and lens selection. It provided opportunities for plant design, diversion analysis, safeguards design, inspection planning and training including data review. It was understood that, for a new plant, it would be a tool for the plant designer, state authorities, and international safeguards authorities. Simulation of plant operation could be used to study its impact on C/S functionality. For instance, if during plant operation the camera view would be blocked, then a second camera could be introduced and checked at a different position. Furthermore, cost estimates could be facilitated for safeguards implementation. Sizes and distances of objects could be specified, i.e., detection capabilities in terms of pixels, categorisation (e.g., human, animal), identification (e.g., human with a toolbox). A trial application was demonstrated to the working group, where use was made of the information provided on the facility design for the aforementioned study on performance assessment of C/S equipment. The tool developer concluded by stating that it was still necessary to consolidate the software functionalities and improve animation systems (e.g., including radiation sensors), to involve inspectors as end-users in the development process, and to investigate other potential applications as a reviewing tool of heterogeneous data sets (camera images and information from other sensors).

In the discussion, the working group addressed issues such as before-the-lens-tampering, image resolution, and memory capacities for image storage. In the future it might be possible to combine the tool with the below mentioned Laser Item Identification System L2IS. The tool could be advantageous for ensuring the continuity-of-knowledge (CoK), e.g., of fuel for long term storage: a movie could be taken on how the fuel was loaded into the cask and then moved within the facility; with a 3D model, it would be possible to test different scenarios and to demonstrate the solution to decision makers. The working group proposed (i) to include in the tool, e.g., Optical Character Recognition for cask ID plates, (ii) to account for varying illumination levels in a facility, and (iii) to assume safeguards activities carried out by a plant operator in the absence of the inspector such as detaching a seal under camera surveillance. The working group was interested in further pursuing this promising approach.

Laser item identification system L2IS: L2IS was designed as an unattended system, i.e., to be operated in the absence of an inspector. The working group took notice of an application in an enrichment plant with incoming UF_6-cylinders being identified and authenticated by laser scanning in the reception area.

In the discussion it was stated that re-coating of a cylinder would require taking of a new reference data set; that the method promised not to be prone to vibration of the trolley on which the cylinder was transported; and that no temperature effects were found either. As an alternative to laser item identification, an electronic safeguards seal on the UF_6-valve could be interrogated under camera surveillance in the absence of an inspector. With regard to the safeguards approach the working group recalled the assumption made by the Hexapartite Safeguards Project: while the UF_6-valve was secured with a safeguards seal, a second valve might be installed for diversion and then removed. Under this assumption, cylinder identification would have to be complemented by cylinder integrity verification. The working group was interested in further pursuing this promising approach.

Remote-monitored sealing array RMSA: The working group learnt that RMSA made use of a low-cost electronic seal with a fibre optic cable to monitor the sealing function. The working group noted the absence of tamper indicating and authenticating features and would be interested in learning about future applications of RMSA.

IAEA's Next Generation Surveillance System NGSS: The working group took notice of the development status and main features of NGSS. Possibly, the most innovative and interesting feature was the NGSS version with a dome camera, i.e., fisheye lens. Such a system was designed to replace up to four single cameras with normal lens systems. Therefore, it might be possible that two users could use one camera with different fields of view. In the discussion the question was raised whether such a system could be used by both IAEA and plant operator. The working group was interested in further pursuing the development of NGSS.

The working group issued a **technical sheet**: The Application of Mailboxes in Safeguards (published in Bull. # 40); and intends to issue technical sheets on: design information verification, optical surveillance techniques, and cap-and-wire seals.

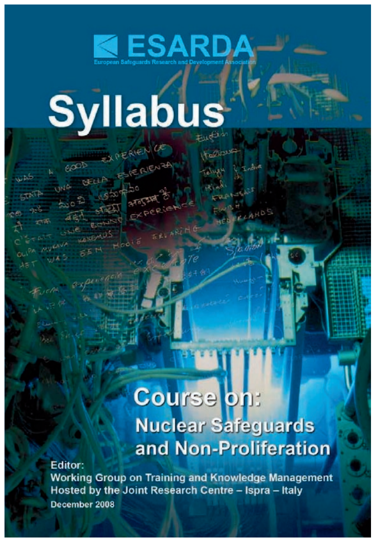
In 2009 and beyond, the working group intends to deal with the following topics: guidelines on sealing, identification and containment verification systems; remote system control; data review; trial application on performance of C/S devices; interface between safeguards, safety, and security.

Report by the Working Group on Training and Knowledge Management (WG-TKM)

G. Janssens-Maenhout
Chairperson

The 4th ESARDA course in Ispra last April was again a success, thanks also to the support of JRC's Nuclear Safeguards Unit. The large demand by many students and young professionals of various nationalities for the course forced to introduce a numerus clausus of 60. The content and pool of lecturers are well established, and the program is mature, requiring only some minor fine-tuning for future courses. The academic student evaluation for the course is settled and the achieved level is illustrated with the two best essays "Successes and Failures of the Nuclear Non Proliferation Treaty" by H. von Brevern and "Key Technical Issues for the Proliferation Resistance of Generation IV Reactors" by A. Tomanin, which are both taken up in this ESARDA Bulletin.

In the meantime the course syllabus is finalised, thanks to the support of the other ESARDA WGs. All 16 revised contributions will be issued in the form of a booklet, expectedly before the fifth ESARDA course in Ispra from March 30th till April 3rd, 2009. The course was advertised at different websites and journals (of the JRC, DGRTD, IAEA, ENEN, ESARDA ...) and we exceeded the numerus clausus before the registration deadline. The ESARDA WG TKM is working on an extension of their training/education activities with additional local courses.



Assessment of the Performance of Containment and Surveillance Equipment

Part I: Methodology

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Abstract

Equipment performance aims at the creation of relevant data. As Containment and Surveillance (C/S) is playing an ever increasing role in safeguards systems, the issue of how to assess the performance of C/S equipment is being addressed by the ESARDA Working Group on C/S. The issue is important not only for the development of appropriate safeguards approaches but also for the review of existing approaches with regard to the implementation of the Additional Protocol (AP) and Integrated Safeguards. It is expected that the selection process of appropriate equipment, especially for unattended operation, is facilitated by the availability of methods to determine the performance of such equipment. Apart from Euratom, the users of assessment methodologies would be the International Atomic Energy Agency (IAEA), plant operators, and instrument developers. The paper describes a non-quantitative performance assessment methodology. A structured procedure is outlined that allows assessing the suitability of different C/S instrumentation to comply with the objectives of its application. The principle to determine the performance of C/S equipment is to define, based on safeguards requirements, a task profile and to check the performance profile against the task profile. The performance profile of C/S equipment can be derived from the functional specifications and design basis tolerances provided by the equipment manufacturers.

Keywords: Containment and Surveillance, performance assessment, unattended instrumentation.

1. Introduction

In the application of International Atomic Energy Agency (IAEA) safeguards, material accountancy is the fundamental measure, whereas containment and surveillance (C/S) are applied as complementary measures. Within a safeguards approach, two roles can be attributed to C/S measures:

- To facilitate accountancy data acquisition.

  For instance, by applying a seal on a spent fuel cask, measurement data are "frozen" so that their validity can be carried forward into the future without re-measurement.

- To ensure that all material flows pass through key measurement points as declared.

  For example, by applying optical surveillance to an open core in a light-water reactor during refuelling.

As far as the applied safeguards measures consist of quantitative measurements with known measurement uncertainties and statistical sampling procedures, the performance of safeguards measures can be determined in a quantitative way with commonly recognised mathematical methods. With C/S measures becoming part of a safeguards system, an overall performance figure or detection probability cannot be derived in such a manner. As C/S is playing an ever increasing role in safeguards systems, the issue of how to assess the performance of C/S equipment is being addressed by the ESARDA Working Group on C/S with top priority. Apart from Euratom, the users of assessment methodologies would be the IAEA, plant operators, and instrument developers.

The IAEA, in its safeguards implementation criteria, addresses performance and assurance assessment by categorising the types of C/S systems into single C/S systems and dual C/S systems. Single C/S systems consist of one or, to enhance system reliability, more devices of a functionally identical type. A dual C/S system consists of several C/S devices based on different physical principles, i.e., with no common failure mode. Different levels of assurance are assigned to the different types of C/S systems. As a general rule, nuclear material under C/S has to be re-measured to increase the assurance provided by the C/S system, even if the C/S systems are evaluated with positive results. The requirements for re-measurement are based on the type of C/S system and on the nuclear material category. The level of re-measurement required is lower for dual

C/S systems, as they are attributed a higher confidence level compared to single C/S systems.

Equipment performance aims at the creation of relevant data, whereas assurance aims at the creation of information in support of the inspector's decision process.

The paper describes a non-quantitative performance assessment methodology. It resulted from an account of work performed for and in cooperation with the ESARDA Working Group on Containment and Surveillance.

2. Methodological Approach

The issue of performance and assurance assessment of Containment and Surveillance (C/S) equipment is important not only for the development of an appropriate safeguards approach but also for the review of existing approaches with regard to the implementation of the Additional Protocol (AP) and Integrated Safeguards. The AP foresees the introduction of novel technologies. It is expected that the selection process of appropriate equipment, especially for unattended operation, is facilitated by the availability of methods to determine the performance and assurance of such equipment.

In a first project phase, a methodological approach for assessing the performance of C/S equipment is addressed. It includes the following steps: (1) Acquisition and analysis of design information and operational characteristics of the facility under consideration, (2) assumptions on diversion and misuse scenarios, (3) definition of safeguards requirements, (4) compilation of candidate C/S equipment, (5) performance assessment of C/S equipment. The definition of safeguards requirements results in a facility specific task profile against which the performance profile of C/S equipment will have to be checked. The performance profile of C/S equipment can be derived from the functional specifications and design basis tolerances provided by the manufacturers.

3. Basic Concept of the Proposed Assessment Approach

The question of suitability of C/S equipment has to be seen in the context of the facility-specific safeguards approach in which the equipment is deployed. A perfectly efficient and reliable C/S system will show bad performance for a given task, if applied under the wrong conditions. For example, a powerful optical surveillance system monitoring the flow of casks will not render sufficient performance, if the facility lighting is regularly switched off.

If C/S equipment is to be applied within a safeguards approach, first of all, a need has to be identified with which the C/S system should comply. The question then is, how to select the most appropriate equipment.

The proposed assessment concept is based on a top-down procedure. In the first step, a **task profile** is developed. The underlying assumption is that the assessment of performance delivered by a system can only be carried out with regard to the expected function the system is intended to fulfil in the context of the whole safeguards approach. These expectations are outlined in the task profile. The task profile describes functional requirements to be met by C/S equipment anticipating the type of equipment.

In the second step, a **performance profile** of possible candidate C/S devices or combination of devices is established and matched against the requirements of the task profile. Candidates that do not meet all of the mandatory requirements of the task profile can be immediately precluded from the further selection process. Many other task profile requirements can be met to a different extent, like for example the technical reliability of the devices, the effort and time needed for maintenance and service of the devices as well as for evaluation of results. Each device or combination of devices will generate a different performance profile that has to be checked against the task profile.

In the third step which is not discussed in this paper, the **assurance profiles** of different solutions can be compared with each other and ranked. Whereas the performance profile assures that all the data needed for safeguards purposes are generated, the assurance profile states, if and to what extent these data may support the safeguards conclusion. The IAEA already honours a combination of devices that generate the data based on different physical principles. Other aspects leading to differences in the assurance profile may be differences in the strength of data authentication, or the possibility of remote data transmission that may lead to increased unpredictability of data review by the IAEA compared to local storage and review of the same data.

4. Establishing the Task Profile

The task profile has to reflect, in detail, all the requirements the C/S device has to fulfil within the safeguards approach. Hence, the task profile is to be based on information very much similar to that required for establishing the safeguards approach:

- Design information of the facility

- facility operation
- diversion and misuse assumptions
- safeguards measures making up the safeguards approach.

For reason of simplicity, the example of a dry storage facility for spent nuclear fuel from power reactors and vitrified highly radioactive waste (HAW) resulting from reprocessing of spent fuel assemblies will be discussed here. HAW casks and spent fuel casks have similar designs. Empty casks may also be stored at the facility.

Furthermore, it is anticipated that spent fuel casks are sealed in the shipping facility and received in the reception area of the dry storage facility. Here, casks are unloaded from the public transport vehicle, prepared for storage and moved with a travelling crane into the storage area. At their storage positions they are placed in an upright position onto the base plate. In case of leakage, casks must be moved back from the storage hall to the reception area for maintenance.

Diversion and misuse scenarios and, accordingly, the safeguards measures applied may vary with the situation in the state under consideration. If an Additional Protocol (AP) is in force and the State as a whole was evaluated by the Agency with a positive "broader conclusion" on the absence of undeclared nuclear activities and materials, some scenarios may not be further regarded with the same relevance as in states without an AP in force.

Diversion scenarios to be considered in the reception area during reception or maintenance work may consist of the following:

- Removal of a cask after receipt is recorded;
- declaration of a HAW cask as a spent fuel cask;
- replacement of a filled spent fuel cask with an empty cask, a dummy or a HAW filled cask.

Diversion scenarios in the storage area could be the following:

- Removal of a cask via normal access route;
- breaking through the outer wall and removing a cask;
- breaking through the outer wall, removing a cask and replacing it with an empty cask, a dummy or a HAW filled cask;
- lifting of a cask, cutting of the bottom, and removing of the content of the cask.

In terms of safeguards, casks are regarded as items. Their nuclear material content was verified at the shipping facility, and this knowledge has to be maintained by means of appropriate C/S measures (continuity-of-knowledge requirement). Re-measurement of the cask content is not possible but only checking of identity and integrity. The system must be capable of distinguishing between spent fuel casks, HAW casks, and empty casks.

The safeguards approach provides for optical surveillance in the reception area to observe the flow of casks until the casks are transported into the storage area. Neutron detectors can be used to discriminate between loaded and empty casks. Seals are used in the storage area to identify casks and secure them against undeclared opening and removal.

In the reception area video cameras are installed at several positions, in order to provide the necessary fields of view. The casks are under surveillance from entering the area until they are transported into the storage area. Neutron detectors are used to support the optical monitoring of loaded casks; i.e., neutron monitoring and optical surveillance are to be correlated.

In the maintenance area which is part of the reception area, the casks are secured with 2 seals (e.g., a metal cap seal and an electronic seal). The metal

NM handling procedure	Transfer of cask from truck to maintenance in the reception area Transfer of cask from the reception area to the storage area
SG task profile (functional profile)	Allow to ascertain that cask identity and integrity will be maintained during storage for the following: – nearly outdoor conditions – transport conditions – operation conditions – general C/S device specifications
Decision on C/S device class or combination of classes	Based on the functional task profile, redundant sealing (e.g., metal cap seal / electronic seal) is foreseen for the storage phase.

Table 1: Decision process for the selection of C/S devices in the reception area.

cap seal serves as a backup, whereas the electronic seal is used to check the identity and integrity of the casks during inspections.

The underlying assumptions and tasks are reflected in Table 1. For each step in the nuclear material (NM) handling procedure, the resulting requirements have to be considered, in order to be able to draw up a task profile.

The following task profile lists, for each step in the nuclear material handling procedures, requirements the C/S equipment has to cope with during transport and storage of the casks in the storage facility:

- Nearly outdoor conditions
  - temperature range: from 0°C to +80°C
  - air humidity: up to 100%
  - weather conditions: dust
  - lighting conditions: varying between quasi daylight and darkness
- Transport conditions
  - crane transport with according impacts (e.g., vibration, shock)
- Operational conditions
  - failsafe (difficult-to-access cask content)
  - unattended operation during transport
  - ability to operate in cask vicinity (e.g., radiation level, decay heat)
  - no dependence on any external supply during operation (e.g., power, light, cooling)
  - in situ verification should be possible
  - probability of inconclusive outcome near zero
- General C/S device specifications
  - reliability
  - detection probability
  - false alarm probability
  - probability of inconclusive outcome
  - tamper indication
  - data capture and storage
  - evaluation effort (effort, skills, time)

In the first step, the requirements are listed as purely functional requirements. In some situations, e.g., in the storage area, the safeguards task could, in principle, be accomplished either by optical surveillance or by grouping casks together and applying a seal for a whole group of casks. The first step in establishing the task profile should not anticipate the choice of a C/S device.

Based on the functional requirements, the class or the combination of classes of C/S devices capable of performing the required functions is identified, e.g., sealing systems, surveillance systems or radiation monitors, and the task profile requirements are then detailed with regard to the C/S device class chosen.

5. Establishing the Performance Profile

The task profile determines the characteristics to be investigated for C/S equipment candidates under consideration. For each device or combination of devices the degree of compliance with the task requirements has to be established.

The following five requirement levels and four performance levels are applied.

Requirement levels: (1) Mandatory; (2) very high; (3) high; (4) medium; (5) low.

Performance levels: (1) good +1; (2) satisfactory +0.5; (3) not relevant ±0; (4) no compliance -1.

In the example (see Table 2), a graduation is shown for the strengths of the requirements and for the degree of fulfilment by two different devices.

Requirements for Nearly Outdoor Conditions	Requirement Level	Performance Level	
		Device 1	Device 2
Temperature range: from 0°C to +80°C	mandatory	+1	+1
Air humidity: up to 100%	very high	+1	+0.5
Weather conditions: dust	very high	+1	+1
Lighting conditions: varying between quasi daylight and darkness	mandatory	+1	+1
Storage period: up to 40 years	mandatory	-1	-1

Table 2: Performance assessment applied to two C/S devices.

In principle, the following rule is applied: **A C/S device failing to meet a mandatory requirement will be excluded from further consideration.** In Table 2, the last requirement of "storage period: up to 40 years" cannot be met by any of today's, and probably future, electronic C/S device, as it seems to be impossible to design electronic equipment that can be used for up to 40 years. However, the assessment result has an impact on the replacement strategy for the device. Therefore, there should be an additional requirement, i.e., to make a statement about the end-of-life of the device in terms of a date, e.g., AD 2018. Then, the response could be that a specific type of C/S device will be available for another 10 years, but each unit will have to be replaced, e.g., after 5 years in the field.

Questions yet to be solved are how to rank alternative solutions that meet all mandatory requirements but show different degrees of fulfilment for graded requirements. A procedure to balance different requirements with each other has still to be developed.

6. Conclusions

A method to determine the performance of C/S equipment in quantitative terms with a sound mathematical approach is still not showing up, and there is a common understanding that there is very little likelihood of being able to develop such a method. The application of C/S measures yields non-quantifiable results that must be evaluated in a strictly objective manner, i.e., by technical means. In connection with the evaluation of surveillance images, some degree of subjective judgement may sometimes be involved, which should be avoided as far as possible.

In the proposed approach for performance assessment, a structured procedure is outlined that allows assessing the suitability of different C/S instrumentation to comply with the objectives of its application. The principle to determine the performance of C/S equipment is to define a task profile and to check the performance profile against the task profile.

The method is still under development and in its first project phase. To explore its capabilities in a practical application it has been applied to a long-term dry storage facility of spent fuel assemblies, which is described in more detail separately in Part II.

Reference

A. Rezniczek, B. Richter; How to Determine the Performance and Assurance of C/S Equipment; Proc. 29th ESARDA Annual Meeting, 2007.

Assessment of the Performance of Containment and Surveillance Equipment

Part II: Trial Application

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Abstract

The adopted methodological approach for assessing the performance of Containment and Surveillance (C/S) equipment resulted from an account of work performed for and in cooperation with the ESARDA Working Group on C/S. It was applied on a trial basis to a dry storage facility for spent nuclear fuel and consisted of the following steps: (1) Acquisition and analysis of design information and operational characteristics of the facility under consideration, (2) assumptions on diversion and misuse scenarios, (3) assumptions on safeguards approach and definition of safeguards requirements, (4) compilation and characterisation of candidate C/S equipment, (5) performance assessment of C/S equipment. The candidate equipment taken into account was routinely used by the IAEA: DCM14-type camera, Type E cap-and-wire seal, COBRA fibre optic seal, and VACOSS electronic seal. Four applications were considered: camera mounted in the reception area, seal on secondary lid of transport and storage cask, seal on protective lid, and seal on group of casks. For these applications, requirements were defined and requirement levels were attributed. The assignment of performance levels was carried out by using the technical specifications and design basis tolerances provided by the equipment manufacturers. The results were entered into four performance assessment tables. Although the assessment methodology was not yet fully developed, its trial application yielded promising results with regard to the selection of appropriate C/S equipment.

Keywords: performance assessment, trial application, spent fuel dry storage, Containment and Surveillance.

1. Introduction

The performance of Containment and Surveillance (C/S) instrumentation in safeguards cannot be determined in a quantitative way, i.e., with mathematical methods, as C/S measures do not consist of quantitative measurements with known measurement uncertainties and statistical sampling procedures. The methodological approach applied here was first presented at the 2007 ESARDA Symposium [1] and is described in Part I [2]. In the following Chapter 2 it is briefly recalled.

The present Part II deals with the case study of a dry storage facility for spent nuclear fuel and vitrified radioactive waste. The paper resulted from an account of work performed for and in cooperation with the ESARDA Working Group on Containment and Surveillance.

2. Methodological Approach

The proposed methodological approach for assessing the performance of C/S equipment includes the following steps: (1) Acquisition and analysis of design information and operational characteristics of the facility under consideration, (2) assumptions on diversion and misuse scenarios, (3) assumptions on safeguards approach and definition of safeguards requirements, (4) compilation and characterisation of candidate C/S equipment, (5) performance assessment of C/S equipment. The definition of safeguards requirements results in a facility specific task profile. The performance profile of C/S equipment is defined by the functional specifications and design basis tolerances provided by the manufacturers. In the assessment process, the performance profile of a C/S instrument is checked against the task profile the instrument is intended to fulfil in the context of the facility-specific safeguards approach.

Candidates of C/S instrumentation that do not meet all of the "mandatory" requirements of the task profile must be, in principle (see section 4), precluded from the further selection process. The extent to which other task profile requirements are met may be different for each C/S device. Examples are the technical reliability of a device, the effort and time needed for maintenance and service of the device, and evaluation of results. Each device or combination of C/S devices will show a specific performance profile that has to be checked against the task profile.

3. Characterisation of the Dry Storage Facility

The facility shown in Figure 1 was designed and licensed for a 40-year interim storage of casks filled with LWR spent fuel as well as casks filled with various types of radioactive waste, in particular, vitrified high-level waste (HLW) resulting from reprocessing of spent fuel assemblies [3-11]. The storage capacity is 3.800 tons of heavy metal. There are 420 storage positions where different types of cask are to be placed in an upright position on a base plate. Empty casks may also be stored at the facility.

The facility was knowingly not equipped with a hot cell or any other heavy shielding and remote handling instruments which would have enabled opening of the casks safely, e.g., for repackaging or re-examination of their content, because the interim storage concept works without cask opening and spent fuel handling in the event of damage. This concept is associated with the advantage of preventing a diversion of nuclear material by facilitating access to the cask content a priori.

Figure 1: View of the Gorleben interim dry storage facility.

3.1 Layout of the Facility

The facility consists of a large hall made of reinforced concrete with a footprint of about 200m by 40m and a height of 20m. The hall is divided into 2 parts (see Figure 2):

(I) reception area

(II) storage area.

The reception area and the storage area are separated from each other by an approximately 8m high concrete shielding wall with a sliding steel door.

<u>Cask Reception Area</u>
Casks are received in the reception area, prepared for storage and transferred into the storage area. The reception area can also be used for maintenance work, e.g., in case of a leakage or failure in the pressure monitoring system.

The entrance to the facility is located in the reception area. There are two sliding doors, one for incoming and one for outgoing casks on heavy duty trucks as well as for personnel access. The cask maintenance room is part of the reception area.

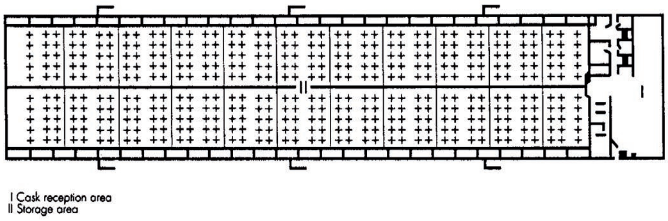

Figure 2: Layout of the Gorleben dry storage facility.

<u>Cask Storage Area</u>
A travelling crane is mounted over the entire length of the storage hall and allows the casks to be transported to each of the 420 storage positions arranged in 42 rows of 10 storage positions, respectively.

Figure 3: Storage hall with newly arrived casks and shock absorbers in the foreground.

Figure 4: Storage hall with storage casks.

Figure 3 shows the length of the storage hall, with newly arrived casks and shock absorbers in the foreground, and, behind the casks, the protective shields used to cover the casks during transport. The arrangement of casks in their storage positions is shown in Figure 4, which also illustrates the dimensions of a cask compared to a human being.

3.2 Transport and Storage Casks

The availability of several licensed cask types enables the storage of various kinds of fuel in different amounts. The design of the different Castor® models consists of a cast iron, thick-walled, cylindrical body with radial cooling fins on the cask surface and a dual lid system comprising a primary and a secondary lid made from stainless steel. Finally, a protective lid is added prior to storage to protect the lid system against mechanical damage. All the three lids are bolted to the cask body as shown in Figure 5. Two trunnions are placed at the top and bottom ends for handling purposes. A basket with definite loading positions contains the fuel assemblies to be stored.

For reducing the neutron dose polyethylene rods are used as moderator which is integrated into the cask body and secondary lid.

Prior to transport the cask is equipped with two shock absorbers, one at each end, to reduce the mechanical load during the transport on public lines, especially in case of a transport accident. The shock absorber, which consists of a closed steel structure filled with several layers of wood, covers the cask ends completely. In addition, the cask is enclosed by a protective coachwork as shown in Figure 7.

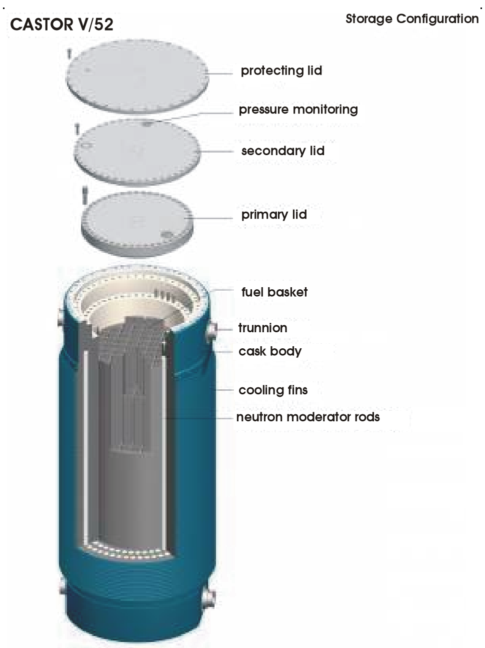

Figure 5: Typical design of a Castor® cask.

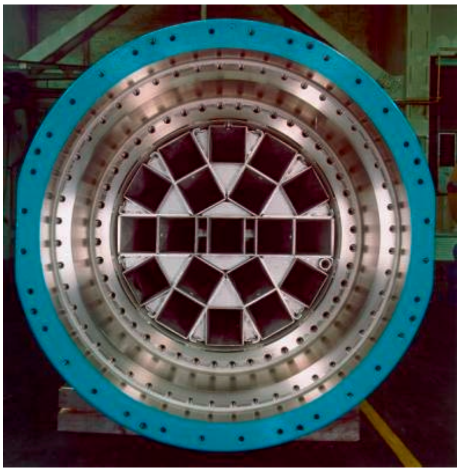

Figure 6: Castor® cask for LWR fuel assemblies.

Figure 7: Cask covered by protective coachwork during transport.

Figure 8: Castor® cask with shock absorbers at both ends.

3.3 Operation of the Facility

The following operational procedures are involved upon arrival of a cask at the storage facility:

- Unloading of the transport vehicle

- removal of protective coachwork and shock absorbers
- tipping of cask to an upright position with the overhead crane
- transfer of cask to the maintenance room
- mounting of pressure sensor on the secondary lid
- leak test of the metal sealing gasket of the secondary lid as well as of the pressure sensor
- pressurization of the control volume between primary and secondary lids to 6 bar with inert gas
- helium leak testing of the secondary lid
- installation (screwing on) of a protective lid
- mounting of connector and cable for the pressure monitoring system
- transport by overhead crane to the storage position in the storage hall and connection to the pressure monitoring system.

The following scenario would be taken into account only, if the primary lid became leaky:

- Decoupling from the pressure monitoring system and transport of the defective cask to the maintenance room
- disconnection of the monitoring system measurement cable
- removal of the protection lid
- insertion of a rabbeting lid on top of the secondary lid
- attachment of the rabbeting lid by welding.

Actions associated with a cask shipment away from the storage facility do not occur as long as a final repository has not been licensed.

3.4 Safeguards Approach

When developing safeguards approaches, the IAEA postulates diversion and misuse strategies a State could consider, in order to divert nuclear material or to misuse the facility. Diversion and misuse scenarios and, accordingly, the safeguards measures to be applied may vary with the situation in the State under consideration, i.e., the safeguards agreement or agreements in force. If an Additional Protocol (AP) is in force and the State as a whole has been evaluated by the Agency with a positive "broader conclusion", some scenarios may be less relevant than if applied in States without an AP in force.

Diversion strategies to be considered would include: undeclared removal of nuclear material from

Figure 9

a safeguarded facility or the use of a safeguarded facility for the introduction, production or processing of undeclared nuclear material. For a static storage facility where no processing of nuclear material takes place, the removal of this nuclear material is the essential diversion strategy.

In developing safeguards approaches, the IAEA assumes that a diversion strategy would include one or more concealment methods to reduce the probability of detection by IAEA safeguards activities. Such actions may begin in advance of the removal of material and may be continued over a considerable period of time. Examples would include:

- Tampering with IAEA containment and surveillance measures
- falsifying records, reports and other documents
- borrowing nuclear material from other facilities in the State to replace the diverted nuclear material for the duration of an IAEA inspection
- replacing diverted nuclear material or other missing items with material or items of lower strategic value (e.g., dummy fuel assemblies or elements).

<u>Diversion Scenarios</u>

For the following discussion it is assumed that casks are sealed in the shipping facility and transported by railway coach and/or truck to the storage facility.

Diversion scenarios to be considered during reception or maintenance work:

- Remove a cask after the receipt is recorded, e.g., load it back onto the transport vehicle
- remove a cask brought back from the storage area to the reception area for maintenance work
- conceal diversion by replacing the removed cask with an empty cask, a dummy or a HLW filled cask
- overstate receipts by declaring an empty cask or a HLW cask to be a spent fuel cask.

Diversion scenarios in the storage area:

- Removal of a cask via normal access route
- break through the outer wall and remove a cask
- conceal the diversion by replacing the removed cask with an empty cask, a dummy or a HLW filled cask
- lift a cask in the storage area, cut the bottom and remove all or part of the content.

3.4.1 Principles and Requirements of the Safeguards Approach

In the dry storage facility under consideration, the content of a cask will not be accessible for verification; in IAEA terminology it is categorised "difficult-to-access" material. The IAEA's safeguards approach for "difficult-to-access" material is to verify the fuel before it is loaded into the cask and then to maintain the continuity-of-knowledge of the cask content. This leads to the following principles and requirements:

- Casks are regarded as items. The knowledge of the nuclear material content was established prior to cask loading in the shipping facility, and this knowledge has to be maintained by means of appropriate C/S measures;
- to ensure that the previously established knowledge of the cask content is still valid, the identity and integrity of the cask has to be verified;
- since re-measurement of the cask content is not possible, the applied C/S measures must be fail-safe to the best possible extent (i.e., dual C/S);
- to support or facilitate the verification of identity and integrity.

3.4.2 Outline of the Safeguards Approach

The IAEA and Euratom are interested in using C/S in such a way that each plausible diversion path is sufficiently covered. To cope with device failures, i.e., to increase the reliability of the C/S measure, devices can be duplicated or backed up, e.g., by attaching an electronic seal to a cask and, as a backup, a metallic cap-and-wire seal. In addition, optical surveillance may be applied. Finally, there may be a safeguards approach with several "layers" of C/S equipment. Since it cannot be excluded that a C/S system that gives positive results has been circumvented by a diverter, a higher confidence-level is assigned to such a multi-layer C/S system in which each plausible diversion path is covered by several C/S devices that are functionally independent and not subject to a common tampering or failure mode. Multiple C/S is normally applied where the verification of nuclear material is difficult to perform, in order to increase confidence in the C/S results and reduce the requirements for periodic re-verification.

In the dry storage facility under consideration here, a dual C/S system is assumed to be implemented. The first component is an optical surveillance system with a single camera observing the complete reception area including the maintenance area. Furthermore, as the shielding wall separating the reception area from the storage area does not reach to the roof, the field of view of the camera is large enough to follow all crane movements in the storage hall. All material movements and all possible diversion and concealment activities are to be recorded by the camera. The second component of the dual C/S system is sealing. Each cask is sealed and, in addition, casks may be sealed as groups to inhibit the scenario that a cask is lifted, cut open at its bottom and its content removed without interfering with the seal on the cask lid.

After removal of the shock absorbers from the arrived cask, the safeguards seal on the secondary lid is accessible for verification. Thus, identity and integrity of each cask can be verified upon receipt. As a back-up measure for the later storage period, a metallic seal is commonly installed by an inspector in exchange of the seal used during transport from the shipping facility. Additionally, each cask is equipped with a seal on the protective lid ensuring the continuity-of-knowledge in terms of nuclear material content, identity of the cask, and integrity of its lid system. As an alternative to the sealing of individual casks, a seal may be applied to a group of casks, in order to reduce the irradiation dose associated with inspections. Furthermore, a group seal will ensure the immobilisation of the casks, thus serving as a back-up measure in case of a camera failure. In general, the inspector attaches the different types of seal to the protective lid. Only the installation of an electronic seal might be done under camera surveillance by the plant operator in the absence of the inspector; seal data and surveillance data could be easily correlated.

Furthermore, the surveillance camera is used to record all cask movements associated with the transfer from the reception area to the final storage position and transfers within the storage area such as lifting the stored casks up or bringing them to another storage position or back to the reception area. Therefore, the camera would also allow to record a possible cask removal and/or replacement with a substitute as well as the unrealistic case of cask opening to remove nuclear material.

4. Task Profile and Performance Profiles

The surveillance camera is assumed to be mounted in the upper corner of the reception area, thus overlooking the whole length of the building (200m). It should be possible to monitor the operations carried out on the cask after entering the reception area, e.g., detachment of the transport seal and attachment of the storage seal. For powering the camera it can be assumed that the operator is able to provide mains power so that a battery is only needed for back-up in case of power outage.

The storage hall will only be manned if necessary for operational reasons, i.e., in case of a receipt, when maintenance or routine check-ups are required. It would be desirable, if the camera could operate at a reduced lighting level, i.e., not requiring full illumination for 24 hours a day. The data capture and storage capacity should be designed for a duration of at least 3 months.

In the following it is intended to compare the performance levels achieved by different types of C/S instrumentation for the same application. The following ratings are applied:

no compliance	not relevant	satisfactory	good
-1	±0	+0.5	+1

If any "mandatory" requirement has a performance rating of -1, the device will have to be excluded from application. However, the situation may be different, if there is no alternative C/S instrument available. Then the possibility of using an available instrument with an appropriate replacement strategy will have to be analysed.

Optical Surveillance

The optical surveillance system approved by the IAEA for routine safeguards use is based on the DCM14-technology [12]. Therefore, the ALIS (All-In-one-System) [13] is the only camera system taken into consideration here.

In view of the dimensions of the building, two ALIS cameras "looking at each other" might be a better solution than one, in order to cope with before-the-lens tampering. Whereas the first camera, installed in the reception area, could possibly overlook human beings that are determined to hide in the storage hall, a second camera would definitely spot a human being, even in remote corners and within cask shadows.

Table 1 shows that the level for the "remote monitoring capability" requirement is set to "high" rather than "mandatory". A remote monitoring capability would enable the retrieval of state-of-health data from the camera, but also of image data for safeguards. Any optical surveillance failure would trigger immediate remedial action on the part of the inspectorate, while there will still be a functioning C/S system in place, as the casks will be sealed. ALIS has no remote monitoring capability. If, however, remote monitoring is required, a DMOS (Digital Multi-camera Optical Surveillance System) or SDIS (Server-based Digital Surveillance System) could be implemented instead of ALIS. DMOS works with up to 16 DCM14-based cameras and SDIS works with up to 6 DCM14-based cameras. The use of more than one camera would increase the review effort, but it may also increase the transparency of plant operations.

Sealing

Seal on the secondary lid

The seal on the secondary lid must be considered as a back-up that only comes into effect, if all other C/S systems fail. Under normal circumstances, this seal is inaccessible, as during storage the secondary lid is covered by the protective lid. The removal of the protective lid is only foreseen in case of a leakage in the lid system.

The environmental conditions concerning temperature and radiation levels are very demanding. Besides the technical requirements, also economical aspects have to be taken into account, like time, effort and cost for the evaluation of results, both for in-field activities and at-headquarters activities.

The following seals have been selected for evaluation: Device A: metallic seal (cap-and-wire) [14]; Device B: COBRA seal [15]; Device C: VACOSS seal [16].

Requirements for camera system	Requirement level	Performance level of Device A	Device B	Device C
Ability to focus on short distances of a few meters up to long distances of about 200 meters (minimum size of object to be identified at 200m distance, e.g., 6m×2.5m)	Mandatory	+1	–	–
Data capture and storage capacity for at least 3 months with the desired picture taking frequency	Mandatory	+1	–	–
Ability to operate under reduced lighting conditions	High	+1	–	–
Operating on mains power supplied by the operator, with battery back-up	Mandatory	+1	–	–
Tamper indication	Very high	+1	–	–
Availability of powerful support to facilitate the picture evaluation	Very high	+1	–	–
System reliability IAEA target: 150 months MTBF	High	+1	–	–
Ease of use usability review passed	High	+1	–	–
Interface with electronic seals	High	+1	–	–
External triggering	High	+1	–	–
Embedded time stamp	Mandatory	+1	–	–
Remote monitoring capability	High	-1	–	–
Status of Health (SoH) information	Mandatory	+1	–	–
End of life	AD 2018	+1	–	–

Table 1

While it is desirable to apply at least two seals with different failure modes, the performance assessment yields **only the metallic seal to be suitable for this application.** COBRA and VACOSS seals do not meet a number of mandatory requirements. Therefore, cost assessment is irrelevant.

Seal on the protective lid

A seal on the protective lid will be accessible at any time. It allows to check the identity and integrity of the cask. It has to be properly applied by threading the sealing wire through at least two bolts of the protective lid on top of the cask in such a way that the bolts cannot be unscrewed without damaging the sealing wire.

The effort required to verify the seal can vary considerably depending on the seal type. If a cap-and-wire seal is used, the integrity of the whole length of the mechanical wire has to be checked visually, i.e., the inspector has to climb to the top of the cask. This requires a lifting platform to be placed in front of the cask and lifting up the inspector to the top of the cask, which is about 6 meters above ground. There are several aspects to be taken into account. First, there must be enough space to place and operate the lifting platform (or a ladder) between the cask rows. Second, the length of the stay in close vicinity of the casks will increase rapidly with the number of casks to be verified. This implies exposure of inspectors and operator staff to high radiation doses.

The same considerations hold true for the COBRA seal. Its sealing wire consists of a fibre optic cable. The manufacturer of the COBRA seal recommends that the whole sealing wire should be checked for its integrity, as there are tools to cut and repair it.

Requirements for seal on secondary lid with protective lid on top	Requirement level	Performance level of Device A	Device B	Device C
Seal wire diameter less than 7 mm	Mandatory	+1	+1	+1
Device height (thickness) less than 25 mm	Mandatory	+1	+1	-1
Operating temperature between 0°C and 120°C *	Mandatory	+1	-1	-1
Unattended and autonomous operation for up to 50 years *	Mandatory	+1	-1	-1
In situ verifiable	Low	-1	+1	+1
Remote interrogation	Low	-1	-1	+1
Capable to function in high-level radiation field (wire and seal device) [refer to test criteria] *	Mandatory	+1	-1	-1
Low effort for seal evaluation in field	Medium	-1	+1	+1
Low effort for seal evaluation at HQ	Low	-1	+1	+1
System reliability	High	+1	+1	-1
Ease of use	High	-1	+0.5	+0.5
Low false alarm probability	Very high	+0.5	+1	+0.5
Embedded time stamp	Very high	-1	-1	+1
Status of Health (SoH) information	Very high	-1	-1	+1

Table 2

* No replacement strategy available: During long-term interim storage with no failure (i.e., leakage) of the primary lid, the seal would be inaccessible, until the cask may be maintained, e.g., because of leakage, or, at a conditioning/fuel consolidation plant, opened for re-packaging of the spent fuel into final disposal casks.

This would not be detectable by the seal reader. It should be noted, however, that repairing the sealing wire would be time-consuming and, thus, imply significant exposure to radiation.

Also, the electronic VACOSS seal has a fibre optic cable as sealing wire. Being monitored by the seal electronics it is more resistant to undetected cutting and repair. However, technological advances may not totally exclude that cutting and repair could be a viable option for concealment. Therefore, experts have recommended to inspect also the VACOSS sealing wire. In contrast to the metallic and COBRA seals, VACOSS offers the advantage of remote interrogation from outside the storage area with a serial cable interconnecting up to 40 seals. With this approach significant radiation exposure can be avoided by inspectors and operator's staff. One could even think of a VACOSS sealing approach which works similar to the operator's pressure and leakage monitoring system, i.e., an unattended system recording alarms in the event of undesirable status changes like low seal battery and opening of the sealing wire.

The performance assessment renders, **in principle, all of the devices suitable for this application.** Therefore, it would be possible to apply two seals with different failure modes, if deemed necessary. Furthermore, for this performance assessment, the ratings have been summed up in the last row of Table 3. The results suggest that the VACOSS seal would be the most appropriate seal for this application. The advantages of this seal are mainly due to its remote interrogation capability and the consequences thereof, i.e., evasion of radiation risk.

<u>Seal on a group of casks</u>

To support verification of the cask integrity, 5 casks can be secured by a common sealing wire. The basic idea is that it will be impossible to move or lift a

Requirements for seal on protective lid	Requirement level	Performance level of Device A	Performance level of Device B	Performance level of Device C
Seal wire diameter less than 7 mm	Mandatory	+1	+1	+1
Wire integrity checked by seal device (no human visual inspection required)	Very high to medium	-1	-1	-1
Maximum wire length at least 10 meters	Very high to medium	+1	+1	+1
Wire can be fixed in bolt drilling so that bolts cannot be unscrewed even with long sealing wire	Mandatory	+1	+1	+1
Operating temperature between 0°C and 80°C (max. temperature of cask body)	Mandatory	+1	+0.5	+0.5
Unattended operation for up to 1 year	Mandatory	+1	+1	+1
In situ verifiable	Very high to medium	-1	+1	+1
Capable to function in high-level radiation field (wire and seal device) [consider this requirement together with replacement frequency]	High	+1	-1	-1
Remote interrogation of seal possible	Very high to medium	-1	-1	+1
Chaining of seals for remote interrogation possible	Very high to medium	-1	-1	+1
Low health impacts (radiation exposure) for seal evaluation for inspector and operator * [this requirement is related to the previous ones, i.e., remote interrogation]	Very high	-1	-1	+1
Low interference with plant operation in terms of required manpower and equipment support from operator [this requirement is related to the previous ones, i.e., remote interrogation]	High	-1	-1	+1
Low effort for seal and wire maintenance in field	High	+1	+1	+1
Low effort for seal and wire maintenance at HQ	High	0	0	0
Low effort for seal evaluation in field	High	-1	+0.5	+1
Low effort for seal evaluation at HQ	High	-1	+1	+1
System reliability **	High	+1	+1	+1
Ease of use	High	-1	+0.5	+0.5
Low false alarm probability	Very high	+0.5	+1	+0.5
Embedded time stamp	Very high	-1	-1	+1
Status of Health (SoH) information	Very high	-1	-1	+1
End of life **	AD 2030	+1	+1	-1
Cost	investment operation	+1 -1	0 0	-1 +1
Supplier(s) and Procurement	***	+1	+1	+1
	sums	**-0.5**	**+4.5**	**+13**

Table 3

* Depending on the number of casks stored in the hall, the duration of the inspector's access may be limited by the radiation dose.

** Replacement strategy to be applied.

*** There must be at least one manufacturer for each type of C/S device to assure the supply. For customised equipment, the intellectual property rights must be vested either with the inspectorate or with a Member State Support Programme to the IAEA.

cask within this group and to cut its bottom or body for the removal of its content without damaging the sealing wire, which must be sufficiently long to be threaded through the bolts of 5 casks.

Obviously, it does not make much sense to use a cap-and-wire seal that has to be removed for verification and replaced with a new one. COBRA and VACOSS seals can be interrogated in situ without removing them. VACOSS could even be interrogated remotely from outside the storage area.

The performance assessment renders **all of the devices suitable for this application.** Therefore, it

Requirements for seal on cask groups	Requirement level	Performance level of		
		Device A	Device B	Device C
Seal wire diameter less than 7 mm	Mandatory	+1	+1	+1
Wire integrity checked by seal device (no human visual inspection required)	Very high	-1	-1	-1
Maximum wire length of at least 25 meters (5 casks) [for A and B difficult to verify the wire integrity beyond 25m]	Mandatory	+0.5	+0.5	+1
Wire can be fixed in bolt drilling so that bolts cannot be unscrewed even with long sealing wire	Mandatory	+1	+1	+1
Operating temperature between 0°C and 80°C (max. temperature of cask body)	Mandatory	+1	+0.5	+0.5
Unattended operation for up to 1 year	Mandatory	+1	+1	+1
In situ verifiable	High	-1	+1	+1
Capable to function in high-level radiation field (wire and seal device) [consider this requirement together with replacement frequency]	High	+1	-1	-1
Remote interrogation of seal possible	High	-1	-1	+1
Chaining of seals for remote interrogation possible	High	-1	-1	+1
Low health impacts (radiation exposure) for seal evaluation for inspector and operator * [this requirement is related to the previous ones, i.e., remote interrogation]	Very high	-1	-1	+1
Low interference with plant operation in terms of required manpower and equipment support from operator	High	-1	-1	+1
Low effort for seal and wire maintenance in field	High	+1	+1	+1
Low effort for seal and wire maintenance at HQ	High	0	0	0
Low effort for seal evaluation in field	High	-1	+0.5	+1
Low effort for seal evaluation at HQ	High	-1	+1	+1
System reliability **	High	+1	+1	+1
Ease of use	High	-1	+0.5	+0.5
Low false alarm probability	Very high	+0.5	+1	+0.5
Embedded time stamp	Very high	-1	-1	+1
Status of Health (SoH) information	Very high	-1	-1	+1
End of life **	AD 2030	+1	+1	-1
Cost	Investment operation	+1 -1	0 0	-1 +1
Supplier(s) and Procurement	***	+1	+1	+1
	sums	**-1.0**	**+4.0**	**+13.5**

Table 4

* Depending on the number of casks stored in the hall, the duration of the inspector's access may be limited by the radiation dose.
** Replacement strategy to be applied.
*** There must be at least one manufacturer for each type of C/S device to assure the supply. For customised equipment, the intellectual property rights must be vested either with the inspectorate or with a Member State Support Programme to the IAEA.

would be possible to apply two seals with different failure modes, if deemed necessary. Furthermore, for this performance assessment, the ratings have been summed up in the last row of Table 4. The results suggest that the VACOSS seal would be the most appropriate seal for this application. The advantages of this seal are mainly due to its remote interrogation capability and the consequences thereof, i.e., evasion of radiation risk.

Therefore, to minimize the radiation exposure of inspectors and operator staff, and also to minimize the verification effort, the best solution would be to use electronic VACOSS seals that can be chained and the whole chain be remotely interrogated, e.g., from the reception area. While the VACOSS seal is reaching its end of life, the IAEA is already replacing VACOSS seals with EOSS seals [17].

5. Summary and Conclusions

Taking the example of an interim dry storage facility for spent nuclear fuel and high-level waste has revealed that there are many parameters that influence the performance evaluation of C/S instrumentation, even in such a simple application as outlined here. Obviously, the number of casks stored in the facility plays a major role. If there are only very few casks to be verified, the application of cap-and-wire (metallic) seals for casks may be an adequate and robust solution. But, the capacity of the studied facility is 420 casks. Furthermore, much of the safeguards approach could be adopted for the on-site interim storage facilities at German nuclear power plants.

Besides problems of defining the level of a requirement and rating the level of fulfilment by an individual C/S system, there are also methodological problems still to be solved, e.g., the problem of comparing and unifying the different nature of factors. How can effects of equipment costs, health impacts on persons due to radiation exposure and levels of reliability be balanced with each other?

It would also be interesting to analyse retrospectively, how verification activities were carried out in practice in comparable facilities and to analyse the practical differences for different facilities. With regard to safeguards assurance, the IAEA does not seem to rely totally on C/S application. In their evaluation criteria for safeguards measures under INFCIRC/153-type agreements the IAEA requires for material under conclusive single C/S and even dual C/S a certain degree of re-verification. Given identical C/S systems, the strategic value of the material safeguarded by this system seems to play a role in assigning safeguards assurance to the results.

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Introduction to the Publication of two Selected Essays by Students of the 2008 ESARDA Course on Nuclear Safeguards and Non-Proliferation

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The 4th ESARDA Course on Nuclear Safeguards and Non-Proliferation took place at the JRC in Ispra from 14 till 18 April 2008 and covered a fully fledged programme of lectures by experts in the field of nuclear safeguards, visits to safeguards laboratories and some classroom exercises.

The course addressed the various aspects of a global nuclear non-proliferation system and explained how this system works in practice, starting from the legal basis of the Treaty on the Non-Proliferation of Nuclear Weapons at international scale and the Euratom Treaty at regional scale, on the one hand, and the technical aspects of the Nuclear Fuel Cycle on the other hand. After having explained the terminology and specification of nuclear materials as subject, the Safeguards Principles were defined, including the statistical aspects of accountancy and auditing. Then, the Nuclear Safeguards technology is described with destructive and non-destructive nuclear material measurements, monitoring of transported or processed bulk material, and containment-and-surveillance techniques. Their application in the field was illustrated by a live-reporting of on-site inspections by the Euratom and IAEA inspectorate. In the course, also innovative technologies used for the Additional Protocol, such as environmental sampling and satellite imagery, were discussed and an excursion on nuclear forensics was given. Last but not least, an overview was given on the management and analysis of information, such as collected from open sources. Also, the analysis of trade data for import/export control was addressed.

To comply with the ambition of an up-to-date course, the standard safeguards aspects were completed in the course with some topical lectures and case studies, such as on Iraq, Nuclear Security, Illicit Trafficking, or Central Fuel Banking.

This compact course was attended by 67 students, of which half were Master Degree and PhD students in Nuclear Engineering or International Relations/Law. 14 students included this course also in their academic curriculum for 3 credits in the European Credit Transfer System, and made a take-home examination and wrote an essay. Two essays were selected for publication in this ESARDA Bulletin and were revised with the comments of the evaluation panel. These papers demonstrate the understanding by the students and give an indication on the level of depth by the lectures in this one week course. In particular, they illustrate the multidisciplinary approach in the course: Hermann von Brevern described more the legal and political aspects in his essay on "Successes and Failures of the Nuclear Non-Proliferation Treaty", whereas Alice Tomanin tackled the more technical safeguards issues in her essay on "Key technical issues for the proliferation resistance of Generation IV reactors".

Key Technical Issues for the Proliferation Resistance of Generation IV Reactors

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Abstract

Many nations believe that nuclear energy will play a key role in the future of energy production because it is an economic and non-greenhouse-gas-emitting way of producing electricity (and also high temperature process heat and hydrogen).

To ensure nuclear energy penetration into future energy production it is necessary for this technology to develop technically advanced solutions in order to be more safe, sustainable, economic and proliferation resistant.

The main idea is that the new generation of Nuclear Energy Systems will provide competitively priced and reliable energy production whilst satisfactorily addressing concerns over nuclear safety, waste, proliferation and public perception.

This essay is focused on the most relevant characteristics of proliferation resistance and physical protection of the Generation IV Nuclear Energy Systems.

It presents the context in which these systems are developed, and the context of research programmes focused on their proliferation resistance aspects.

In particular, it refers to the Generation IV International Forum research programme (G.I.F.), which selected the six most promising systems with respect to the Generation IV goals.

The proliferation resistance characteristics of these systems are evaluated with respect to the criteria used by the G.I.F. to select them.

Keywords: Generation IV; nuclear system; proliferation resistance; fuel cycle.

1. Introduction

"Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism"

This is the Proliferation Resistance and Physical Protection goal for Generation IV Nuclear Energy Systems (NESs) as it was formulated by the Generation IV International Forum [1].

What has been done and was has to be done to reach this goal?

1.1. What does Proliferation Resistance mean?

Nuclear Proliferation means the spread of nuclear weapons, and of all fissile materials, weapon-applicable nuclear technologies and information which could be used for military purposes.

In order to impede nuclear proliferation and to promote peaceful nuclear energy applications, in 1957 the International Atomic Energy Agency was created, "to supervise and control civilian nuclear technology and know-how in order to prevent the proliferation of nuclear weapons" (Article II) [2].

According to the IAEA [3] Proliferation Resistance is defined as:

"*That characteristic of an NES that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State seeking to acquire nuclear weapons or other nuclear explosive devices.*"

In this sense, the analysis of the proliferation resistance characteristics of an NES is focused on the analysis of the barriers that the system offers to a potential proliferation threat. These barriers are divided in two main groups: intrinsic and extrinsic barriers.

Intrinsic barriers are the material qualities and the technical aspects of the system that make it unattractive for diversion or theft of nuclear material, such as isotopic composition, radiotoxicity, mass, chemical and physical form of the nuclear materials, facility accessibility, diversion detectability, time, skill and knowledge required for diversion.

These are the *key technical issues* for proliferation resistance analysed in this essay.

The extrinsic barriers are the institutional barriers, that include international treaties, agreements, national policies and laws, safeguards inspections, control and accounting (MPC&A) and export control.

Concerning the extrinsic barriers, the Non-Proliferation Treaty (NPT), which came into force in 1970, obliges every Non-Nuclear Weapon State (NNWS) that ratifies the Treaty to sign a Comprehensive Safeguards Agreement (CSA) with the IAEA regulating the surveillance and control of nuclear material handled by the State [4].

The objective of the safeguards performed by the IAEA is the timely detection of diversion of significant quantities of nuclear material. The safeguards goals, which are applied to set up the safeguards inspection scheme, are:

- *Significant Quantity* (SQ) – related to the mass of nuclear material needed to construct a critical mass, and depends on the material considered and its isotopic composition and enrichment grade.
- *Timeliness* – the time within which the inspectors should detect the diversion of a SQ.
- *Detection Probability* – the probability for the detection of a false alarm and for non-detection of a diversion.

The NPT also concerns export control [5], to reveal indications of undeclared nuclear activities and to verify completeness of State declarations: a State subjected to IAEA safeguards has to provide the Agency with information about the import and export of nuclear materials, relevant equipment and technology.

In 1992, export control developed to include also dual use item control. Dual use items are those which could be used both in civilian and in military nuclear applications, for example remote manipulators for highly radioactive materials, such as spent fuel, and uranium isotope separation equipment. The items subjected to export control are listed [6] and are periodically updated.

Technology alone cannot prevent nuclear proliferation, because every barrier can be evaded if the State has an extremely high wish to develop an overt nuclear weapon programme and ample economical, technical and human resources to do it.

However, intrinsic barriers can hinder development of a covert nuclear weapon programme.

Implementation of proliferation resistance and physical protection in the design phase of an NES, which is the basic idea of all research programmes in this field, not only forms the intrinsic barriers, but also includes development of specific safeguards measures for the characteristics of the system, as inspection plans or built-in safeguards instrumentation that cannot be removed without detection. In order to reach this goal, a strong collaboration with the IAEA from the very start of the project is essential.

1.2. Proliferation Resistance in the context of Generation IV Nuclear Energy Systems

To consider the challenges of the Generation IV NESs in meeting future energy needs, in 2000, ten countries joined together to form the Generation IV International Forum (G.I.F.). The countries now involved in this project are Argentina, Brazil, Canada, China, the Euratom, France, Japan, the Republic of Korea, the Republic of South Africa, the Russian Federation, Switzerland, the United Kingdom and the United States [7].

The purpose of the GIF is to formulate a guideline for R&D in order to reach Generation IV NES goals.

Having previously clearly defined the goals for Gen IV NESs, the work then focused on the selection of the most promising systems and the creation of a Technology Roadmap to guide R&D.

The goals are defined in the four broad areas of sustainability, economics, safety and reliability, proliferation resistance and physical protection, and are related to the entire fuel cycle. The ideological basis of the Technology Roadmap is to integrate the R&D regarding all these goals, at every stage of the design and implementation of the System.

The six most promising concepts selected to represent the Next Generation Nuclear Systems [8] are:

- Gas-Cooled Fast Reactor System (GFR)
- Sodium-Cooled Fast Reactor System (SFR)
- Lead-Cooled Fast Reactor System (LFR)
- Molten Salt Reactor System (MSR)
- Supercritical-Water-Cooled Reactor System (SCWR)
- Very-High-Temperature Reactor System (VHTR)

Evaluation of the performance of an NES related to the proliferation resistance goal has included defining criteria and metrics that represent the most important features of the goal itself.

From the strict point of view of proliferation resistance and physical protection, the evaluation methodology used [9] analysed the system response to a specific threat in terms of the following measures:

- *Proliferation Technical Difficulty* – the inherent difficulty required to overcome the multiple barriers to proliferation
- *Proliferation Cost* – the economic and staffing investment required to overcome the multiple barriers to proliferation, including the use of existing or new facilities
- *Proliferation Time* – the minimum time required to overcome the multiple barriers to proliferation
- *Fissile material Type* – a categorisation of material based on the degree to which its characteristics affect its utility for use in nuclear explosives
- *Detection probability* – the cumulative probability of detecting a proliferation segment or pathway
- *Detection Resource Efficiency* – the efficiency in the use of staff, equipment and funding to apply international safeguards to the NES.

The threats considered for proliferation resistance were the concealed or overt diversion of declared facilities, misuse of declared material, and the existence of clandestine dedicated facilities [10].

After a brief description of the six most promising systems selected by the G.I.F, their proliferation resistance characteristics will be discussed with respect to the measures previously defined and the safeguards goals set by the IAEA.

2. The Generation IV Nuclear Energy Systems [11]

2.1. Gas-Cooled Fast Reactor

The GFR is a fast-spectrum helium-cooled reactor with a closed fuel cycle. The reactor size ranges from 288 MWe to 1200 MWe. It uses a direct-cycle helium turbine for electricity production (Brayton-cycle) and, given the very high outlet temperature of the gas (850°C), it can also produce process heat for the thermochemical production of hydrogen. Through the combination of a fast-neutron spectrum and full recycling of actinides, GFRs minimise the production of long-lived radioactive waste isotopes. The GFR's fast spectrum also makes it possible to utilise available fissile and fertile materials. The GFR reference assumes an integrated, on-site spent fuel treatment and refabrication plant. The fuel cycle will be based on either advanced aqueous or pyrometallurgical processing options. Research is being carried out on core design, to achieve a fast neutron spectrum for effective conversion with no fertile blanket.

A composite ceramic-ceramic fuel (cercer), with closely packed, coated (uranium, plutonium)carbon (U,Pu)C kernels or fibres, is the best option for fuel development in order to achieve an average burnup of 250 GWD/MTHM. Alternative fuel options for development include fuel particles with large (U,Pu)C kernels and thin coating, or ceramic-clad, solid-solution metal (cermet) fuels. Core configurations may be based on prismatic blocks, pin- or plate-based fuel assemblies.

The requirement for active safety is minimised by various passive approaches, evaluated for the ultimate removal of decay heat in depressurization events.

2.2 Sodium-Cooled Fast Reactor

The SFR system is a sodium cooled reactor with a fast-neutron spectrum and a closed fuel cycle for efficient conversion of fertile uranium and management of actinides. The primary coolant can either be arranged in a pool, where all primary system components are housed, or in a compact loop layout. There is an intermediate sodium circuit, which transfers heat to the steam generators, to avoid sodium-water reaction in the primary circuit.

In any case, the sodium is at atmospheric pressure and provides a great thermal inertia in case of a loss-of-coolant accident (LOCA).

A full actinide recycle fuel cycle is envisioned with two major options: the first is an intermediate size (150 to 500 MWe) sodium-cooled reactor with a uranium-plutonium-minor-actinide-zirconium metal alloy fuel, supported by a fuel cycle based on pyrometallurgical processing in co-located facilities. The second is a medium to large (500 to 1500 MWe) sodium-cooled fast reactor with mixed uranium-plutonium oxide fuel (MOX), supported by a fuel cycle based upon advanced aqueous processing at a central location serving a number of reactors. The outlet temperature is approximately 550°C for both.

The average burnup has been estimate as 150-200 GWD/MTHM and the conversion ratio expected is in the range 0.5-1.3.

2.3. Lead-Cooled Fast Reactor

LFR systems are lead or lead-bismuth alloy-cooled reactors with a fast neutron spectrum and closed fuel cycle. The main purpose is to achieve an efficient conversion of fertile uranium and management of actinides producing electric, but the high temperature that lead can reach makes it possible to enter the market for hydrogen and process heat in the future.

Options include a range of plant ratings, including a battery of 50–150 MWe that features a very long refuelling interval (15 to 20 years), a modular system rated at 300–400 MWe, and a large monolithic plant option at 1200 MWe. (The term battery refers to the long-life, factory-fabricated core, not to any provision for electrochemical energy conversion.)

In order to achieve higher temperatures, the fuel options studied are metal or nitride-based, containing fertile uranium and transuranics.

The preferred option for the fuel cycle is pyroprocessing, with advanced aqueous as an alternative.

As in the SFR, the coolant is at atmospheric pressure and provides a great thermal inertia. The LOCA event in the primary circuit is eliminated because the primary heat exchangers (steam generators) are inside the vessel, so there is no need for pipes.

The average burnup has been estimate as 100-150 GWD/MTHM and the conversion ratio expected is in the range 1.0-1.2.

2.4. Molten Salt Reactor

The MSR system features an epithermal to thermal neutron spectrum and a closed fuel cycle adapted to the efficient utilisation of plutonium and minor actinides. In the MSR system, the fuel is a circulating liquid mixture of sodium, zirconium, and uranium fluorides. The molten salt fuel flows through graphite core channels, producing a thermal spectrum. The heat generated in the molten salt is transferred to a secondary coolant system through an intermediate heat exchanger, and then through another heat exchanger to the power conversion system. Actinides and most fission products form fluorides in the liquid coolant. The homogenous liquid fuel allows the addition of actinide feeds with variable composition by varying the rate of feed addition.

The fuel cycle options are: a maximum conversion ratio (up to 1.07) using ^{233}Th and uranium; a denatured ^{233}Th-uranium converter with minimum inventory of nuclear material suitable for weapon use; a denatured once-through actinide burning; and actinide burning with continuous recycling. In any case, the average burnup has been estimated to be very high. The option for reprocessing is the pyro-chemical process. Refuelling, processing and fission product removal can be performed online and there is no need for fuel fabrication. The reference plant has a power level of 1000 MWe. The system operates at low pressure (<0.5 MPa) and has a coolant outlet temperature above 700°C.

2.5. Supercritical-Water-Cooled Reactor

The SCWR system is a high temperature, high pressure water-cooled reactor that operates above the thermodynamic critical point of water (374 °C, 22.1 MPa) to achieve a thermal efficiency approaching 44%.

It may have a thermal or fast-neutron spectrum, depending on the core design and the amount of moderator added to thermalise the core, due to the low density of supercritical water.

The fuel cycle for the thermal option is a once-through low-enriched uranium cycle. The fast-spectrum option uses MOX, with central fuel cycle facilities based on advanced aqueous reprocessing for actinide recycle. In either option, the reference plant has a 1700 MWe power level, an operating pressure of 25 MPa, and a reactor outlet temperature of 550°C. Passive safety features are incorporated.

The average burnup has been estimate as 45 GWD/MTHM.

2.6. Very-High-Temperature Reactor

The VHTR system is a helium-cooled reactor with a thermal neutron spectrum and a once-through low enriched uranium cycle. It also has the flexibility to adopt uranium/plutonium fuel cycles.

The system uses a direct-cycle helium turbine for electricity production (Brayton-cycle).

The VHTR system is primarily aimed at relatively quick deployment of a system for high temperature process heat applications, such as coal gasification and thermo-chemical hydrogen production with superior efficiency, due to the very high outlet temperature of the gas (above 1000 °C). The system may incorporate electricity generation equipment to meet cogeneration needs.

The reference reactor has a 600-MWth power level.

The fuel is contained in TRISO coated particles, which can perform high burnup (maximum burnup in the order of 150-200 GWD/MTHM) and high temperatures. The core can be a prismatic block core or a pebble bed core.

VHTR has the ability to accommodate a wide variety of mixtures of fissile and fertile material without significant modification on the core design, because of decoupling of the optimisation of the core cooling geometry from the neutronics.

3. Proliferation Resistance and Physical Protection of IV Generation NESs

The following analysis is focused on two major aspects: the fuel cycle and the reactor system.

In particular, the fuel cycle has been investigated in depth because it has to assure that the possibility to access weapon-usable materials at every stage is minimised.

In the past years, some States decided to adopt the option of direct storage of the spent fuel (e.g. United States), whilst others chose the reprocessing option.

The US had considered reprocessing too much of a proliferation concern, because it implied handling spent fuel and plutonium extraction.

Now, since three of the six most promising systems are fast breeder reactors, which require a closed fuel cycle with reprocessing, this option has been reconsidered while researching for more proliferation resistant techniques.

In 2006, the United States proposed the Global Nuclear Energy Partnership (GNEP), which now has 25 partner countries.

The GNEP proposes to allow a few States to possess the technology for production and reprocessing of nuclear fuel, and to provide fuel and reprocessing to all the State users in the world.

The US department of Energy [12] said: "Through GNEP, the United States will work with other nations possessing advanced nuclear technologies to develop new proliferation-resistant recycling technologies in order to produce more energy, reduce waste and minimize proliferation concerns. Additionally, the partner nations will develop a fuel services program to provide nuclear fuel to developing nations allowing them to enjoy the benefits of abundant sources of clean, safe nuclear energy in a cost effective manner in exchange for their commitment to forgo enrichment and reprocessing activities, also alleviating proliferation".

Although this proposal has been criticised, because it could create an uncompetitive market and subject user States to political pressure due to their dependence on a few suppliers, it is a sign of the effort that the international community is making in order to find a solution to the problems concerned with the threat of proliferation.

3.1. Proliferation Resistance and Physical Protection in the fuel cycle

The main features that increase proliferation resistance and physical protection of the Generation IV NESs are the fuel and the fuel cycle.

The once-through and the closed fuel cycle adopted by the next generation nuclear systems offer different barriers to the proliferation risk.

The fundamental difference between the two options is that in the once-through cycle the spent fuel is stored once it has produced energy in the reactor, while in the closed cycle the spent fuel is reprocessed: the fissile uranium and plutonium, and also the actinides for transmutation, are extracted and utilised to fabricate new fuel.

In the case of direct storage, the plutonium in the spent fuel, which has a longer life than the other fission products, is initially made secure by the other fission products' radiation. When the fission products radiation decays, the storage offers a high risk in proliferation because it can be seen as a plutonium mine. The intrinsic proliferation resistance of the once-through cycle clearly decreases with time. Furthermore, if all the nuclear spent fuel of the global nuclear plants is put in storage without reprocessing, the number of storage sites will increase in the future, creating a significant problem in terms of safeguards measures required to control that great amount of nuclear material all over the world.

It also needs to be considered that plutonium is not the only weapon-usable material in the spent fuel, but any radioactive waste could become hazardous weapon-usable material for dirty-bombs or terrorist attack.

These are the fundamental reasons why five of the six candidate systems have selected the closed fuel cycle option (the SCWR system features both the fuel cycle options).

The aim of the closed fuel cycle is to reduce the amount of final waste in storage by reprocessing the spent fuel, eliminating fissile material like plutonium and ^{233}U by burning it as a fuel both in thermal and fast reactors, eliminating long-lived radioactive wastes (such as iodine and technetium) by separation and transmutation and eliminating long-lived actinides by burning them in fast-spectrum reactors or in accelerator-driven systems. The MSR system has also been projected for the purpose of transmutation.

Coupling completely recycle and transmutation means that the final waste stored will be only the stable fission products, which are less than 0.3% of the spent fuel mass and have a radioactive life of about a century. This means that safeguards on the storage will focus on small masses of hazardous materials, and this improves the *Detection Resource Efficiency.*

This requires methods of reprocessing for spent fuel.

Two main types of process can be applied to the separation of long-lived radionuclides: hydro-metallurgical ("aqueous") and pyro-chemical ("dry") processes.

The industrial hydrometallurgical reprocessing technique employed today on a commercial scale (LWR/UOX and LWR/MOX reprocessing) is the PUREX process, and it separates uranium and plutonium into two different pure flows, which are than recombined for the fuel fabrication.

The presence of a pure plutonium stream at a certain stage in the reprocessing facility increases the risk of nuclear proliferation.

The advanced separation technologies studied for Generation IV NESs, i.e. advanced aqueous processing or pyro-chemical processing, are designed to avoid the separation of plutonium from uranium and minor actinides, so as to make more difficult the separation of plutonium from the fuel and increase the *proliferation technical difficulty*.

In all the phases of the reprocessing plant, plutonium is never separated from uranium and actinides, and at all times it remains in extremely hostile environments and in chemical and physical forms that would require additional processing to extract weapons-suitable material. Moreover, plutonium is always coupled with highly radioactive waste during all the reprocessing, fuel fabrication and also plant operating phases, so that it would be impossible for a human being to come into direct contact with it. The fuel must be remotely fabricated and inspected. The facilities developed are completely inaccessible hot-cells, because of the radiation, and all systems are automated to the extent possible. The only penetrations are portals at each end to move spent fuel in and fresh fuel and waste products out, and additional portals for equipment transfer and to shift samples to the laboratory. Cameras continuously view processing equipment and staging areas.

Because of heat, neutron and gamma signatures, the locations of the fuel and the fuel cycle products are easily detected. On the other hand, this makes it difficult to undertake precise measurement of the plutonium in the system. However, because of the limited number of portals and movement of materials, containment and surveillance should be effective if properly implemented as the system is developed.

In the aqueous process, spent fuel is dissolved in an organic solvent, and then it is separated using differences in thermodynamic stability between complexes of the actinides.

An advanced aqueous process under development is the UREX process, in which plutonium and neptunium remain together in a single stream. The process can be configured such that this stream can also include some other higher transuranic isotopes. A daughter product of neptunium can provide a stream signature that increases real-time *detection probability*.

In the pyro-chemical process, refining is carried out in molten salt media, based on electrorefining or on distribution between non-miscible molten salt-metal phases. This process has been demonstrated only on a pilot-scale, and the feasibility of transuranic recovery still needs to be demonstrated. The processes studied may be grouped into the following categories: melt-refining, zone melting, electrorefining, vacuum distillation, fractional crystallization, gas-solid reactions, and liquid-liquid extraction using either non-miscible molten metal phases or non-miscible molten salt-metal phases.

Pyro-chemical separation often relies upon the electrorefining technique, which has been studied in the IFR project before 1994 [13], but was carried out on only a laboratory scale.

In an electrorefiner, chopped metal fuel (oxide fuel is previously reduced to a metal) is loaded into an anode basket and submerged in a molten salt along with a cathode. When current is passed between the anode basket and the cathode, uranium and all components of the fuel that are less noble than uranium are oxidised and dissolve in the molten salt. At the cathode, uranium, which is the least noble species dissolved in the molten salt, is electrodeposited. Using a liquid metal cathode (typically Cadmium), plutonium and the minor actinides are electrodeposited along with the uranium. The active metal fission products accumulated in the molten salt are eventually adsorbed into zeolite and converged into a glass-bonded sodalite waste form. The noble metal fission products and the cladding that remain in the anode basket are melted into an iron-zirconium alloy metal waste form [14].

Since the molten-salt has a greater radiation stability than the organic solvent of the aqueous technique, it is possible to reprocess highly radioactive spent fuel, with no need for long cooling times and associated proliferation risk during storage.

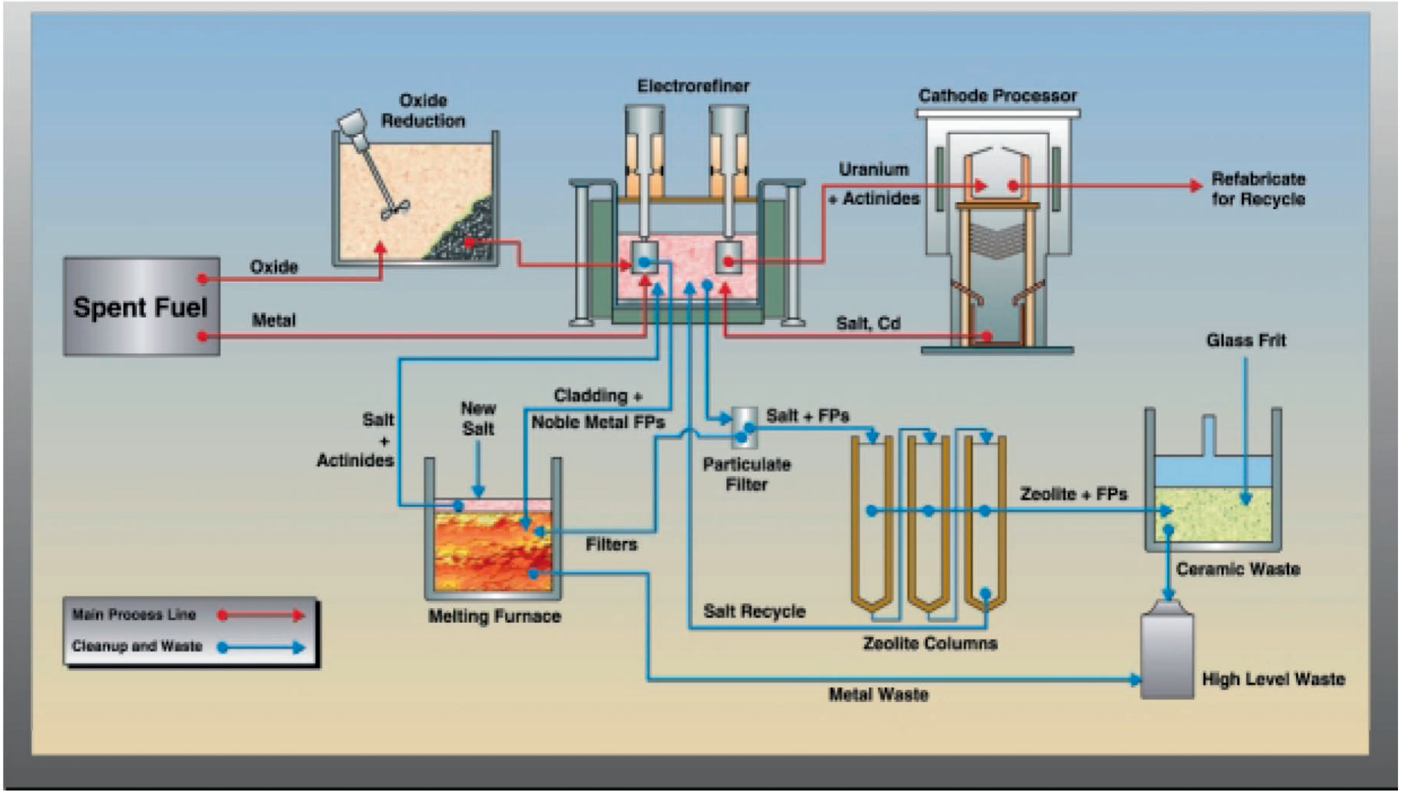

Figure 1: Pyro-chemical process.

The facility is filled with an inert atmosphere (for example argon gas) and equipment is operated at high temperature (ranging from 500 to 1700 °C), making it completely inaccessible.

Moreover, for the pyro-chemical process, no oxygen or water vapour is needed, in contrast to the PUREX and aqueous processes. This means that a detector for oxygen or water vapour inside a pyro-chemical process facility could immediately indicate the presence of a clandestine plutonium separation in the facility (if it is carried out with the conventional PUREX process).

This is an obvious advantage for *detection probability* and also means that to separate plutonium using the PUREX process, additional equipment (maybe also an entire additional facility) is needed and this increases the *proliferation technical difficulty* and the *proliferation cost*. Moreover, the additional equipment needed is subjected to *export control*, and this provides another barrier to be overcome in the development of an undeclared separation process.

The pyro-process technology offers a great compactness of equipment and less dependence on economy of scale, providing the possibility to form an integrated facility complex for irradiation, reprocessing and refabrication. This reduces the needs for transport of nuclear materials and therefore the risk of theft during transport, which is a *physical protection* concern.

For the reason presented, the pyro-chemical process seems to be the most attractive in terms of its intrinsic proliferation barriers. Of course, it is the natural reprocessing process for MSR fuel and for metal fuel.

For the once-through fuel cycle option, the proliferation resistance of the cycle can be improved by producing smaller quantities of weapon-usable material, with an isotopic composition that makes it difficult to construct a nuclear weapon with them and in a spent fuel form that makes it difficult to extract fissile material [15].

This fuel cycle option has been chosen by the VHTR and the SCWR systems.

The usability of plutonium in nuclear weapons depends on its isotopic composition. Higher burnup produces isotopic mixtures that are more difficult to use in the construction of weapons, and also produces smaller quantities of weapons-usable material per unit of power.

If compared with a classical PWR, which has an average burnup of 33 GWD/MTHM (modern fuel designs and cladding materials appear to be capable of peak assembly burnup values of greater than 60 GWD/MTU), all the Generation IV NESs have higher burnup, of the order of 100-200 GWD/MTHM, except for the SCWR which has a burnup of 45 GWD/MTHM.

This creates plutonium which has to be highly processed before it becomes a weapon-usable material. Due to this *fissile material type*, the *proliferation cost, time* and *technical difficulty* are increased.

This is of particular importance in the VHTG and MSR, in which the dominant plutonium isotope is ^{242}Pu. ^{242}Pu has a critical mass about an order of magnitude larger than ^{239}Pu. It is clear that 8 kg of ^{242}Pu is a much smaller proliferation risk than 8 kg of ^{239}Pu.

Isotope	Weapons Grade	LWR (PWR)	MSR
$_{239}Pu$	93	56.6	30
$_{240}Pu$	6.5	23.2	18
$_{241}Pu$	0.5	13.9	14
$_{242}Pu$	0.0	4.7	38

Table 1: Isotopic composition (%) for weapon-grade plutonium, PWR plutonium and a proliferation resistant molten salt reactor.

Concerning the recovery of plutonium from spent fuel, a more proliferation resistant fuel form has been studied for the VHTR: the coated particle [16].

This fuel option has been considered also for the GFR system.

This fuel geometry has been developed for the high temperature reactor (HTR) in several countries in two main directions: the pebble bed concept studied in Germany, Russia, China and South Africa and the prismatic core studied in the United States, United Kingdom, Japan and Russia. The reactor core type under development for the VHTR can be either a prismatic block core or a pebble bed core.

In both designs, the basic fuel-containing unit, the coated particle, is the same. It is a spherical kernel of uranium dioxide (UO_2) or uranium carbide (UCO) enclosed in four layers of porous carbon buffer, inner pyrolytic carbon, silicon carbide and outer pyrolytic carbon (TRISO particle). The diameter of the uranium kernel is 0.5 mm, and the diameter of the whole coated particle is 0.92 mm.

In the pebble bed design, the fuel element is a 60 mm diameter sphere made up of a carbon outer zone and an inner region with 15,000 coated particles uniformly dispersed in a graphite matrix. In the prismatic core design, the fuel element is an hexagonal graphite block 750 mm long and 350 mm

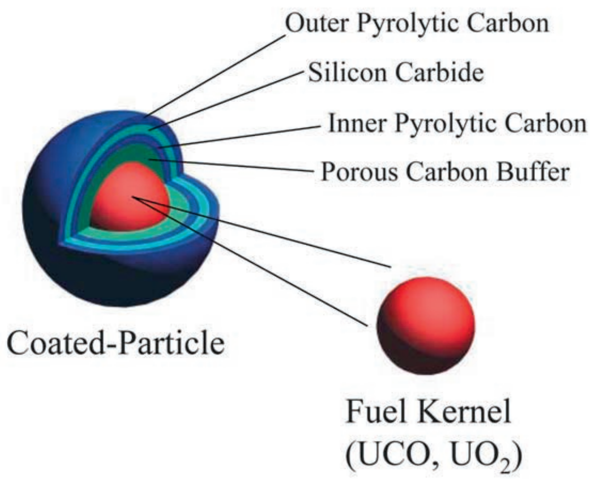

Figure 2: Coated-Particle fuel.

across flats. Alternate fuel and coolant holes are drilled in an hexagonal array. Fuel rods, consisting of coated particles bonded in a closed packed array by a carbonaceous matrix, are stacked in the fuel holes in the prismatic block.

Although several studies on reprocessing of coated particles were carried out in Germany before choosing the direct disposal strategy, it is clear that to extract a sufficient quantity of plutonium from that small particle requires a lot of work, time and money. For example, if someone wished to extract 8 kg of ^{239}Pu (which is the *significant quantity* goal set by the IAEA for this material) from a coated particle spent fuel, supposing that the isotopic composition of VHTR plutonium in the spent fuel is the same as for the MSR (30% ^{239}Pu in 1 kg of plutonium), and that the spent fuel includes 0.9% of plutonium (this is true for a commercial nuclear plant of Generation III, and VHTR's higher burnup will create less plutonium), he must reprocess more than four thousand million particles (assuming spent fuel density as 11,000 kg/m^3). This is a very good intrinsic barrier from the point of view *of timeliness* for detection, *proliferation time, cost and quantity.*

Other fuel options, such as nitride, metal or inert matrix options are under development to increase the ratio of plutonium that can be burned in a reactor core and allow multiple recycling of plutonium. In fact, today's technologies allow plutonium to be only 12.5% of the MOX fuel, because of the intrinsic safety limits [17].

The inert matrix fuel (IMF) enables plutonium to be burnt without producing additional plutonium because there are no fertile materials in the matrix, but plutonium is simply diluted in zirconium or magnesium oxide. Although this is good from a non proliferation point of view, this means that in the inert matrix production facility there will exist some pure streams of plutonium, creating a concern for safeguards as in the PUREX process.

Moreover, the intention of Generation IV NESs is both to burn excess plutonium and to create a future supply based on breeding, and this goal is not reached with the IMF.

Another fuel option very interesting for its intrinsic proliferation resistance is thorium fuel [18]. This option has been considered for the MSR, to provide a high thermal conversion ratio.

Thorium is a fertile isotope that can breed a fissile isotope, ^{233}U, so a neutron chain reaction can only be sustained with thorium if fissile materials are available (^{235}U, ^{233}U, ^{239}Pu). By mixing such fissile isotopes with thorium it becomes possible to operate a nuclear reactor with a thorium cycle in which ^{233}U is produced. As with plutonium, ^{233}U is then partly burned in the reactor, and the remaining part can be used to produce new fuel after reprocessing.

The options under development include the joint use of thorium fuelled thermal reactors and uranium fast spectrum reactors.

In these systems, less plutonium is produced and its isotopic composition is highly degraded. Furthermore, the thorium cycle produces less long-lived actinides than the uranium cycle, and this reduces the amount and the radiotoxicity of the ultimate waste which could be used as hazardous material for dirty-bombs or terrorist attack.

With regards to recycling, the separation of ^{233}U and thorium is done with a wet liquid-liquid extraction using the THOREX process, and this might create some concern for safeguards because of the pure stream of fissile material that it generates. Actually technical analyses indicate that 12% ^{233}U in ^{238}U is equivalent to 20% ^{235}U in ^{238}U [19]. However, the joint use of thorium and uranium cycles might enhance proliferation resistance through increased ^{232}U and ^{238}Pu content in recycle feedstock.

3.2. Proliferation Resistance and Physical Protection in reactors

Focusing particularly on two systems, the LFR and the MSR, there are some technical aspects of these two reactors that play a relevant role in proliferation resistance and physical protection.

The LFR battery option is top ranked in proliferation resistance because of its long-life core of about 15-20 years. This means that plutonium and other fission materials produced remain in the inaccessible reactor for so long as to make this reactor an absolutely unattractive route for diversion of weapon-usable materials in terms of *proliferation time*.

The battery option has been considered for developing countries that may not wish to develop an indigenous fuel cycle infrastructure to support their nuclear energy systems. As was said previously, intrinsic barriers to proliferation work well if the countries that wish to divert nuclear materials have not the economic, technical and human resources to overcome the barriers, and this is the case of the countries for which this system has been developed.

Since it is not economically viable to build an in-site fuel cycle facility to support a long life core, every 15-20 years the spent fuel has to be taken to a reprocessing facility and fresh fuel has to be brought to the plant. The reprocessing and fuel fabrication facility could also be located in another country.

Strong safeguards and *physical protection* measures need to be taken in the transportation, to avoid theft or sabotage.

Moreover, international regulatory developments are needed for the cases where new regional fuel cycle centres, owned by a consortium of clients operating under international safeguards, close the fuel cycle and manage the waste.

In complete opposition to the LFR long-life core there is the MSR on-line refuelling option, which could potentially provide a continuous stream of spent fuel from which to extract weapon usable material. This spent fuel is in the form of molten salt fluorides, and requires pyro-chemical coupled with aqueous processes to extract a pure plutonium flow for a weapon.

Although this system does not offer a barrier for the *proliferation time*, it increases the *proliferation technical difficulty* and *the proliferation cost*.

An advantage offered by the MSR system is that no fuel fabrication is needed, and this eliminates a step of the fuel cycle which may cause some concern in terms of proliferation resistance.

Finally, every system described has adopted passive safety systems, so to minimise the need for maintenance that requires outsiders to enter the plant. This makes the facility more inaccessible, and increases *physical protection* on the plant and on the nuclear materials inside.

4. Conclusions

The barriers to proliferation offered by the six systems described provide a good improvement in proliferation resistance and physical protection.

The complete recycle of plutonium and minor actinides provided by these systems reduces the stock of weapon suitable materials all over the world.

The closed fuel cycle coupled with the pyro-chemical process reduces the final waste disposed and makes access to weapon suitable material difficult.

The once-through fuel cycle risks to proliferation are reduced by the adoption of high burnup fuel, which creates an isotopic composition of plutonium unsuitable for a nuclear weapon, and of a fuel form that makes recovery of plutonium very difficult.

The long-life core of the LFR battery system makes the facility very unattractive for diversion of nuclear materials.

More research is needed for the Thorium fuel cycle, which could create further improvement on proliferation resistance of the NESs and for the MSR online refuelling option, which must be submitted to very strong safeguards measures.

In conclusion, recalling the PR&PP goal

"*Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism*"

As it is put in evidence in this goal, enhanced proliferation resistance and physical protection of a nuclear system is a work that is never going to end. Even if a system is supposed to be the least desirable route for diversion or theft of weapon-usable materials, research is needed because there is always room for improvement.

Acknowledgements

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Acronyms

- **AFCI** – Advanced Fuel Cycle Initiative
- **CSA** – Comprehensive Safeguards Agreement
- **DOE** – Department of Energy (U.S.)
- **GFR** – Gas-cooled Fast Reactor
- **GIF** – Generation IV International Forum
- **GNEP** – Global Nuclear Energy Partnership
- **GWD/MTHM** – Gigawatt-Days/Metric Tonne Heavy Metal
- **GWD/MTU** – Gigawatt-Days/Metric Tonne Uranium
- **LEU** – Low Enriched Uranium
- **LFR** – Lead-cooled Fast Reactor
- **LOCA** – Loss Of Coolant Accident
- **LWR** – Light Water Reactor
- **MOX** – (U,Pu)O2 Mixed OXide fuel
- **MSR** – Molten Salt Reactor
- **NERAC** – Nuclear Energy Research Advisory Committee
- **NES** – Nuclear Energy System
- **PR&PP** – Proliferation Resistance and Physical Protection
- **PUREX** – Plutonium and Uranium Recovery by Extraction
- **PWR** – Pressurized Water Reactor
- **SCWR** – Super critical Water Reactor
- **SFR** – Sodium-cooled Fast Reactor
- **SNF** – Spent Nuclear Fuel
- **UREX** – Uranium Recovery by Extraction
- **VHTR** – Very High Temperature Reactor

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Successes and Failures of the Nuclear Non-Proliferation Treaty

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Abstract

This Essay will present the reader with a fairly comprehensive analysis of the achievements made and failures suffered under the regime of the NPT since its entry into force on 5 March 1970.

Following the timeline of non-proliferation efforts, a basis will be laid for understanding the role that the NPT has played over the years. After that we will use key issues to draw conclusions as to whether the NPT-regime was rather successful or not, to finally point out the obstacles and challenges for the treaty in the time ahead.

Keywords: non-proliferation; NPT; history.

1. Introduction

Ever since the explosion of the first atomic bomb on the morning of 6 August 1945 over the Japanese city of Hiroshima, the world is aware of a horrific threat, called nuclear warfare. The device exploded there was crude, unsophisticated and low-powered by modern standards, but it caused several thousand deaths, both immediate and in the aftermath, as well as inconceivable affliction for the survivors and their descendants. Even today, the terror of Hiroshima has not lost its tremendous impact and is still a memorial, reminding the world of the horrors of nuclear warfare. It is the mission of international diplomacy, to let this remainder not be in vain but to ensure that something like that can and will never happen again.

1.1. The Baruch Plan

The first international approach after these events was to found the UN Atomic Energy Commission in 1946 by the first resolution of the United Nations General Assembly "to deal with the problems raised by the discovery of atomic energy" [1]. In June 1946, Bernard Baruch, the United States representative to the Commission, made a proposal, called the Baruch Plan, that the US (at the time the only state possessing nuclear weapons) would destroy its nuclear arsenal on condition that the UN imposed sufficient controls (safeguards) on atomic development which would not be subject to UN Security Council veto. These controls would decline any non-peaceful use of atomic energy. The US would hand over all scientific data to the commission, which would in turn have the sole right to mine uranium and thorium, owning materials, refining the ores, and constructing and operating plants necessary for the use of nuclear power [2]. The plan was passed by the Commission, but not agreed to by the Security Council because the Soviet Union (USSR) abstained. Stalin was suspicious of the Western Powers and aware that he could almost always be outvoted in the UN. Debate on the plan continued into 1948, but it was soon clear that an agreement was unlikely.

1.2. Atoms for peace

In 1949, the USSR became a nuclear power, the United Kingdom in 1952. East and west, which had been allies only ten years ago, were now adversaries. In this menacing situation US President Eisenhower said in his highly regarded speech on 8 December 1953 in front of the UN General Assembly: "To the making of these fateful decisions, the United States pledges before you – and therefore before the world – its determination to help solve the fearful atomic dilemma – to devote its entire heart and mind to find the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life."[3] Eisenhower succeeded in conveying a spirit of comfort to a terrified world that the horror of Hiroshima and Nagasaki would never to be experienced again. He promoted the idea that "the governments principally involved"[3] (explicitly including the Soviet Union) should transfer fissionable material from their stockpiles to an "International Atomic Energy Agency" [3], set up as part of the UN. This Agency should then make use of the material "to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind [and …] to apply atomic energy to the needs of agriculture, medicine and other peaceful activities." [3] The idea of the IAEA was born.

But in other ways, the speech also laid out the "Rules of Engagement" for the Cold War which had already begun. Eisenhower spoke of "swift and resolute reaction" [3] to any aggression as well as the "great retaliation capability" [3] of the US, through which "an aggressor's land would be laid waste." [3]

President Eisenhower addresses the UN General Assembly on 8 December 1953

Photo: IAEA/United Nations

1.3. Founding the IAEA

Seal of the IAEA

Photo: IAEA

The world gave merit to Eisenhower's idea. Let alone the fissionable material bank was found too difficult to implement [4]. In 1956, the eight-nation-group of USA, United Kingdom, France, Canada, Australia, South Africa, Belgium and Portugal, enlarged by the USSR, Czechoslovakia, India and Brazil to a twelve-nation-group [4] laid down the statutes of the new agency (based on a draft of the eight-nation-group) which included:

- Research and development of nuclear energy for peaceful purposes (Article III.A.1) [4]
- Foster the exchange of scientific and technical information (Article III.A.3) [4]
- Establish and apply safeguards to ensure that any nuclear assistance or supplies with which the IAEA was associated should not be used to further any military purposes – and apply such safeguards, if so requested, to any bilateral or multilateral arrangement (Article III.A.5) [4]
- Establish or adopt nuclear safety standards (Article III.A.6) [4].

On the proposal of the Soviet Union, the Statute required the IAEA to submit reports to the Security Council if, in connection with the IAEA's work, "there should arise questions that are within the competence of the Security Council [...] as the organ bearing the main responsibility for the maintenance of international peace and security" (Article III.B.4). This provision would thereby also enable the Soviet Union to exercise its veto in the Council if its interests required that (precisely what the Baruch plan had sought to avoid). [4]

When the twelve-nation group met, the USA put forward much more detailed proposals. The safeguards procedures it proposed were modelled on the safeguards prescribed in the numerous nuclear co-operation agreements that the USA was now concluding [5]. These safeguards were to become the substance of Article XII of the Statute as it was finally approved [4].

On 29 July 1957 the Statute entered into force, when 26 states (including those whose ratification was required) had deposited their instruments of ratification.

1.4. Emergence of the NPT

In the following years several new nuclear weapon states emerged; France tested its first nuclear weapon in February 1960, China followed in 1964. France supposedly also helped Israel acquiring atomic weapons during this period [6,7]. Foreseeing this development, Ireland proposed in 1961 an UN Resolution which called upon all states, especially the nuclear weapon states to negotiate an agreement of non-proliferation [8]. The resolution was adopted unanimously.

The Cuban Missile Crisis two years later showed the world the urgency of reaching a consensus for dealing with nuclear weapons in non-Nuclear-Weapon-States. Meanwhile the Twelve-Nations-Group was enlarged to be the Eighteen-Nation-Disarmament-Committee (ENDC).

In January 1964, the USA and the USSR each proposed an agenda for the ENDC in Geneva. Their proposals had four subjects in common, one of them being a nuclear non-proliferation treaty which had been agreed upon as the primary goal of the conference by 1965 [9]. It was agreed that any state which would have manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January 1967 would be referred to as a Nuclear Weapons State (NWS) [10]. The main purpose of the treaty was to bind both NWS and NNWS so that the former would not proliferate any kind of nuclear explosive device or any kind of control over those to the latter and the latter would not accept such proliferation from any vendor and would refrain from developing such devices themselves [11]. After many consultations, the US and the USSR agreed, that the treaty should require all NNWS to accept the safeguards of the IAEA [12]. Meanwhile, the NNWS insisted that the treaty should impose obligations on the NWS to reduce, and later eliminate their nuclear weapons and should ban all nuclear tests [13].

Leading industrial NNWS pushed for formalisation in that the treaty would not hinder economic development or nuclear trade. Additionally their access to advanced nuclear technologies such as enrichment and reprocessing could not be allowed to be blocked [14]. As an incentive for developing countries to join the treaty it was assured that their needs for nuclear technology [15] as well as their participation in every benefit of peaceful application would be granted [16]. The treaty was opened for signature on 1 July 1967 and entered into force on 5 March 1970. Today all members of the UN are members of the NPT; except Israel, India, Pakistan and North Korea (DPRK).

2. NPT in action – Successes and Failures

2.1. The Cold War era

For over thirty years after its introduction in 1957, the IAEA remained essentially irrelevant to the nuclear arms race [17]. However, the block-building with the two hegemonic superpowers, both of them concerned about proliferation (at least about the other side proliferating), ensured that the NPT system was fairly stable during the time of the Cold War. Even though brinkmanship was an often used strategy in foreign relations, it was almost never implemented in nuclear matters. "Going to the brink" of total annihilation was simply too dangerous. The Cuban missile crisis in 1962 had shown that to everyone.

During the same year, President John F. Kennedy predicted gloomily that by the end of the century 15-20 new nuclear powers would exist [18]. And there were also many who saw the NPT already dead or futile from the beginning on, like an anonymous official who lamented in 1968 that…

> *"The Treaty appears in some ways to be a negation of history. All people with the knowledge and resources they needed have progressed through evolutions and revolutions in industry, transport and weapons; from the manual to the machine, from sailing ships to steamers, from the oxcart to the aeroplane, and from the club to gun and bomb."* [19]

But as we know today, the stability due to the delicate balance of the Cold War era provided the framework that the NPT allowed to work perfectly. Up to 1967 there were a total of five nuclear powers, and in 1990 there was only one more, India, which had never been party to the NPT; far less than President Kennedy predicted, thanks to the NPT-regime. Instead, a lot of states disbanded their nuclear ambitions or dismantled their military programs. The latter took place in Algeria [20], Argentina, Australia, the Republic of Korea, Sweden, Brazil, Canada, Egypt, Switzerland, the Republic of China (Taiwan), and Yugoslavia [21]. The former happened i.e. in Italy, Germany, Japan and Norway [21]. Likewise, the former Soviet republics Ukraine, Belarus and Kazakhstan abandoned their inherited weapons and joined the NPT as NNWS. All these states could today have been Nuclear Weapon States for long. The reason that this did not happen is among others the existence of the NPT and this is one of its greatest and most unnoticed successes.

In this context also the case of South Africa should be mentioned, which is the only country that developed nuclear weapons by itself and later dismantled them. In the years following 1989 the state closed down its military programme, subsequently disassembled its already existing bombs, and

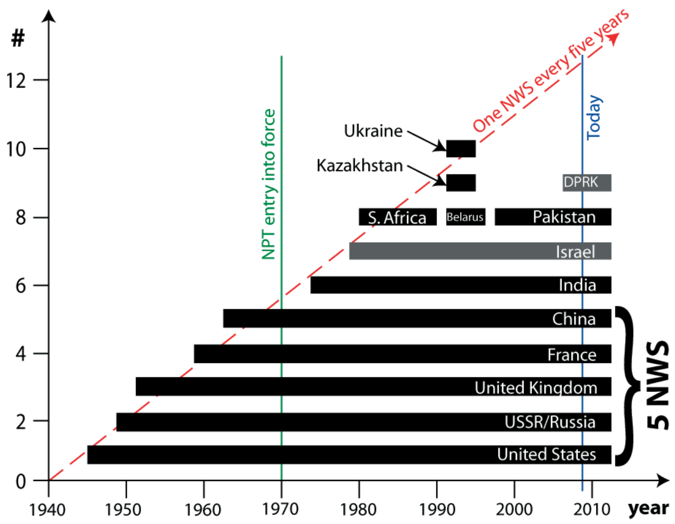

Figure 1: Nuclear Powers and Proliferation over the last 60 years. Status of weaponization of Israel and North Korea is uncertain (hence marked grey)

placed everything under IAEA safeguards. Although this seems to be correlated with preparations for the transition of power to the African National Congress, the instance is very noteworthy.

The following chart shows the proliferation over the last sixty years. The decline in rate after the entry into force of the NPT is remarkable. If this had not taken place, today there would be more than 12 nuclear powers (whereas the linearity is an altogether optimistic assumption).

Consequently, the available data point to a forty-year decline in the rate of proliferation [22].

2.2. Iraq

Following the 1990 Gulf War came the first real challenge for the NPT and with it for the IAEA. By the cease-fire resolution No. 687 in April 1991 the IAEA was requested to scrutinize the Iraqi nuclear programme and to close down everything. But it was a much longer way than the Security Council (and most other people) initially thought.

Iraq had joined the NPT in 1970 and had concluded a safeguards agreement with the IAEA. The international community back then was convinced that NPT NNWS would remain committed to their pledges, and thus, the Agency's role would simply be the verification of declared nuclear installations and materials of the State [23]. The mistake was to overlook that the verification system lacked measures aimed at detecting if a state was trying to deceive the system via the conduct of undeclared activities [23].

So, in 1991 inspectors had comprehensive rights to ensure their success. For the first time ever, inspectors had access to every site and every person whenever they wanted, and they were backed by the international community every time Iraq did not comply. They found a lot of evidence for the weapons programme; most disturbing they found it at the very places and in the very buildings which they had inspected so many times earlier which had then been cleaned out in preparation for their visit [23].

The consequence was an initiative to provide this meaningful verification system, which came to be known as safeguards under an additional protocol agreement [24] which is now the standard verification procedure in most countries.

Therefore, in summary, Iraq cheated and the NPT-regime could not prevent it, but had to be adjusted to the situation. The same had also happened in 1974 after the Indian nuclear test with the introduction of full scope safeguards. One can argue, already something bad will always have happened before the system adapts. But in reality, no regime will ever be perfect, will ever rule out every possibility of misuse. So truly it is a real strength of the NPT-regime that it can adapt to new challenges instead of collapsing when faced with a crisis. Damage followed by repair and growth is usually associated with robust systems [22]. Failing systems, in contrast, do not respond to challenges and therefore grow weaker and fall [22]. But Iraq also showed a second important issue: how crucial political and technical support from outside was to the success of the inspectors. During those years when the Security Council and its member states backed the IAEA without reservation, great progress was made. At the turn of the millennium this crucial support crumbled and the world went blind. It took four years till the inspectors came back. They found no new developments nevertheless, but the world chose not to believe them; so the US-led coalition had to find out the hard way that there were no nuclear activities left in Iraq.

2.3. Nuclear Brinkmanship – North Korea

Basically the same underlying problem – diversity of opinions inside the Security Council and lack of back-up for the IAEA makes the Iranian and Korean situations as difficult as they are. With respect to all differences between both processes, the reasons why both states could often exploit their positions are discrepancies inside the Security Council.[1] Therefore, we will only discuss some aspects of the problem of North Korea; most of the conclusions drawn from that will also work for the case of Iran.

Kim Jong-Il
Photo: Wikimedia Commons

In 1961, North Korea started with assistance of the USSR the construction of the Nyongbyon Reactor Complex, which was finished 3 years later. A reprocessing facility for extracting Pu from spent fuel rods was added to the graphite moderated reactor some time after that. Finally in 1985, the state joined the NPT but did not conclude a safeguards agreement until May 1992. Two years later the DPRK left the IAEA whose member it was since 1974 and developed the opinion that the safeguards agreement was therefore not really binding anymore. The crisis

1 The differences are of course profound; Iran denies developing nuclear weapons while N. Korea claims to have tested one. But the patient reader will see that those differences are of no great impact to the conclusions drawn.

could only be defused when US President Clinton aided by Peace-Nobel-Laureate Jimmy Carter, claiming a huge victory, appeased the DPRK's quest for a nuclear weapon by promising goods and two light-water reactors, all in all about US$ 5bn worth. All over the world this deal was seen as a cave-in and a huge blow to the NPT. If using graphite moderated reactors for Pu-production and researching weapons technology while being a NNWS party to the NPT was that rewarding, why should not others do it as well?

Moreover the deal did not hold very long. The US held back large parts of the deal while the DPRK was hedging bets by expelling the inspection teams and, depending on the current political situation, operating or shutting down facilities on nearly a weekly basis.

In 2003 after the 2002 "axis-of-evil"-speech of US-President Bush the situation escalated truly, with North Korea testing missiles and even withdrawing from the NPT.[2] In 2006 the DPRK even ignited a nuclear test explosion which fizzled in fact [26], but shook the world thoroughly nevertheless. Today the situation is certainly grave, but the fact that North Korea is signalling to use its nuclear capacities as bargaining chips indicate that the process back to a nuclear free Korean peninsula is not completely stuck.

But one more basic problem arises by dealing with Iran or the DPRK: How many parts of the nuclear fuel cycle can be entrusted to not really trustworthy states? If at all, on what legal basis can that restriction happen; certainly the NPT is unequivocal in putting all NNWS on the same level. Until recently, this question was not an issue at all; both the US and the USSR dealt with that question in their respective hemispheres by themselves. But now we have to answer the question one way or another.

Definitely, dealing with North Korea in the way that it has been done proved to be a failure. A failure of the NPT? One can see it that way, but then one should keep in mind that the Korean issue is also a clash of interests between China and the US. If the world's superpowers look upon proliferation and the NPT as to something negotiable, no regime can ever stop that.

2.4. Rehabilitation of India?

India did never sign the NPT. When the country ran its first nuclear weapons ("peaceful nuclear device") test in 1974, it became under the NPT-regime some sort of nuclear outcast. India was a nuclear weapon state without being able to count as such under the rule of the NPT. Therefore the world demanded over decades India's renunciation of nuclear weapons to be able to trade again nuclear materials and technology. Meanwhile, the world's largest democracy has become a very important trading partner for the international economy. India's economic growth has few equals in the world, which also implies a growing energy shortage throughout the country. Not only in that respect India has similarities to China. Together, they house nearly half the world's population. Both have an immensely growing economy and are equally hungry for energy. But there is an important difference: although both of them are NWS, only China is a "legitimate" one and therefore only China can acquire nuclear materials and technologies to assuage its energy needs.

Of course, India is trying to acquire China's status as well. And because of India being an important market as well as a strategic counterweight in Asia against China, the United States are currently supporting that quest. Alone in 2006 almost US$ 9bn were committed to power projects, including 9354 MW_e of new generating capacity, taking forward projects to 43.6 GW_e and US$ 51bn overall [27]. However by trying to give India a special exemption, the US are threatening the NPT's carrot-and-stick approach which until now has dissuaded countries that are capable of building or buying nuclear arms from doing so; from South Korea to Turkey to Saudi Arabia [28]. Moreover, President Bush is threatening the very existence of the NPT by undermining the fundamental principles of the treaty. When it is possible for potent countries to simply circumvent or even dismiss limitations forced upon them by the treaty, who can expect any other country to still place faith in the NPT-system and obey its legislation?

Clearly, the NPT cannot work under such circumstances.

2 It is controversial if North Korea's withdrawal is effective, because North Korea announced its withdrawal from the NPT effective as of 11 January 2003. No agreed statement on the matter has been issued by the NPT States Parties, or by the NPT depositary States (Russia, UK and USA), or by the UN Security Council. (Article X.1 of the NPT states that a State Party in exercising its national sovereignty has the right to withdraw from the Treaty... it shall give notice of such withdrawal to all other Parties to the Treaty and to the United Nations Security Council three months in advance... [and] shall include a statement of the extraordinary events it regards as having jeopardised its supreme interests.) The IAEA is not a party to the NPT and hence it is not in the position to determine the status of any State Party's membership of the Non-Proliferation Treaty. NPT States Parties´ comprehensive safeguards agreements with the IAEA provide that such agreements would remain in force as long as the State is party to the Non-Proliferation Treaty.[25]

2.5. The NPT-Review-Process

Since the NPT's entry into force, every five years a Review Conference was held. In the seventies and eighties, Cold-War issues like the nuclear arms race, SALT, the ABM-Treaty, etc. were debated. The need for a Comprehensive Test Ban Treaty (CTBT) was formulated and later, after negotiation in the Conference on Disarmament (CD), implemented. From the eighties on, several NWFZ's (nuclear weapons-free zone) were formed. But from the first conference on, several issues could not be resolved. These are: (a) the treaty obligations to enter into negotiations on nuclear disarmament under Article VI, (b) nuclear cooperation under Article IV and (c) universality, or the case of Israel, Pakistan and India.

After the end of the Cold War, many demanded rethinking and saw the unique chance to solve all three problems together. But it proved to be more difficult. Therefore, and because of frustration about delays in CTBT-negotiations, the 1990 Review Conference reached no final declaration.

Five years later, again no final declaration could be reached, but several decisions had been made beforehand nevertheless. It was decided upon "Strengthening the Review Process of the Treaty"[3] [29], "Principles and Objectives for Nuclear Non-Proliferation and Disarmament" (which included concluding negotiations for a CTBT no later than 1996, a FMCT[4] and systematic and progressive efforts to reduce nuclear weapons, with the "ultimate goal of eliminating those weapons") [30], indefinite extension of the Treaty [31] and a Resolution on the Middle East, which calls for conclusion of a NWFZ by all states located there and universal adherence to the NPT [32].

In 2000, the next Review Conference was then the first to adopt a final resolution since 1985. The document included the so-called "Thirteen Practical Steps" for the systematic and progressive efforts to implement Article VI. These Steps require inter alia [33]:

1. Earliest possible entry into force of the CTBT
3. FMCT, negotiated at the Conference on Disarmament (CD)
4. Establish a mandate so that CD will deal with nuclear disarmament
5. Implement the principle of irreversibility with respect to nuclear disarmament, arms control and reduction measures
6. Undertake unequivocally to accomplish the total elimination of nuclear arsenals, leading to nuclear disarmament
7. Early entry into force of START II and conclusion of START III a.s.a.p., while preserving and strengthening the Anti-Ballistic Missile (ABM) Treaty
9. A diminishing role for nuclear weapons in security policies to minimize the risk of their usage
10. Place excess weapon fissile material irreversibly under IAEA or other international verification arrangements to ensure that such material remains permanently outside military programmes
13. Develop further verification capabilities

These measures all had the support of the United States at the time of their adoption. But that changed in January 2001 when the Bush administration took office. The US left the START talks and withdrew from the ABM-Treaty.

Consequently, the next Review Conference in 2005 was characterized by the US blocking negotiations on the disarmament commitments made in the previous conferences and the NAM[5] reacting accordingly with an equally uncompromising stance. Two other long standing problems also troubled the conference: the issue of Iran and the inherent problem of Article IV benefits for NNWS as well as the Middle-East-Situation created by Israel's unwillingness to abandon their (unofficial) weapons and to accede to the NPT as a NNWS. The latter was pushed forward by Egypt. Especially Iran sought to confront the US directly[6]. The conference remained tied up in quarrelling about procedural issues over a long time and therefore no agreement on a substantial final document (just a summary of conduct) was reached. Canada's Ambassador Meyer spoke for many when he said in his closing statement: "We have let the pursuit of short-term, parochial interests override the collective long-term interest in sustaining this Treaty's authority and integrity."[34]

3 Also in the year directly following a Review Conference there would be held a Preparatory Committee [29]

4 Fissile Material Cut-Off-Treaty

5 Non-Aligned-Movement, one of the three major political groups at the Review Conferences; the others being Western Group and Others (WEOG) and the Eastern Group.

6 Iran presented a 'list of eight examples' demonstrating "the abysmal record, achieved unilaterally by the United States in the short span of five years (that) testifies to a mentality which seeks solutions solely through demonstration of power." (Source: www.un.org)

3. Conclusions

The NPT-regime was a great success-story for over 30 years. Most of its achievements have gone nearly unnoticed, but they are real nevertheless. There are, in fact, fewer states seeking nuclear weapons today than at any point since World War II [22]. During the time when the NPT was formed, the situation was much worse. The number of countries seeking nuclear weapons capabilities was a lot higher and the quality of the resulting threat incomparable to the problems of the present. As threatening as it may seem that DPRK or Iran might seek to be nuclear weapons states, policy makers from decades past found themselves in a far more threatening situation in terms of proliferation [22].[7] In the 1950s and 1960s, the number of countries interested in acquiring nuclear weapons was roughly twice as high as in the subsequent three decades altogether [22]. To summarise, the NPT significantly reduced the number of countries seeking to acquire nuclear weapons.

Another often missed fact is the role the NPT played in the change of public perception of nuclear weapons over the years. In the 1960s, for any power "to be of importance" meant having nukes. Nuclear weapons were a part in every tactical military environment, it was expected that in limited conflicts, too, small nukes would actually be used. Nuclear weapons were not only a strategic deterrent; they were used for surface-to-air missiles, depth charges, recoilless rifles and even demolition packages.[8]

Today, few armies would employ those kinds of weapons (especially if they are to be used first) in any tactical context outside their utilization by certain strategic plans[9] (like SIOP[10]). Countries still trying to acquire nuclear weapons are outcast in the international community; they are called "rogue states". In other words, there is a wide consensus that it is decidedly immoral and exceptional to newly obtain such weapons. The mental and normative conception of proliferation changed in the decades following the NPT's entry into force [22].

However, it would be short-sighted not to mention the flaws and failures of the NPT-regime. First of all, it is repressive in its haphazardly selection of "haves" and "have-nots" without leaving any possibility of "advancement" (if we can call it that) between the different castes. But more to the point, the class of NNWS is practically divided into several groups of states, which enjoy different levels of freedom in dealing with nuclear issues. Nothing in the treaty justifies for example the discrepancy of Germany or the Netherlands using the very latest in centrifuge technology while denying Iran even the basics. The difference between the democratic principles of the NPT and their implementation discourages many countries which do not belong to the group of First-Class-NNWS. Article IV obviously seems to be valid only for some parties of the treaty; instead of all. This does not mean necessarily that Iran should get full access to the fuel cycle and its technology. But a legally profound basis for differentiation has to be built.

Second, the NPT-community fails to overcome the imbalance imposed to national security by nuclear weapons. Those weapons are the ultima ratio of national security to all their possessors and an implicit threat to everyone else. The idea of NSA[11] tries to tackle that. But after banning chemical and biological WMD's, nuclear weapons are the sole credible assurance for military unassailability of their possessors' homelands. Obviously that is something not to be given up lightly. But on the other hand, the equalization of both threats and securities is a non-negotiable condition for the NNWS.

All NWS have adopted the obligation under Article VI of the treaty "to pursue negotiations in good faith […] on general and complete disarmament under strict and effective international control" in exchange for the NNWS' abdication of those weapons. None of the five NWS has honoured this obligation. Every arms-control agreement as yet was more of a cost-restriction programme than of real disarmament. There are still over 25.000 nuclear warheads in the arsenals of the five NWS [37] and there is no indication that this will significantly change in the near future.

Thirdly, the NPT has never incorporated ways of dealing with international terrorism and black mar-

7 In context, it is difficult to imagine a more threatening possibility than the 1960s concern that China under Mao would get the bomb. Mao had said that nuclear weapons were paper tigers, that China could fight and survive a nuclear war, and that he would share nuclear weapons technology with other poor countries. In response, US policy makers explored a preventive nuclear attack in concert with the Soviet Union and considered sharing of US nuclear weapons with India or Japan in order to balance against the Chinese bomb.[35, 36]

8 For example the US M-388 Davy Crockett w/ Mk-54 warhead (1 to 20kT yield) or the W54 SADM

9 There are the examples of Russia thinking about using battlefield Nukes in the 2nd Chechnya war or the US developing nuclear tipped bunker-buster ammunition. But the former refrained from the use for political reasons while in the latter case Congress stopped the program. So, in both cases it did not happen, which is of course the point.

10 Single-Integrated-Operations-Plan (SIOP); US, "the plan for World War III". Now officially renamed CONPLAN.

11 Negative Security Assurance

kets, some say the greatest challenge to the present. That is, because the NPT obviously deals only with nation-states. Still, non-proliferation efforts and the number of NWS which the NPT has controlled for a very long time are paramount for combating these threats. Less NWS mean fewer opportunities for terrorists to steal their material and knowledge. Less NWS should also mean less black marketers. It is very hard to imagine that a network like that of the infamous A. Q. Khan, which would have been wholly unconnected to a weapon state would have been as successful as Khan was [22].

However, the biggest challenge for the NPT will be how the issue of non-proliferation will be handled in the future. The question of unilateralism versus multilateralism will decide, if the NPT has any future at all. The Treaty has proven its worth and it has succeeded many times in the past. It can also do that in the future; whether it will or will not prevail, lies in the hands of a few global players, above all the United States. They have sponsored and backed the Treaty for many years. Without their support the Treaty will most definitely collapse. Moreover, there are certain indications that neo-conservative strategy wants to achieve exactly that [38].[12] It remains doubtful notwithstanding, if this path would really assuage US needs for non-proliferation in the long term; especially with their current low of moral acceptance in the world. Fortunately, there are some signs that change is beginning to happen though.[13]

Non-Proliferation and eventually nuclear disarmament can only work if all states concerned work together and link their actions, acquiring mutual trust and collaboration. Unilateralism, even if sometimes beneficiary in the short term – if used widely – will carry the world into a new era of dangers of unimagined magnitude.

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12 The institution of the NPT formalizes rewards and punishments, but responsibility ultimately rests with the great powers to mete them out. In this respect, the US-India agreement is perhaps an ideal case study for international relations realists. It demonstrates the often illusory force of institutions like the NPT, which codify rather than constrain the dominance of the most powerful states. The United States can sidestep the NPT framework when it wishes because the NPT has little force without US backing [38].

13 U.S. President Elect Barack Obama pledged during his Presidential campaign to "set a goal of a world without nuclear weapons, and pursue it."[39]

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Technical sheets

Integrated Safeguards in the Non-Nuclear Weapon States of the European Union

This Technical Sheet briefly describes the evolution of safeguards in the European Union from the 1950s to the present day.

The 1957 Treaty establishing the European Atomic Energy Community ('EURATOM Treaty') requires that the European Commission applies nuclear safeguards to make certain that nuclear materials are not diverted to purposes other than those for which they are intended. The means by which these safeguards objectives are achieved are essentially:

- A requirement for the operators on nuclear installations to provide the Commission with information ('Basic Technical Characteristics') describing the location and intended activities of the installation;
- A requirement that operators keep and report nuclear materials accountancy records;
- Provision for the Commission to inspect the installations and records; and
- Provision for the imposition of sanctions by the Commission in the event of infringement of safeguards obligations.

The safeguards reports required from operators are described in European Commission Regulation (Euratom) No. 302/05.

On the global international scale, nuclear safeguards are implemented by the International Atomic Energy Agency (IAEA), which aim to verify that a State uses nuclear energy for only peaceful purposes.

'Comprehensive' IAEA Safeguards

Following the conclusion of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1968, the IAEA was charged with verifying the 'peaceful use' commitments made under the Treaty. It also took on a similar role under other international agreements. These commitments require non-nuclear weapon States (NNWS) to conclude a 'comprehensive' safeguards agreement with the IAEA based on a model agreement described in IAEA (Information Circular) INFCIRC/153. These safeguards agreements submit all nuclear material in the State to the scrutiny of IAEA safeguards inspectors.

The NNWS of the European Union (EU) are subject to a single comprehensive safeguards agreement with the IAEA and Euratom, INFCIRC/193. Safeguards in the EU are undertaken on a Joint Team (Euratom/IAEA) partnership approach, designed to minimise the safeguards burden on nuclear plant operators whilst ensuring that both Inspectorates are able to meet the goals of their respective safeguards regime.

Developments in Iraq and in the Democratic People's Republic of Korea (DPRK) in the 1990s revealed shortcomings in 'comprehensive' IAEA safeguards, by drawing attention to the fact that the effectiveness of the safeguards regime was, at least in part, dependent upon States acting in good faith in declaring all their holdings of nuclear material and related activities (i.e., IAEA's verification of all State-declared nuclear materials and activities). The IAEA subsequently developed an improved system of safeguards aimed at increasing safeguards effectiveness (i.e., a strengthened ability to detect undeclared nuclear materials and activities) and efficiency (e.g., improved administrative arrangements). Some features of the improved system are implemented under the existing legal basis of INFCIRC/153 safeguards agreements, but others have required new legal authority.

<u>IAEA Additional Protocol</u>

The new legal basis is provided in the form of protocols additional to safeguards agreements, based on a Model Additional Protocol (IAEA document INFCIRC/540). There is a single additional protocol for the EU NNWS, INFCIRC/193/Add.8.

Under the Additional Protocol, States are required to provide the IAEA with broader information covering all aspects of their nuclear fuel cycle-related activities, including research and development and uranium mining. In the EU, some of these reporting requirements fall under the responsibility of Euratom to provide whilst others are the responsibility of States, although some States have delegated this responsibility to the European Commission. States must also grant the Agency broader access rights and enable it to use advanced verification technologies.

Specific measures provided for in an Additional Protocol include:

- information about, and access to, all aspects of States' nuclear fuel cycle, from uranium mines to nuclear waste and any other locations where nuclear material intended for non-nuclear uses is present;
- information about, and Agency inspector access to, a State's nuclear fuel cycle R&D activities not involving nuclear material;
- information on general plans for the development of the nuclear fuel cycle over the following ten year period;
- IAEA inspector access to any building on a nuclear site, within two hours of a request during a routine safeguards inspection;
- information on the manufacture and export of nuclear-related items;
- access to other nuclear-related locations; and
- collection of environmental samples beyond declared locations when deemed necessary by the IAEA.

With wider access, broader information and better use of technology, the IAEA's capability to detect and deter undeclared nuclear material or activities is significantly improved. This strengthened safeguards system, based on 'comprehensive' safeguards agreements and 'additional protocols' to those agreements, has established a new and higher standard for effective, co-operative verification of States' nuclear undertakings.

Integrated Safeguards

A key factor leading to the agreement of INFCIRC/540 was the understanding by States that the new measures would not simply be added to the 'traditional' measures implemented under comprehensive safeguards agreements (INFCIRC/153), but that the two would be combined in an optimal manner to achieve the maximum effectiveness and efficiency within the resources available to the IAEA to produce a so-called 'integrated safeguards system' that would be based on a State Level Approach (SLA). This would allow State-specific factors to be taken into account when drawing up the integrated safeguards approach, for example the strength and independence of a State's National Authority, which is known as the 'State System of Accountancy and Control' (SSAC). The Euratom Regional System of Accountancy and Control (RSAC) includes extensive accountancy and inspection activity, which should enable a highly effective integrated safeguards approach in the EU NNWS, with the potential to save significant IAEA resources.

Integrated safeguards includes a redefinition of safeguards implementation parameters, particularly for less sensitive nuclear material (e.g. depleted, natural and low enriched uranium and spent fuel), with corresponding reductions in the level of inspection effort on such declared material. For NNWS with both a comprehensive safeguards agreement and an additional protocol in force, the IAEA has the ability under the strengthened safeguards system to draw conclusions, and hence provide credible assurance, of both the non-diversion of nuclear material from declared nuclear activities (the focus of comprehensive safeguards agreements) and the absence of undeclared nuclear material and activities in the State as a whole (the focus of additional protocols). Once such credible assurance has been obtained for a State (which must be reaffirmed on an annual basis), an 'integrated safeguards' State level approach can be implemented in that State.

The details of the implementation of integrated safeguards in the EU NNWS at the different types of nuclear installation are described in IAEA/Euratom 'partnership approach' papers. These are supplemented with facility-specific annexes where necessary.

Further information on the safeguards system of the IAEA including integrated safeguards can be found on the IAEA website at www.iaea.org.

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