Following decades of scientific research, political contemplation and socioeconomic considerations, we see the first geological disposal systems for spent nuclear fuel worldwide entering their implementation phase in two countries of the European Union. This process has resulted in the construction of novel types of nuclear installations, namely underground repositories and spent fuel encapsulation plants. As a consequence, this calls for a parallel development of new safeguards concepts and applicable techniques by the relevant regulatory bodies.

In a period of shrinking resources, EURATOM has to face the additional challenges posed by the ever increasing quantities of nuclear material (NM) and defueling of nuclear power plants (NPPs) in Europe by employing the most efficient technological solutions. The geological disposal projects in the Nordic European countries are a fine example of implementation and combination of novel and emerging technologies.

An array of technical challenges have arisen in the development of safeguards approaches for underground repositories and spent fuel encapsulation plants, namely:

- The location and method for the last measurement of spent fuel assemblies before their placement into the disposal canister;
- Operation of spent fuel assembly measurement systems in unattended mode;
- Remote Data Transmission of measurement data and of data from C&S systems;
- Maintaining continuity of knowledge (CoK) on the spent fuel from the wet storages at the nuclear power plants through the encapsulation plant and until its entry to the geological repository;
- Methods for the identification of each disposal canister.

For each of the above challenges currently available technologies have been considered and assessed and some promising emerging technologies that could lead to considerable efficiency gains have been evaluated. On the one hand the sheer number of spent fuel assemblies to be disposed of underground and on the other the national and international requirements to establish the best possible knowledge of the quantities of nuclear material that will be buried inside the geological repository call for state-of-the-art solutions and also for flexibility in the design of the novel facilities. Initially, the safeguards inspectorates will rely on currently available technologies but the operation of the geological repository for as long as a hundred years means that space and volume must be 'reserved' in the design of facilities to allow for more efficient or effective technologies to be installed at a later stage, once they are proven, tested and commercially available. To this end, all involved stakeholders (international inspectorates, national authorities, operators of power plants and designers of repositories) have engaged in a dialogue over the last eight years, putting Safeguards by Design (SbD) in practice, and identifying the currently optimal solutions.

A top example of this forward-looking flexible approach is the measurement technique for establishing the knowledge of the NM in each spent fuel assembly. As we speak, the best available method internationally is a combination of DCVD and Ion Fork measurements at wet conditions in the wet storages of the NPPs. This method can cover the partial defect diversion scenario with an accuracy of well below 50% of the fuel pins removed. At the same time R&D reports are being published on very promising performances of tomography methods (Passive Gamma Emission Tomography) that can push the accuracy levels down to one missing pin. Such a tomography instrument, when commercially available is foreseen to be fitted in the Drying Cell of the Finnish encapsulation plant and employed to measure the NM content of the spent fuel, very late in the encapsulation process, thus lifting strict CoK requirements that currently need to be imposed for the transfer of verified nuclear fuel from the power plants to the final disposal facilities. Even more ambitious, methods aiming at the determination of nuclear material amounts in spent fuel assemblies are under development.

Many similar examples exist on all the fields of technical challenges of final disposal. They may range from Containment and Surveillance methods, to canister Identification Techniques and NM gamma or neutron monitor. The following table illustrates a number of such examples.

	Technique/equipment	
	Available and ready to be applied	Potentially applicable/ Under consideration
Final Verification of SNF assemblies	*Ion Fork* *DCVD*	*- Gamma tomography* *- High resolution gamma spectroscopy* *- Advanced neutron interrogation techniques*
Canister ID	*Engraved numbers* *Laser scanning*	*- Ultrasonic weld characterisation* *- X-ray or Gammagraphy* *- Eddy current* *- Neutron-gamma mapping* *- Muon radiography*
Canister Re-verification	*Neutron fingerprinting*	*- Neutron-gamma mapping* *- Muon radiography*
Underground retention and BTC verification	*3D laser scanning as built-as-designed verification tool with a deposition tunnel face "sealing" capacity*	*Geophysical surveying techniques (e.g. geo-radar, VLF*, ERT*, etc.)*
NM flow monitoring, and CoK retention during transport	*Optical and electronic seals* *Surveillance cameras* *Mobile unattended neutron detectors*	*Advanced RF ID combined with sealing*
Black Box monitoring	*Environmental sampling* *Satellite imagery*	*- Seismic-acoustic monitoring/surveying* *- Advanced use of spatial data (SAR*, DSM*, regional activity supervision etc.)* *- neutrino detection based monitoring*

*VLF – Very Low Frequency surveying
*ERT – Electrical Resistance Tomography
*SAR – Synthetic Aperture Radar
*DSM – Digital Surface Model

The first Geological Repositories and Encapsulation Plants in the world are under construction in Europe. More countries are to follow in their attempt to address the issue of radioactive waste management. Sharing the experiences and lessons learnt within the international safeguards community will contribute to building international capacity, by facilitating the efficient implementation of proven technologies and SbD principles in other countries where Geological Repositories and Encapsulation Plants will be constructed.