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Overview of less advanced programmes and their requirements

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ABSTRACT

Geological disposal (GD) of radioactive waste is close to becoming a reality for Finland, Sweden and France. High-technology development and advanced knowledge has made it possible to defend the feasibility and the safety of such facilities, making the European Union a leader in the field. Other European countries are closely behind, developing high competence through advanced research programmes, research infrastructures and public engagement.

At the other extreme, there are countries whose GD programmes are at an early stage and no systematic research programmes exist. These include several new Member States but not the Czech Republic and Hungary, both of which have already initiated a siting process.

There are several common reasons for this delay in schedule: small and relatively younger nuclear energy programmes, return of the spent fuel (especially from research reactors) to the countries of origin, open fuel cycle concept (requiring at least 50 years of wet and dry storage). In this context, there has been little pressure on setting up an early GD programme. Currently their disposal concepts are only generic and in most of these countries need updating, taking into account the current socio-economic context.

However, some of these new Member States still aim to have a GD in operation within several decades, e.g. 2055 in Romania and 2067 in Slovenia. Strategic planning based on the experience of more advanced programmes shows the GD process should start immediately in order to be able to achieve these deadlines.

In this context, the implementation of the EC Directive 70/2011 gives the opportunity to progress the advancement of the GD process in these countries.

Keywords: Romania, geological disposal, New Member States.

Introduction

Major research activities in waste management in Europe are focused on the implementation of GD. Many EU Member States with a long history of operating Nuclear Power Plants (NPP) and running large nuclear power programmes are now facing the

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challenge of how to dispose of high-level waste and/or spent fuel (SF). 2025 has been set as the date for implementation of the first GD facility (IGD-TP, 2009). Finland, Sweden and France are at the forefront of this process.

At the opposite end of the disposal spectrum there are countries (such as Croatia, Greece, Lithuania, Poland, Romania, Slovenia, Slovakia) whose GD programmes are at a very early stage and no dedicated and systematic research programmes exist. The disposal concept is only generic and in most of these countries needs updating, taking into account the current socioeconomic context.

According to the current national strategies in these countries, SF and long-lived intermediate-level waste (LL-ILW) are currently in safe storage awaiting final disposal. In some cases a deadline for the commissioning of a GD facility is specified. This is foreseen for 2055 in Romania, 2067 or even 2087 in Slovenia and 2055–2060 in Poland and in order to achieve these deadlines their geologic disposal programmes must start now.

Implementation of GD has become even more important in the light of the requirements of the European Council Directive 2011/70/EURATOM ('Waste Directive'), which requests each Member State to define strategies and accompanying implementation programmes to ensure the responsible and safe management of SF and radioactive waste, including at storage and disposal facilities (OJEU, 2011).

The Waste Directive calls for clear national policies on SF and radioactive waste management. In this regard, the Member States need to establish and maintain a national legislative, regulatory and organizational framework, a competent regulatory authority, and to allocate responsibilities for the safety of SF and radioactive waste management facilities. Each Member State is also requested to ensure that the national framework: allows for the development of the necessary expertise and skills needed to implement the safe management of the SF and radioactive waste; ensures adequate financial resources and transparency; and, gives the opportunity for participation of the public in the decision-making process.

In order to put into practice the national strategy and policy for SF and radioactive waste management, the Waste Directive requires the development and implementation of a national programme providing information on: the objectives of the national policy on SF and radioactive waste management; important milestones and time-frames; inventory, concepts and technical solutions from generation to disposal; and the RD&D activities needed.

Outline of nuclear programmes in Central and Eastern European countries

There are two major contributors to GD in Central and Eastern European countries: nuclear power plants and research reactors.

Nuclear research programmes started in Central and Eastern European countries in the early 1950s, with the operation of the first research reactors. Until 1997, Romania operated a VVR-S reactor which is now being decommissioned (Dragusin, 2011). A TRIGA 14 MW has been operating in Pitesti since 1975. A full conversion from HEU (High Enriched Uranium) to LEU (Low Enriched Uranium) was finalized in 2006 (ICN, 2014). All highly enriched SF was sent back to the countries of origin: Russian Federation (Dragusin *et al.*, 2011) and the USA (Ciocanescu, 2008), but the LEU SF has to be managed by the Romanian authorities.

Slovenia, which operates a TRIGA MARK II reactor (IJS, 2014), also returned 70% of its SF to USA in 1999 (Ravnik, 2008). Another ten fresh fuel elements were shipped to France in 2007. Therefore, there is currently no SF in the pool of the TRIGA research reactor.

Bulgaria shut down its VVER research reactor in 1990 and all SF was sent back to the Russian Federation (IAEA, 2008).

In Poland all SF from the research reactors EWA (currently being decommissioned) and MARIA (in operation) was returned to the Russian Federation within the framework of Global Threat Reduction Initiative (GTRI) implemented by Poland (Poland, 2014).

The return of SF from the research reactors to the countries of origin, which is a common feature of the New Members States, has removed the pressure to define and implement a GD programme.

The nuclear energy programmes in this region started in 1974 in Bulgaria, followed by Slovenia and Romania (Table 1). By 2025 it is expected that nuclear power will also be part of the energy mix in Poland. The total installed capacity in these countries is quite small compared to, for example Sweden, one of the most advanced states in terms of GD, which also operates an open fuel cycle. The programmes in Bulgaria, Slovenia and Romania are expected to generate smaller volumes of SF and long-lived waste than the Swedish programme.

TABLE 1. Size of the nuclear power programs in some Central and Eastern European countries.

Country	Total installed nuclear capacity*	Number of NPP units/type	First commissioned
Bulgaria	2000 MWe (O)	2 VVER 1000/320	1974
	1760 MWe (D)	4 VVER 440/230	
Romania	1200 MWe (O)	2 CANDU 600	1996
	1200MWe (P)	2 CANDU 600	2018
Slovenia	700 MWe (O)	½ Westinghouse PWR	1983
Poland	6000 MWe (P)	NA	2025
Sweden	9429 MWe (O)	10 units	1964

*O – in operation, D – being decommissioned, P – planned.

The option of an open fuel cycle applied in these countries is another common characteristic, which is the major reason for the delay in the geological programmes. In Romania, the SF has to be kept in wet storage for a period of 6–10 y, and for at least another 50 y in a dry storage facility before being disposed of in a GD facility. Therefore, such a facility needs to be operational by 2055 (Andrei *et al.*, 2013).

The same approach is adopted in Slovenia: a sufficient cooling period of 45 years is required prior to disposal to allow optimal utilization of canister capacity. Depending on the life time of the Krško NPP which may be extended by 20 y, the repository needs to be operational by 2067 or 2087 (Železnik and Kegel, 2011). In Bulgaria the SF from the Kozloduy NPP is sent back in the Russian Federation for reprocessing and storage. However, a GD facility is needed for the high-level waste and LL-ILW waste resulting from SF-processing activities, but no date is foreseen for its commissioning (Naydenov, 2006). In Poland the GD programme is dependent on the nuclear energy programme, which plans to commission the first reactor in 2025 and which is linked to the implementation of the Waste Directive. There is, therefore, a requirement to have an operational facility at the earliest by 2055–2060 (Poland, 2014).

In addition to the above, another possible reason for the late start of the process is the lack of societal pressure due to previous political regimes in these countries.

TABLE 2. Indicative SF and LL-ILW inventory resulting from nuclear-energy production.

Country	Volume*	LL-ILW
Romania	525,000 FA (7200 HMT) for 2 Units	1000 m^3
	1,050,000 FA (14550 HMT) for 4 Units	2000 m^3
Slovenia	1553 FA (620 HMT) for 40 y of operation	36 m^3
	2281 FA (912 HMT) for 60 y of operation	

*FA – fuel assemblies, HMT – heavy metal tons.

Legal framework and strategies for SF and LL-ILW disposal

All the countries considered in this review have set up legal frameworks and appropriate institutions for the safe management of radioactive waste. Data are available for only a rough characterization of the inventory of SF and LL-ILW (Table 2). For instance, in Romania and Slovenia the total inventory depends on the future evolution of the nuclear programme (construction of two new Units at Cernavoda NPP and life-time extension) (Železnik and Kegel, 2011). Only generic disposal concepts are available in Romania and Slovenia, both based on existing concepts appropriate for the potential host rocks and the SF characteristics. These are summarized below.

In Romania, the implementer of the radioactive waste management is the Nuclear Agency for Radioactive Waste (ANDR) which in 2008 incorporated the former waste organization ANDRAD (created in 2004). The responsibilities and related activities are specified in the National Strategy on Medium- and Long-Term Management of Spent Nuclear Fuel and Radioactive Waste, including the Disposal and Decommissioning of Nuclear and Radiological Facilities, issued in 2004 (Ordin,

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2004). Other national documents which support radioactive-waste management throughout the programme until final disposal include: Law no. 105/1999 for ratifying the Joint Convention on the safe management of SF and on the safe management of radioactive waste; Law 378/2013 for the implementation of Waste Directive establishing a community framework for the responsible and safe management of SF and radioactive waste (OJEU, 2011); laws implementing the Aarhus and Espoo Conventions; and the Environmental Protection Law 265/2006 (ANDR, 2014).

In accordance with the national strategy currently in place in Romania, SF must be disposed of directly in a repository, without reprocessing, after 56–60 y of cooling in appropriate storage facilities built on the NPP site.

Romania operates a CANDU type reactor and therefore the current GD concept considered for cost estimation purposes is similar to the Canadian concept (Andrei *et al.,* 2013). The repository will dispose of both SF and long-lived wastes from four CANDU 6 units and their decommissioning (Table 2). The waste consists of:

- SF: 14,550 Heavy Metal Tons (HMT) for all 4 units; and
- long-lived wastes: 15,660 standard drums from operation; 19,000 standard drums from decommissioning.

The design is based on encapsulation of SF in copper/steel double-shell containers, each with a capacity of 324 bundles, and emplacement of these containers inside vaults using a horizontal configuration.

The non-retrievable facility will be located at 500–1000 m depth, and will be preceded by the construction of an Underground Research Laboratory (URL). In Romania no host rock has been selected and there is no proposed site. However, as a result of desk studies, six potential geological formations for hosting the GD facility have been identified. These are a greenschist from central Dobrogea, granite in the south and basalt in the western Carpathians, clay in the western plains and respectively the north-western Moldavian platform, salt and volcanic tuff in the central part of Romania (Radu and Nicolae, 2007).

A technical project in cooperation with the IAEA was carried out between 2007 and 2008, entitled ‘Developing a geological disposal concept for spent nuclear fuel in Romania’ and included: a review of the available geological information existing in Romania to identify potential host-rocks for the GD; an analysis of greenschists from Central Dobrogea, a possible site of the future GD, carried out in the NAGRA laboratories (Switzerland); and, development of a ‘roadmap’ including the future site selection and construction considerations.

Potential host rocks were identified based on existing information on Romanian geology. Research on deep GD was performed as part of the international projects Euratom FP and IAEA, and the national R&D programme, but not in a systematic integrated national approach.

In Slovenia the waste-management programme is implemented by ARAO and the official legal document is the National Radioactive Waste and SF Management Programme issued in 2006, which covers the period 2006–2015. There are two distinct operational programmes for SF management: for the SF generated by the NPP and the second one – for those generated by the research reactor . The SF management process at NPP Krško and the NPP Krško programme represent short-term activities, and the decommissioning of the research reactor and disposal of the SF and low- and intermediate-level waste are longer-term projects (Železnik and Kegel, 2011). The Jozef Stefan Institute which operates the TRIGA Mark II research reactor is considering the option of further use of the reactor beyond 2016 and is negotiating with USA about the possibility of returning SF elements after 2019. A final decision has not yet been taken.

The current strategy is wet SF storage until the end of NPP operation (2023 or later) followed by its transfer to dry storage for ~35 y before direct disposal. As a result of stress tests performed after the Fukushima accident, an action plan was developed to improve the safety of operation of NPP Krško and this requires that dry storage on the NPP Krško site should start by 2018.

In Slovenia there are currently no operational plans for a SF and long-lived waste (LL-ILW) disposal facility. The 2006 National Programme of Management of Radioactive Waste and SF does not include a solution for final disposal of SF and LL-ILW. Because of the joint ownership and joint responsibility of NPP Krško by both Slovenia and Croatia, the intergovernmental agreement requires a disposal solution which must be acceptable to both owners. Yet to be decided is whether Slovenia will build its own repository or participate in an international/multinational shared GD facility (if available).

However, if a GD facility were to be built in Slovenia it is likely that it would commence operation in ~2067 (Železnik and Kegel, 2011).

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The Slovenian concept is based on direct disposal of the SF without reprocessing. The repository will be constructed in a hard-rock environment at a depth of 500 m and the entire disposal system will be based on the Swedish KBS-3V concept. The repository development also includes the construction and operation of an underground testing facility at the future repository site. As stated above, a sufficient cooling period is required prior to disposal to allow optimal utilization of canister capacity (4 SF elements per copper canister); a 45-y total storage period (wet + dry) is therefore required before disposal. With regard to siting, only a hard-rock environment is currently being considered, but there are no indications of potential sites.

In Bulgaria, the management of radioactive waste outside the place of generation is governed by the State Enterprise Radioactive Waste (SE RAW) established by the Act on Safe Use of Nuclear Energy, which came into force in 2002. In accordance with this Act, the basic documents controlling the management of SF and radioactive waste are the 'Strategy for management of spent nuclear fuel and radioactive waste' adopted by the Council of Ministers in 2004, updated in 2011 and covering the period until 2030, and the 'Regulation for safe management of the radioactive waste' adopted by the Council of Ministers in 2004.

Currently in Bulgaria there are only two VVER units in operation, at the Kozloduy NPP, with plans for another four. The SF is stored in the reactor pools and then transferred to the Wet SF Storage Facility located in a separate building on the reactor site. Some of the SF inventory is shipped annually to the country of origin for reprocessing and storage. A Dry SF Storage Facility designed for long-term storage of VVER-440 SF was built on the NPP site. Bulgaria is now looking for alternative solutions for radioactive waste management and GD is under consideration.

The Bulgarian GD programme for SF and LL-ILW has been running for the last 10–15 years. SE RAW has started a project looking at the feasibility of constructing a GD facility. This project will define the main concepts for disposal based on the analysis of several options (Naydenov, 2006). Extensive research has led to the development of the national programme including the initial assessment of prospective geological conditions for disposal. An important target has been to determine the main requirements for site selection and development of an associated disposal programme.

As a result of these activities four potential sites have been identified: two Lower Cretaceous clayey marl sites in the northwest of the country and two granite pluton sites in the southeast. These have been compared in order to select the most appropriate site. The investigation and selection process is still in progress.

In Poland, the responsibility for spent nuclear fuel management and radioactive waste management belongs to the Radioactive Waste Management Plant, the legal entity designated to perform the collection, treatment, conditioning, interim storage and, in particular, the activities ensuring permanent feasibility of GD (Poland, 2014). The Act of Parliament on Atomic Law of 29 November 2000, and its further amendments introduced a consolidated system ensuring nuclear safety and radiological protection in Poland. This Act implemented into Polish legislation the requirements of the Waste Directive and introduced safety requirements dedicated to radioactive waste and SF management. This included the development of a national programme for spent nuclear fuel and radioactive waste management associated with the nuclear power programme. The Act on Access to Information on the Environment and its Protection and on Environmental Impact Assessments governs the process of public engagement and information. The National Plan of Management of Radioactive Waste and SF requested by the Council of Ministries in April 2008 is the document describing the new national strategy regarding radioactive waste management and SF management and, in its current version, takes into consideration the implementation of the Waste Directive.

The Polish Nuclear Power Programme, adopted in January 2014, states that two nuclear power plants will be built, the first planned for 2025. Based on previous studies, an open fuel cycle was selected as the basis for these plants (Poland, 2014).

Despite the fact that the nuclear programme in Poland is only in the planning phase, Poland has already pre-selected geological formations for GD. Assessments carried out in the 1990s considered clay, salt and magmatic rocks. A detailed review of these past assessments is now planned, as well as additional geological and geophysical studies.

At present, site selection for GD lies under the jurisdiction of the Ministry of Economy. Studies of possible sites for GD restarted in 2014 and a project to develop a Polish Underground Research Laboratory (PURL) has been proposed.

Addressing the EC Waste Directive

All the strategies presented above have had to be reviewed and updated according to the Waste Directive requirements and to the socio-economic situation in each country, and national programmes have to be developed in order to answer the Waste Directive (OJEU, 2011).

The first step in transposing the Directive consisted of the review and completion of each national framework in order to ensure all appropriate requirements exist to support the deployment of the SF and radioactive waste-management strategy. The date for completion of this process was 23 August 2013. Included in this review was an in-depth analysis of the entire legal framework and of its compliance with the Directive requirements. Particular attention was given to: the establishment of legislation ensuring transparency, communication and participation of all stakeholders (including the public) throughout the process; securing sufficient and transparent funding; as well as a national framework covering the necessary skills and competencies for strategy implementation. All these aspects have been reviewed and where inconsistencies or gaps were identified, the respective laws were updated accordingly.

The second step which was even more challenging for countries with less advanced programmes is the development of national programmes with a deadline for submission to the European Commission of 23 August, 2015. To help the New Member States develop their national programmes the NAPRO Guide has been developed (ENEF, 2013). In addition, the experience of the most advanced programmes, as well as recommendations of the IAEA experts through its technical cooperation programme, are also utilized by these countries (Andrei *et al.*, 2013).

New Member States' requirements for geological disposal

The experience of the more advanced programmes showed that it is likely to take more than 30 years to implement a GD programme, which is about the timescale from today that most of the East European countries will need to develop a GD facility for their SF and LL-ILW. For example, the preliminary planning for the Romanian GD programme anticipated starting the R&D programme and siting process in 2011 in order to have a final decision on the selected site by 2044, with an initial construction period between 2045–2054 (Gheorghe-Sorescu, 2013). These milestones are more relaxed for Slovenia (Fig. 1) which plans starting the siting process in 2030 (Železnik and Kegel, 2011).

Each country has different priorities related to GD, most of them aimed currently at addressing the Waste Directive. For example, In Romania there is an urgent need for a national inventory update and for the review of the radioactive waste strategy. Other disposal options such as recycling of the spent nuclear fuel generated by CANDU Units of Cernavoda NPP are being considered in the strategy. In the near future ANDR plans to develop and implement a strategic programme which will include the initial stages of siting, Underground Research Laboratory development, safety case development, and review of the costs for GD.

In Slovenia activities are centred on SF disposal and in particular data acquisition on potential host rocks, safety analyses of proposed designs, and participation in an international/multinational shared GD facility.

In Bulgaria, the main priority is the initial assessment of the main GD concept for prospective geological conditions, using available research, as the basis for the development of a national programme (Naydenov, 2006).

Poland's activities are centred on strengthening its personnel and resources in order to provide effective and safe management of SF and LL-ILW, and to continue its site selection process for the GD facility including the site of the Polish Underground Research Laboratory. Activities are particularly focused on the implementation of an open fuel cycle whilst keeping a watching brief on current advances in SF reprocessing. The Polish programme is flexible in that apparent changes can be introduced as required. In addition, they are also interested in international/multinational projects for a shared GD facility (Poland, 2014).

New Member States R&D needs in geological disposal

Comprehensive R&D studies have been carried out in all these countries for low- and intermediate-level (LIL) waste disposal, which has contributed to the building of national competence. For GD, however, no systematic approach for the development and implementation of a R&D programme at a national level has been put in place. Some R&D studies have been carried out either at a domestic level or via IAEA Technical Cooperation or European Framework programmes.

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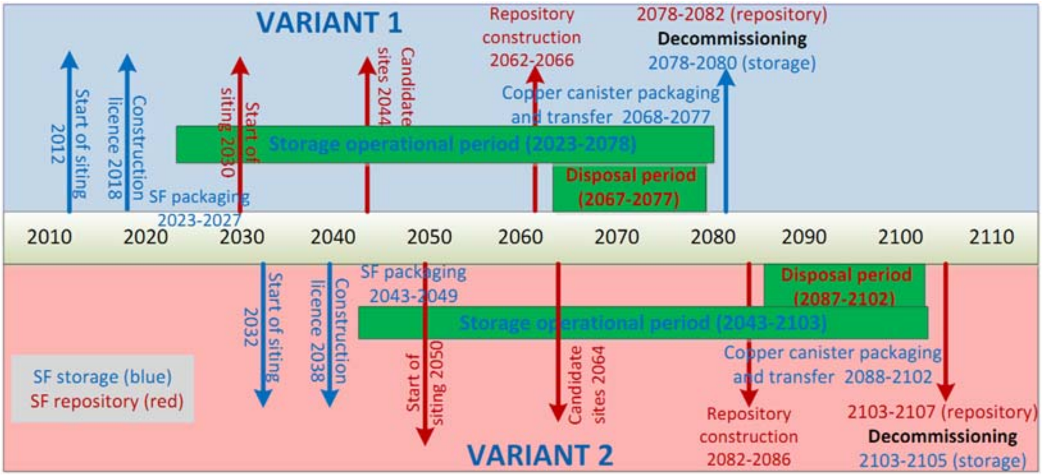

FIG. 1. Slovenia: storage and repository phases and time schedules for SF and LL-ILW.

In Romania these studies addressed a large spectrum of topics: development of experimental methods for radionuclide measurement in SF and LL-ILW; optimization of the repository concept; desk research bases on the existing geology data; laboratory tests on backfill materials (bentonite, crushed salt); gas migration; SF behaviour (UO_2 dissolution in different pore-water compositions), modelling of the radiological impact of a generic repository in granite and salt; and methodology for public participation.

In Slovenia, efforts have concentrated on: identifying a suitable geological environment; repository planning, management and disposal concept; criticality issues in the repository; and alternatives for SF and LL-ILW management (reprocessing options, partitioning and transmutation).

Developing, maintaining and advancing the competence in fission safety remains among the highest priorities for these Member States. It is now time to develop and implement dedicated national R&D programmes in support of GD implementation. These programmes should be aligned to an updated waste management strategy and be able to integrate coherently existing national competencies and the advanced knowledge base developed by western countries.

For New Member States a viable roadmap would be, to start from the existing experience and knowledge created during the LIL-SL waste disposal process, then to build the missing national competencies specific to GD including: safety and performance assessment (approaches, use of modelling, calculations, safety arguments, uncertainties, etc.); monitoring (strategies for environmental, engineering and radiological monitoring, methodologies and techniques, stages, etc.); site characterization (programmes, techniques, equipment, issues related to SF and LL-ILW); waste forms and their behaviour (inventory and waste forms, characterization, release processes and interaction with near field, chemical behaviour, modelling, etc.); and development of the strategy for repository implementation (approaches and processes, selection of optimal design, licensing, interaction with safety authorities and their technical support organizations, etc.).

Education and Training programmes in these countries will have to be adapted to include the new requirements related to GD, which would entail a review of their curricula and the use of advanced training schemes available at a European level.

A special role should be given to knowledge transfer from the most advanced to less advanced programmes. To facilitate this New Member States should take advantage of the regional networks created under European Commission framework projects such NEWLANCER and set up regional infrastructures able to enable continuous knowledge transfer (NEWLANCER, 2013).

Development of an R&D national programme as required by article 8 of the Waste Directive is essential to ensure the necessary expertise and skills for the national programme for SF and radioactive waste management. The NEWLANCER project showed that an R&D programme aligned to the

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national priorities in radioactive waste management, including GD, is seen by the New Member States as the most suitable framework taking advantage of existing competencies, and also for facilitating the efficient knowledge transfer from the most advanced programmes.

A national R&D programme is also essential for the future European Joint Programming in radioactive waste management, which will enable the New Member States to participate in large research projects addressing common priorities.

Conclusions

This paper gives an overview of a review of the current status of GD in four countries with less-advanced programmes (Bulgaria, Poland, Romania and Slovenia).

The analysis showed that:

- the SF and long-lived waste are managed safely according to best international practice;
- currently, direct GD of SF and long-lived waste is considered the end-point to ensure sustainable, safe and secure long-term management;
- the programme for implementing GD of SF and LL-ILW is in the initial stages:
  - generic disposal concepts have been proposed;
  - no siting procedure has been initiated but potential host rocks have been identified based on existing geological data;
- some R&D activities for GD have been developed; and
- there is a need for a coherent national R&D programme in support of GD to be able to integrate existing national competences and ensure the transfer of knowledge from more advanced programmes at a European level.

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