Course on "Radioactive Waste Management"		
Units and LO Statements		
Unit 1 – Generation, treatment and conditioning of wastes (7,5 hours)	**Responsibility / Autonomy**	
	The student is able to understand in detail the problem of radioactive and nuclear waste in general	
	Skills	**Knowledge**
• Generation, types and classification of radioactive waste • Waste from the first part of the nuclear fuel cycle and its stabilization • Waste generated in the nuclear power plants during operation • Waste generated in radioactive facilities • The General Plan of Radioactive Waste of Spain.	• Comprehensive understanding of the generation, types and classification of radioactive waste. • Capability to understand the characteristics of the waste from the first part of the nuclear fuel cycle and its stabilization • Capability to understand the characteristics of the waste generated in the nuclear power plants during operation • Capability to understand the characteristics of the waste generated in radioactive facilities • Comprehensive understanding of waste management in the General Plan of Radioactive Waste of Spain.	• Generation, types and classification of radioactive waste. Natural and artificial radioactive nuclides.- The accumulation of radioactive products in the nuclear reactor.- The toxicity of radioactive nuclei.- Classification of residues by their origin.- Classification of radioactive residues by their specific activity, isotopic content and half-life- Internationally recommended classifications. Legal classification in Spain. • Waste from the first part of the fuel cycle and its stabilization. Most significant radioactive minerals.- Waste from mining and metallurgy and the manufacture of concentrates.- Situation in Spain. Application examples: FUA, La Haba, Saelices and other uranium mines in Spain.- Waste from conversion, enrichment and fuel manufacturing facilities. • Waste in nuclear power plants (NPP). Generation of radioactive waste in nuclear power plants.- Systems for treatment of radioactive fluids.- Types of solid waste generated in nuclear power plants.- Waste of NPP operation: treatment techniques, packaging and segregation.- Nuclear power plants waste production forecast in Spain. • Waste in radioactive facilities. The Spanish regulations.- Classification of radioactive facilities: types of waste and their conditioning.- General overview for medical facilities, research centres, industry and agriculture.- ENRESA-SEPR technical guides on the management of waste materials with radioactive contents in health care, research and teaching facilities. • The General Radioactive Waste Plan (GRWP) of Spain. Background of the general radioactive waste plan. Creation of ENRESA: responsibilities and resources.- The evolution of the GRWP of Spain.- The Plan in force: VI GPRW, lines of action.- Draft

		of the VII General Plan of radioactive waste.
Unit 2 – Basic safety and radiological protection criteria (10,5 hours)	**Responsibility / Autonomy**	
	The student is able to apply the safety regulation system, is committed to safety and understands the safety culture for nuclear power and radiation applications.	
	Skills	**Knowledge**
• The IAEA Fundamental Safety Principles. Application to the management of radioactive waste • Detection and dosimetry of radiation • Health effects caused by the exposure to ionizing Radiation • Criteria and objectives of radiological protection • Criteria for the management of materials with very low radioactive content • Regulations applicable to the management of radioactive waste in Spain. • Modelling the biosphere in radioactive waste disposal safety assessment.	• Know and reason the basic criteria of safety and radiological protection. • Find and apply the relevant regulations and guidance for the planned exposure situation within its responsibility • For each exposure situation, apply European and national laws, regulations, recommendations and standards related to radiation safety • Identify the legal radiation protection obligations in daily practice • Understand the legal requirements regarding notification, authorisation, registration and licensing. • Apply the legal requirements and practical solutions which can be used to enhance safe storage, handling and disposal of radioactive materials.	• The IAEA Fundamental Safety Principles. Application to the management of radioactive waste. Historical development.- Regulatory regime of the IAEA.- Fundamental concepts.- Safety objective.- The ten safety principles.- Conclusions. • Detection and dosimetry of radiation. Fundamental dosimetric quantities. Physical, limiting radiological and operational limits for external irradiation. Measuring devices, detectors and dosimeters. Dosimetry in radiation protection. External personal dosimetry.- Internal dosimetry. • Health effects of exposure to ionizing radiation. Effects of ionizing radiation at the cellular level.- Effects of ionizing radiations at the organic level.- Radiation risk assessment.- Epidemiological methodology. Recent and ongoing studies.- Summary of the UNSCEAR quantitative estimates. • Criteria, objectives and principles of radiological protection. .- The recommendations of the International Commission on Radiological Protection.- Application to the management of radioactive waste.- Radiological protection of the environment. • Criteria for the management of materials with very low radioactive content. The concepts of exemption, exclusion and clearance of the regulatory control of waste and materials with very low activity.- Basic principles of exemption and clearance.- Methodology for assessing the radiological impact.- The particular case of natural materials with radioactive content (NORM).- The situation in Spain.- Studies carried out by ENRESA.- Application to the decommissioning and dismantling.- Conclusions. • Regulations applicable to the management of radioactive waste in Spain. The normative structure.- International conventions and norms.- The European Directives.- National regulations applicable to the management of radioactive waste: Norms of constitutional rank; Legal

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<tr><td></td><td></td><td>standards; Regulatory standards; Administrative rank standards; Technical standards, guidelines and recommendations.- Current trends in regulation of radioactive waste management.
• Modelling the biosphere in safety analysis. Modelling of radionuclide transport processes: Atmospheric, terrestrial and aquatic media; The geosphere-biosphere interface.- Long-term assessment.- Methodologies to evaluate the radiological impact in the biosphere.
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<tr><td rowspan="3">Unit 3 – Management of very Low, Low and Intermediate specific activity level wastes (12 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">The student is able to work professionally in the companies of the nuclear sector, designing, coordinating, directing and integrating the necessary knowledge to participate in the start-up and support to operation of very Low, Low and Intermediate specific activity level wastes disposal facilities.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Waste inventory and characterization
• Delivery and transport of radioactive waste
• Basic criteria for management and final storage in surface facilities
• Safety assessment of surface disposal facilities
• "El Cabril" Low and Intermediate Level Waste (LILW) Disposal facility.
• Very low activity waste (VLLW) disposal facilities.</td><td>• Know the technologies for the management of very low, low and medium activity waste.
• Participate in the waste inventory and characterization phases.
• Understand the development of a delivery and transport plan of radioactive waste
• Know the basic criteria for management and final storage in surface facilities
• Perform a basic safety assessment of a surface disposal facility.</td><td>• Inventory and characterization of waste. Inventory. Types of waste.- Reduction of volume of LILW in the operation of NPP.- Database.- Storage of operational waste in NPP: current situation.- Acceptance criteria of storage units.- Description of the acceptance process of primary packages and packages of LILW.- Laboratory of verification of the quality of the waste.
• Delivery and transport of radioactive waste. LILW / VLLW package inspection and delivery processes. - LILW / VLLW transport packaging. - Packaging tests. - Applicable regulations. - Transport of LILW / VLLW packages. - Logistics and transport equipment.
• Basic criteria for the management and final storage in surface installations. Safety principles and criteria. Bases of design and safety assessment: characteristics of waste; Multibarrier system; Safety and radiological protection objectives; Radiological limits and regulatory conditions. The regulating control of the LILW storage. Peculiarities for very low-activity waste.
• Evaluation of the safety of surface storage facilities. Definition of the context of the evaluation. Description of the storage system (characteristics of waste, engineering barriers and natural barriers). Generation of scenarios. Evaluation of the scenarios: development / modelling. Interpretation of results.</td></tr>
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		• "El Cabril" Low and Intermediate Level Waste (LILW) disposal facility. Background.- General design criteria.- The storage system.- The site.- General description of the installation.- Conditioning of waste.- Development of the project.-Operational experience of the storage facility of "El Cabril". • Very low activity waste storage facilities. Background .- Installations of "El Cabril" .- General criteria of design.- The storage system.- The site.- Conditioning of waste.- General description of the installation. The planned inventory. • TECHNICAL VISIT: "El Cabril" Very Low, Low and Intermediate Level Waste (LILW) Disposal facility. (Córdoba, Spain)
Unit 4 – Management of High specific activity level radioactive wastes (14 hours)	**Responsibility / Autonomy** The student is able to work professionally in the companies of the nuclear sector, designing, coordinating, directing and integrating the necessary knowledge to participate in the start-up and support to operation of High specific activity level radioactive wastes disposal facilities.	
	Skills	**Knowledge**
• Temporary storage of irradiated fuel: Technical solutions and safety criteria • Temporary storage of irradiated fuel: Applications and situation in Spain • Centralized Temporary Storage (CTS) of spent fuel and high activity level radioactive waste • Reprocessing of spent fuel and separation of long-lived products • Transmutation of long-lived radioactive waste • Final disposal of high activity level waste: Technical solutions, safety criteria and conceptual design • Deep Geological Repositories (DGR): The Near Field and the Geosphere • Deep Geological Repositories: Performance Assessment • Deep Geological Repositories: Site Characterization • Natural analogues of DGR: The Oklo phenomenon and other natural analogues. •	• Know the technologies for the management of waste of high activity. • Apply technical solutions and safety criteria in the Temporary storage of irradiated fuel. • Understand the characteristics of a Centralized Temporary Storage of spent fuel and high activity level radioactive waste • Understand the reprocessing of spent fuel and separation of long-lived products • Understand the transmutation of long-lived radioactive waste • Apply technical solutions and safety criteria in the conceptual design of a high activity waste repository. • Assess the influence of the Near Field and the Geosphere in the performance of a Deep Geological Repository. • Understand the basis of the Performance Assessment techniques for a Deep Geological Repository. • Know the site characterization techniques normally used in the development of a Deep Geological Repository. • Understand the utility of natural analogues in	• Temporary storage of irradiated fuel: Technical solutions and safety criteria. Characteristics of irradiated nuclear fuel.- Functions and technologies of temporary storage.- Temporary storage in wet conditions.- Temporary storage in dry conditions.- Overview of the international situation.- Safety aspects.- The behaviour of irradiated nuclear fuel during prolonged periods of storage temporary. • Temporary storage of irradiated fuel: Applications and situation in Spain. Criteria for selection of temporary storage options.- The storage of spent fuel in the fuel pools of the nuclear power plants: regrouping, Spanish cases.- The content and analysis of the authorizations granted: monitoring of compliance.- Individual interim storage facilities (ATI).- The ATI of Trillo NPP.- The ATI of José Cabrera NPP.- The ATI of Ascó NPP. • The Centralized Temporary Storage (CTS) of spent fuel and high activity radioactive waste. ENRESA studies and projects for the design and construction of a Centralized Temporary Storage (CTS).- Technical characteristics of the CTS.- The study of safety of the CTS and its evaluation by the regulatory body.- The transport: forecasts and

	the design of a DGR.	safety aspects .- The associated Technological Centre. • The reprocessing of spent fuel and the separation of long-lived products. Alternatives in the nuclear fuel cycle.- Technical, chemical and nuclear aspects of reprocessing.- Treatment, conditioning, quantities and characteristics of the radioactive waste generated in reprocessing facilities.- Utilization of recovered uranium and plutonium in reprocessing facilities .- The separation of actinides and other long life products for their transmutation: technologies and developmental state. • Transmutation of long-lived radioactive waste. Introduction: Function of transmutation. - Physical concepts of transmutation of radioactive waste. - Strategies of waste management including transmutation. - Technological options for systems of transmutation of radioactive waste. - State of technology and research for transmutation. • Final disposal of high activity level waste: Technical solutions, safety criteria and conceptual design. Characteristics of these long-lived waste.- Types of final disposal systems.- Safety criteria and objectives.- Safety assessment and demonstration.- Conceptual design of deep geological repositories (DGR): generic and specific designs for clays, granites and salt as host rock.- International activity . • Deep Geological disposal: Performance Assessment (PA). Stages of the evaluation.- Performing of calculations.- Analysis of sensitivity and uncertainties.- Analysis of the results and conclusions.- Brief international review of the exercises of evaluation of the PA.- Practical example. • Deep Geological disposal: The Near Field and the Geosphere. Components of the near field. - Effects in the near field. - Mathematical models to evaluate the near field behaviour. - Transport of radionuclides to the far field. Flow modelling: quantitative problems: Description of the porous medium.- Fluid mechanics in porous media.- Analytical resolution of the diffusion equation.- Modelling of transport: qualitative problems: transport of miscible substances in porous media. • Natural analogues of DGR: The Oklo phenomenon and other natural analogies. Requirements of

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<tr><td></td><td></td><td>analogies. Types of natural analogues. Fuel analogues, containers, clay barriers, geological barriers. Oklo: discovery; Characteristics of natural reactors; Characteristics of the rocks and crystalline structures. Other examples of natural analogies. Process analogues.
• Characterization of sites. Site functions in radioactive waste management facilities. Criteria for selection of sites (DGR, El Cabril, CTS). Characterization systematic: DGR site; El Cabril site; CTS site.
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<tr><td rowspan="3">Unit 5 – Decommissioning and dismantling of nuclear installations (8,5 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">The student is able to work professionally in the companies of the nuclear sector, designing, coordinating, directing and integrating the necessary knowledge to participate in the start-up and support to operation for decommissioning and dismantling of nuclear installations.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Dismantling of nuclear facilities
• Integrated Plan for the Improvement of CIEMAT Facilities (PIMIC). Dismantling project.
• Project to decommissioning and dismantling the José Cabrera Nuclear Power Plant.</td><td>• Know the main technologies for the dismantling of nuclear facilities.
• Know the different waste flows generated and their management strategies and technology.
• Apply safety and structural analysis, short and long-term planning of a decommissioning and dismantling project.
• Have a comprehensive understanding of the different phases of a decommissioning and dismantling project.</td><td>• Dismantling of nuclear facilities.- Most relevant aspects of decommissioning.- Decommissioning policies.- International references on dismantling.- IAEA regulations.- Decommissioning of installations in Spain.- Scope of dismantling.- Power reactors: Dismantling and decommissioning of the Vandellós I NNP.
• Integrated Plan for the Improvement of CIEMAT Facilities (PIMIC). Dismantling project.- Objectives and scope of the Project.- Preparation of the site.- Construction of auxiliary facilities.- Dismantling of active parts.- Methodology of declassification.- Demolition of buried deposits, swimming pool and other structures.- Recuperation of contaminated soils.- Management of materials.
• Project to dismantle and decommissioning José Cabrera NPP.- Background.- Project objectives.- Approach, development and phases of the dismantling project.- More significant figures.
TECHNICAL VISIT: Dismantling project.
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<tr><td rowspan="3">Unit 6 – General and institutional aspects (7,5 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">The student is able to address ethical, social, legal and institutional issues related to the management of radioactive waste.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Quality in the management of radioactive</td><td>• Apply quality policies in the management of</td><td>• Quality in the management of radioactive waste.</td></tr>
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waste • R & D in the management of radioactive waste. • International overview. • Social aspects of radioactive waste management. • Information and communication with the public.	radioactive waste. • Know the main radioactive waste management policies around the world. • Know the state of R & D in the management of radioactive waste at international level. • Comprehensive understanding of the importance of social participation in decision-making for the management of radioactive waste. • Inform and communicate with the public about management of radioactive waste issues.	Previous concepts: Terminological clarifications.- Quality policy in the management of radioactive waste.- ENRESA quality assurance system.- Practical application.- Evolution of the concept of quality. • International Overview. Activities of the European Commission in the field of radioactive waste management.- Member States' programs on radioactive waste management.- The Joint Convention on "Management of spent fuel and radioactive waste". • R & D in the management of radioactive waste. Context and baseline of the R & D plan. The ENRESA R & D Plan. Objectives and criteria. Areas, programs and lines of research. Funding, organization, monitoring and knowledge management. International collaboration. The Euratom R & D Framework Program. • Social participation in decision-making for the management of radioactive waste. The social dimension of the problem.- The main stakeholders. Recommendations and models for social participation: NEA; IRPA; COWAM. Featured cases. • Information to the public and communication. Characteristics and objectives of a company such as ENRESA.- What ENRESA needs to fulfil the mission entrusted by the parliament.- Communication in the management of radioactive waste.- Communication in ENRESA: a strategy aimed at promoting the social acceptability of waste. (...)
Assessment criteria = to demonstrate mastery of basic and advanced techniques and skills for Radioactive Waste Management.		
Recommended assessment methods: Practical and written test, covering the main themes. Writing and presentation of an original work deepening in some of the topics of the Course.		

Course applicable (in part or fully) for the following job profiles:

- Undergraduate or graduate students in science or engineering willing to enrich their background on Radioactive Waste Management beyond purely academic knowledge.

- Professionals (scientists, engineers) working in non-nuclear fields needing a complete introduction to Radioactive Waste Management.
- Professionals (scientists, engineers, technicians) working in the nuclear field and needing a more advanced education and wider knowledge about Radioactive Waste Management.