SAFEGUARDS FOR GEOLOGICAL REPOSITORIES

XA0100058

A. Fattah
International Atomic Energy Agency,
Vienna

Abstract

Direct disposal of spent nuclear fuel in geological repositories is a recognised option for closing nuclear fuel cycles. Geological repositories are at present in stages of development in a number of countries and are expected to be built and operated early next century. A State usually has an obligation to safely store any nuclear material, which is considered unsuitable to re-enter the nuclear fuel cycle, isolated from the biosphere. In conjunction with this, physical protection has to be accounted for to prevent inadvertent access to such material. In addition to these two criteria — which are fully under the State's jurisdiction — a third criterion reflecting international non-proliferation commitments needs to be addressed. Under comprehensive safeguards agreements a State concedes verification of nuclear material for safeguards purposes to the IAEA. The Agency can thus provide assurance to the international community that such nuclear material has been used for peaceful purposes only as declared by the State. It must be emphasised that all three criteria mentioned constitute a 'unit'. None can be sacrificed for the sake of the other, but compromises may have to be sought in order to make their combination as effective as possible. Based on comprehensive safeguards agreements signed and ratified by the State, safeguards can be terminated only when the material has been consumed or diluted in such a way that it can no longer be utilised for any nuclear activities or has become practicably irrecoverable. As such safeguards for nuclear material in geological repositories have to be continued even after the repository has been back-filled and sealed. The effective application of safeguards must assure continuity–of–knowledge that the nuclear material in the repository has not been diverted for an unknown purpose. The nuclear material disposed in a geological repository may eventually have a higher and long term proliferation risk because the inventory is substantially large. Change in social, economic, environmental and other scenarios might demand recovery of nuclear and other material from the repository sometime in the future. To this end, the Department of Safeguards has developed a policy paper to guide the planner, designer and operator to incorporate safeguards related features, as appropriate. In parallel, a programme for the Development of Safeguards for Final Disposal of Spent Fuel in Geological Repositories (SAGOR) was launched to foster technological advancement. The mission of SAGOR has been to ensure that the safeguards systems developed for the final disposal of spent fuel effectively meet the objectives of IAEA safeguards, optimise IAEA resources, and make best use of existing technologies while still meeting the requirements for safety and environmental protection.

1. INTRODUCTION

Direct disposal of spent nuclear fuel in geological repositories is a recognised option for closing nuclear fuel cycles. Geological repositories are at present in stages of development in a number of countries and are expected to be built and operated early next century. Geological formation for direct disposal may include clay, crystalline rock, salt or tuff. The operational life of a repository is expected to be 20–70 years before it is finally closed, completely back-filled and sealed. The spent fuel in a filled repository is expected to contain 2000–200 000 tons of uranium and 20–2000 tons of plutonium. A repository would thus contain nuclear material of strategic interest creating a long term proliferation risk. Safeguards has to play a role in order to continually assure society of 'no diversion' under any circumstances.

Geological repositories for the disposal of spent fuel are being designed to ensure their isolation from the human environment for an extremely long period of time. This is being achieved by using engineered and natural barriers in order to prevent or reduce the migration of radio-nuclides stored in the repository. An adequately designed, constructed and located repository with such passive features is considered by safety experts to provide sufficient safety awareness during the hazardous lifetime of spent fuel. Nevertheless, there are arguments in favour of certain activities related to the repository post-closure phase. These activities are aimed at, for example, preventing or decreasing the likelihood of intrusion into the repository and providing additional assurance to the public.

To ensure a safe and reliable repository performance, spent fuel in repositories may remain retrievable for some time prior to back-filling and closure. A State may require that the spent fuel in a repository remains retrievable for several decades to provide ample time to evaluate not only the overall safety performance, but also future requirements of the fissile material contained therein.

A State usually has an obligation to safely store any nuclear material, which is considered unsuitable to re-enter the nuclear fuel cycle, isolated from the biosphere. In conjunction with this, physical protection has to be accounted for to prevent inadvertent access to such material. In addition to these two criteria — which are fully under the State's jurisdiction — a third criterion reflecting international non-proliferation commitments needs to be addressed. Under comprehensive safeguards agreements a State concedes verification of nuclear material for safeguards purposes to the IAEA. The Agency can thus provide assurance to the international community that such nuclear material has been used for peaceful purposes only as declared by the State.

It must be understood that all three criteria mentioned constitute a 'unit'. None can be sacrificed for the sake of the other, but compromises may have to be sought in order to make their combination as effective as possible. Therefore, the design of a spent fuel disposal site which is largely dictated by environmental and physical protection requirements will also have to incorporate safeguards measures, not only during operation, but also after closure.

2. SAFEGUARDS OBJECTIVE

The objective of safeguards is the "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection." By applying a set of measures the Agency should be able to draw a conclusion on the non-diversion of nuclear material from declared activities and on the absence of undeclared nuclear material and activities, thereby providing the international community with credible assurance.

To this end, the effective application of safeguards for spent fuel in a geological repository, throughout the repository operation period and beyond, must assure continuity–of–

knowledge that the nuclear material in the repository has not been diverted for an unknown purpose.

3. CASE AND CONDITIONS FOR TERMINATION

The safety community has yet to fully estimate the wisdom of implications of non-proliferation undertaking of nuclear commitments and hence has tried to argue for termination of safeguards for all nuclear material including spent fuel disposed in geological repositories.

INFCIRC/153 (Corr.), the basic model safeguards agreement for States party to the Non-proliferation Treaty, provides three circumstances under which nuclear material safeguards may be terminated. The versions given here paraphrase the actual text.

- Article 11 provides for termination upon a determination by the Agency that nuclear material subject to safeguards has been consumed or diluted in such a way that it can no longer be utilised for any relevant nuclear activity, or has become "practicably irrecoverable".
- Article 12 provides for termination when nuclear material has been transferred out of the State and the recipient State has assumed responsibility.
- Article 13 provides for termination, by mutual agreement, when nuclear material is used for non-nuclear purposes such as alloys or ceramics.

Article 35 of INFCIRC/153 (Corr.) also deserves attention to note that "where the conditions of (Article 11) are not met, but the State considers that the recovery of safeguarded nuclear material from residues is not for the time being practicable or desirable, the Agency and the State shall consult on the appropriate safeguards measures to be applied." The Agency's Legal Division interprets that Article 35 does not permit the Agency to terminate safeguards where the conditions of Article 11 are not met.

Based on these requirements, safeguards can be terminated only when the Agency determines that the material has been consumed or diluted in such a way that it can no longer be utilised for any nuclear activities or has become practicably irrecoverable. In the event that safeguarded nuclear material cannot be considered to be practicably irrecoverable, the State and the Agency may apply appropriate safeguards measures.

At this point, one may ask for an accommodation to define technical criterion based on the "consumed", "diluted" or "practicably irrecoverable" attributes which could qualify spent fuel to be withdrawn from the nuclear fuel cycle. Spent fuel in storage facilities either at the reactor site or away–from–the–reactors which is used for interim storing, cooling and conditioning until suitable repositories are available does not meet the requirement of being "practicably irrecoverable". Spent fuel placed in any form of interim and retrievable storage facilities remains accessible and nuclear material therein can be recoverable. Spent fuel stored for a long time after discharge becomes more easily recoverable as radioactivity decreases considerably after several decades and plutonium extraction becomes more feasible.

Geological repositories would be the source of large quantities of plutonium and other potentially valuable elements. Changes in institutional system and social needs may provide incentives for recovery of spent fuel for energy generation or as sources of other minerals. The possibility to recover nuclear material exists even following closure of a permanent geological repository and any country which emplaces spent fuel could at any given time retrieve it. The same technology, skill and effort are required for emplacement as well as retrieval and advancement in mining technology will even make it easier. Should a State be intent on diverting material contained in fuel elements and deposited permanently in a geological repository, there is no conceivable way of making the material irrecoverable.

We are, therefore, confronted with a very fundamental question, i.e. to what extent should safeguards on spent fuel be continued? However, before deciding the fundamentals of a safeguards policy, the safety issues may be examined more carefully.

4. SAFETY ISSUES AND SAFEGUARDS IMPLICATIONS

Experts have argued that a number of basic safety considerations should be fulfilled for safe operation of geological repositories. The safety issues and their interpretation may be revisited or expanded in the light of safeguards issues for advancing an integrated approach.

Safety of future generations

Radioactive waste shall be managed in a way that predicted impacts on the health of future generations do not exceed levels that are acceptable today. This principle is derived from an ethical concern for the health of future generations. In order to ensure the protection of human beings in the future, radioactive waste should be isolated from the human environment over extended periods of time and, while it is not possible to ensure total containment indefinitely, the intent is that there will be no significant impacts when radionuclides enter the environment. In deep geological repositories, isolation will be achieved by a system of barriers surrounding the spent fuel — some engineered (the waste canister and the back-fill material) and some natural (the geosphere and the biosphere). The concept of barrier is also applicable for assurance of non-diversion of the material content. While the safeguards consideration involves control down to a few kilograms, safety concerns demand attention to the microgram level.

Burdens on future generations

Radioactive waste shall be managed in a way that limits burdens on future generations. The ethical basis for this principle is the premise that the generation that produces waste should bear the responsibility for managing it and assure safety for future generations. Considerations of importance to safety or a burden on safety are primarily of an economic and social nature. Non-proliferation is a veritable concern and hence a burden that would eventually be inherited by future generations. It cannot be eliminated but can be controlled by a sound safeguards approach.

Responsibilities of the present generation

Nevertheless, safety experts have identified responsibilities of the present generation including (i) development of the technology, (ii) construction and operation of the facility, and (iii) provision of funds for adequate control and plans for management of radioactive waste. These developments would help to ensure an effective safeguards regime.

Institutional control

Safety prescribes that the management of radioactive waste should, to the extent possible, not rely on long term institutional arrangements or actions as a necessary safety feature, although future generations may decide to utilise such arrangements, for example, to monitor radioactive waste repositories or retrieve radioactive waste after closure has been effected. The identity, location and inventory of a radioactive waste disposal facility should be appropriately recorded and the records maintained.

Long term in safety interpretation is extremely long, some thousands or millions of years ahead, making it beyond any prediction or interpretation of nature or concept of institutional control. It is expected that near-term experience with safety (and safeguards) practice along with technological advancement will dictate the nature of institutional control to be adopted. A number of near-term safety measures would be able to provide assurance of non-diversion of nuclear material. Uncertainties related to institutional and technical development probably will require that safeguards for geological repositories, once established, be re-evaluated from time to time.

Integrated approach

It is important that once a repository has been closed and sealed that it is not disturbed in a way which could impair its safety barriers. For repositories containing spent nuclear fuel (and possibly also for those containing high level wastes) safeguards are to be continued in order to prevent possible diversion of nuclear materials for use in weapons production. A possible issue concerns the nature of the safeguards needed for repositories and, in particular, whether that would disturb the passive safety features of a repository. It is expected that safeguards measures take into account safety considerations. Safeguards requirements are also mutually beneficial for waste management safety, e.g. the proposed long term surveillance of closed repositories, would place a burden on future generations, but on the other hand would benefit safety assurances. Various consultations with international experts on both disciplines have recommended that in order to ensure that safeguards requirements are developed which are compatible with plans for long term isolation of radioactive waste, safeguards and waste disposal safety experts should work in close co-operation.

5. DEFINING A SAFEGUARDS POLICY FOR SPENT FUEL

In view of various technical, social and political concerns, the IAEA has taken the initiative to develop an international consensus on the future policy of safeguards for spent fuel placed in permanent geological repositories. An Advisory Group Meeting on *Safeguards Related to Final Disposal of Nuclear Material in Waste and Spent Fuel*, held at IAEA Headquarters in September 1988, was attended by 43 representatives from 17 Member States and Euratom. Discussed at length was the basic issue of whether mere placement of spent fuel in a geological repository — or perhaps whether some added characteristic of the repository or degree and method of conditioning — would make the spent fuel practicably irrecoverable. It was recommended that:

> *Spent fuel does not qualify as being practicably irrecoverable at any point prior to, or following, placement in a geological repository, or even after closure of the repository, and the IAEA should not terminate safeguards on spent fuel.*

Further meetings were held to fully elaborate on this basic recommendation contributing to the development of an IAEA policy for spent fuel disposal in geological repositories. It is expected that this will provide sufficient guidance to identify safeguards measures beginning with the planning and design phase, in particular: to indicate the requirements to be used for the application of safeguards, to ensure that these requirements are integrated into the repository design and to permit adherence to these requirements during the construction and operation of the repository in order to establish an effective and efficient safeguards system.

6. HIGHLIGHTS OF THE POLICY

Spent fuel disposed in geological repositories is subject to safeguards in accordance with the applicable safeguards agreements. Safeguards for such material are to be maintained after the repository has been back-filled and sealed and for as long as the safeguards agreement remains in force. The safeguards applied should provide credible assurance of non-diversion and absence of any undeclared activities.

The safeguards systems must meet rigorous system specifications and standards in order to function for a very long time period with minimum or no service, perhaps in a rugged environment and preferably in an unattended mode. Since emplaced spent fuel cannot be re-verified, sufficient redundancy, diversity and robustness should be incorporated into the safeguards system and adequate maintenance measures applied to avoid system failure and ensure continuity–of–knowledge. The safeguards systems for a repository will be based on an integrated safeguards verification system (ISVS) and design information verification (DIV) to confirm that no nuclear material is removed by any declared or undeclared access routes; and maintenance of continuity–of–knowledge on the nuclear material content.

An ISVS will be applied to verify transfer, flows and inventory of the spent fuel disposal containers and to maintain continuity–of–knowledge on the nuclear material. It should be comprised of elements of containment and surveillance (C/S), monitoring and non-destructive assay (NDA) systems, as well as DIV along with geophysical, environmental and radiological systems, as applicable. An ISVS should have the capability of functioning, as far as is practicable, in automated, remote control and remote data transmission modes. An ISVS should have high system reliability and capability to detect component failures and to notify the IAEA in a timely manner of such failures, preferably by remote transmission.

DIV constitutes an important safeguards measure during the pre-operational and operational phases. DIV should confirm the design of the geological repository and detect any undeclared modifications and activities, both in the repository and in its vicinity. The IAEA should verify that the excavation areas are as declared and that there are no undeclared excavations. As the repository design will change during excavation, for example to adapt to geological findings, the application of DIV must be a flexible, ongoing process. During the operational phase, the IAEA should also provide assurance of the absence of undeclared underground reprocessing and assurance of no undeclared operational capability underground which could mask the substitution between containers.

Once the repository is closed and sealed, safeguards should consist of suitable surface monitoring measures to provide assurance of 'no access' to nuclear material, e.g. visual observation through photographic techniques or video-recording, remote surveillance including optical, satellite, geophysical and environmental techniques. These measures should be adapted to site specific requirements. Upon request by the IAEA, the State should provide access to any building or to any location at the geological repository site or to any location outside a geological repository site which the IAEA considers might be functionally related to the geological repository. Arrangements should be made with the State for advance notification to the IAEA of any: a) intention to access the sealed geological repository after final closure; b) intention to retrieve the spent fuel from the geological repository; c) intention to retrieve any other material from the geological repository; and d) tunnelling, mining or blasting activities in the vicinity of the repository.

7. TECHNOLOGICAL DEVELOPMENTS INITIATIVE

In parallel, a programme for the Development of Safeguards for Final Disposal of Spent Fuel in Geological Repositories (SAGOR) was launched to foster technological advancement. The mission of SAGOR has been to ensure that the safeguards systems developed for the final disposal of spent fuel effectively meet the objectives of IAEA safeguards, optimise IAEA resources, and make best use of existing technologies while still meeting the requirements for safety and environmental protection.

In September 1991, following the recommendations of a Consultants' Meeting, the Director General announced the SAGOR task with participation of Member State Safeguards Support Programmes (MSSPs). Eight Member States (Belgium, Canada, Finland, France, Hungary, Sweden, UK and USA) participated in this task which began in 1994 and culminated in 1998 with the publication of a five volume report. A model safeguards approach has been developed for the different operations associated with spent fuel disposal, assessing diversion paths, addressing verification techniques and identifying R&D needs. The technical work was conducted by MSSPs; task management was provided by the IAEA. Important areas for future development work include a variety of geological techniques, e.g. satellite, seismic, radar, electromagnetic, acoustic and thermal. Use of environmental monitoring along with information analysis would detect any undeclared activities. Remote transmission of data would be able to reduce costs and provide early detection of diversion. However, these would require further development work in order to perform effectively in various geological environments.

8. CONCLUSIONS

Safeguards for nuclear material in geological repositories have to be continued even after the repository has been back-filled and sealed. The effective application of safeguards must assure continuity–of–knowledge that the nuclear material in the repository has not been diverted for an unknown purpose. The nuclear material disposed in a geological repository may eventually have a higher and long term proliferation risk because the inventory is substantially large. However, the safeguards measures must be flexible enough to respond to changing technological developments and to changing needs of current as well as future generations. Change in social, economic, environmental and other scenarios might demand recovery of nuclear and other material from the repository sometime in the future.

There are some generic features applicable to geological repositories, but detailed threat analysis, diversion strategies and safeguards approaches will need to be examined separately for each specific repository. The primary assumption on which the threats and diversion strategies for geological repositories are based is that spent fuel will be disposed only as verified nuclear material on which continuity–of–knowledge has been maintained.

Current development effort will have to be tuned with other factors such as:

- variation in geological formation — with consequent differences in excavation difficulties and scope for use of geophysical techniques;
- the technical concepts (e.g. repository layout, depth, potential for retrievability, time period for which the repository will be kept open);
- potential technological advancement in safeguards, safety and mining;
- socio-political factors (e.g. regarding the other institutional controls, the importance of safeguards in the distant future is not known);
- compliance with the principle of radioactive waste management; and
- climatic developments (e.g. periodic glaciations may make safeguards irrelevant).

Close co-operation between the IAEA and international community is the key to effective and efficient safeguards for such a complicated facility. In addition, participation of experts as well as advancement in other disciplines, namely safety, waste management, environmental protection, whose understanding of safeguards needs are indispensable, will have a significant role in geological repository affairs. Possible retrievability should be the guiding consideration in defining safe and proliferation resistant methods in geological repositories.

BIBLIOGRAPHY

FATTAH, A., LINSLEY, G.S., "Interface between Nuclear Safeguards and Radioactive Waste Disposal", International Nuclear Safeguards (Proc. Int. Symp Vienna, 1994), IAEA, Vienna (1994) 321-329.

INTERNATIONAL ATOMIC ENERGY AGENCY, The Agency's Safeguards System, (1965, as provisionally extended in 1966 and 1968), INFCIRC/66/Rev.2 (1968).

INTERNATIONAL ATOMIC ENERGY AGENCY, The Structure and Content of Agreements between the Agency and States required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (corrected) (1972).

INTERNATIONAL ATOMIC ENERGY AGENCY, Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected).

INTERNATIONAL ATOMIC ENERGY AGENCY, Advisory Group Meeting on Safeguards Related to the Final Disposal of Nuclear Material in Waste and Spent Fuel (AGM–660), STR–243 (Rev.) (1988).

INTERNATIONAL ATOMIC ENERGY AGENCY, Consultants' Report on Safeguards for the Final Disposal of Spent Fuel in Geological Repositories, STR–274 (1991).

INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management, Safety Fundamentals, Safety Series 111–F, IAEA, Vienna (1995).

INTERNATIONAL ATOMIC ENERGY AGENCY, Report of the Consultants' Group Meeting on Safeguards for the Direct Final Disposal of Spent Fuel in Geological Repositories, STR–305 (1995).

INTERNATIONAL ATOMIC ENERGY AGENCY, Issues in Radioactive Waste Disposal, IAEA–TECDOC 909 (1996).

INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards Policy Series, No. 15 (1997).

INTERNATIONAL ATOMIC ENERGY AGENCY, Report of the Advisory Group Meeting on Safeguards for Final Disposal of Spent Fuel in Geological Repositories, STR–309 (1997).

INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards for the Final Disposal of Spent Fuel in Geological Repositories, SAGOR Report Vol. 1–5, STR–312 (1998).

QUESTIONS (Q), COMMENTS (C) & ANSWERS (A) AFTER THE PRESENTATION

Q: You mentioned that some sorts of high level waste could remain under safeguards in the repository. What kind of high level waste do you mean?

A: Well, it would depend on the concentration level. According to the safeguards agreements it could be terminated only if it could be proved that it had been consumed or become practically irrecoverable. Suppose, for example, that you have an accident and you have an amount of material that has been leaked and now classified as waste. That would not be terminable because of the material concerned. The material has the potential to recover, if terminated, and diverted for non-peaceful purposes. Accordingly, the Agency, as I have explained, devised a set of criteria taking the concentration level into consideration. If HLW does not fulfil these criteria, safeguards has to be continued even after disposal in geological repositories.