Theme / Specific content	time		Type
	Unit.	Total	
(1) Fundamentals			
1.1 Radioactivity	6	9	CM
• Physical principals			
• Table of isotopes			
• Principal radionuclides present in nuclear waste			
• Metrologie/Detectors	3		CM/TP
1.2 Codes : Origen/Cesar…	8	8	TP
• Evolution of the radioactivity alpha, beta and gamma with time			
• filiation			
• heat generation			
1.3 Criticality	5	5	CM
• nuclear fission and chain reaction			
• economics of neutrons			
• geometrical constraints			
• effect of water and other moderators			
1.4 Fundamentals on nuclear reactor and fuel cycle		5	CM
• principals of reactor design			
• from 1st to 3rd generation			
•from mine to fuel			
• reprocessing schemes			
1.5 Radiolysis and radiation damage		5	
• Alpha, beta and gamma radiolysis of water			
• Radiolysis at interfaces			
• Dose distribution and dose evolution in nuclear waste systems			
• Basics of radiation damage in solids			
1.6 Chemistry of actinides/ fission and activation products in the environment at surface and in deep geological formations (+ EBS)		12	CM
• Hydrolysis and complexation of cations			
• Precipitation, coprecipitation, solubility			
• Redox chemistry			
• Colloid formation			
• Mobility/immobility/ retention processes			
1.7 Basic natural properties of geological formations (structural, mineralogical, microstructural, geochemistry, geomechanics…)	5	11	CM
• Recall of generics in sedimentary and ignous rock, rock mechanics, heat transfer in rocks			

• Granite (fissuration...	1		CM
• Salt (Diapirism, placticité…)	2		CM
• clay	3		CM
1. 8 Principals on transport properties in geological and engineered formations (heat, water, gaz, solutes…)		5	CM
• Basic notions: permeability, porosity…			
• Laws of Darcy, Fick, convection/diffusion			
• Porous medium			
• Fissured medium			
• Methods of characterization			
• Comparison of different formations			
1.9 Geochemical and transport modelling in porous media : Processses, models an codes		10	
• processes for anion and cation transport	2		CM
• geochemical modelling	5		TP
• coupled geochemical and transport modelling	3		TP
1.10 Biogeochemistry of radionuclides		12	CM
• Transfer soil/plant			
• Microorganism/ humic substances			
• Analytical/Characterisation methods			
1.11 General principles for long-term sustainable management of nuclear waste and radioactive materials		8	CM
Recycling to reduce waste volumes and to conserve resources			Conferences
Deep geological disposal or surface storage			
Transmutation: an option for the future?			
Stocks of deleted U, of Th and of Pu. Residues from U and Th mineral processing			
Towards a sustainable nuclear fuel cycle (GenIV)			
International comparison			
Total (1)		**90**	
(2) Waste types, conditionning and storage			
2.1 Classification of wastes, origin, inventories			
2.1.1 Classification schemes for radioactive wastes in various countries		2	CM
2.1.2 - "Industrial nuclear waste" ***The nuclear fuel cycle and its waste and radioactive matter streams: principals and materials fluxes and wastes: operational wastes and waste products*** • High and medium active long lived wastes • Reactorwaste		11	CM

• Radioactive waste streams form reprocessing • Modifications with future fuel cycles			
• Graphite waste			
• Short-lived waste			
• Wastes for U-and Th mineral processing			
Inventories of nuclear waste types		3	CM
• Predicted evolution of inventory accumulation as function of waste management scenario			
• Scenarios/strategies for reduction of waste radioactivity			
2.1.3. Decommissioning of nuclear installations and wastes • Types of sites: reactors, waste tanks, plutonium facilities…		12	Visite
• Very weak radioactive waste/secondary wastes/other categories			
Viste of a dismantling site: Brennelis			
2.1.4 Other nuclear installations and "small scale" nuclear waste		3	
• Radioactive wastes form military installations			
• Wastes from hospitals	2		Visite
• Waste from research			Visite
• Others ("nucléaire diffus")	1		
2.1.5 Waste acceptance criteria for storage/disposal (various countries)		2	CM
· Waste package specifications			
· Procedures for accepting the waste at storage/disposal sites			
· Transport			
· Surveillance			
2.2 Waste conditioning and waste packages			
2.2.1 Confinement matrices		4	CM
• Objectives			
• Methods for waste volume reduction (compaction...)			
• Industrial confinement procedures for various waste streams: vitrification, cementation, bitumisation...			
• New solid phases for fixation of individual radionuclides : actinides, Cs, I. types of phases, mineralogy and methods to make them			
2.2.2. Generic properties of confinement matrices (chemical, mechanical, thermal stability and resistance against radiation)		10	CM

• Matrices for low and intermediate level waste (cement, bitumen)			
• high active waste glasses			
• spent nuclear fuel as waste matrix			
• new phases			
2.2.3 The container for highly active waste		3	CM
• Choice of container materials			
• Choice of over packs			
• Proceedures of container fabrication/welding			
• Properties			
2.2.4 The waste package (type and properties)		4	CM
• For direct disposal of spent fuel from LWR, BWR and gas cooled reactors			
• For HLW glasses			
• For graphite waste			
• For compacted hulls/structural parts			
• Quality assurance of waste packages			
2.2.5 Visit of a waste treatment site (if possible CSDC compaction at AREVA+vitrification plant)		10	visite
□			
2.3 Industrial solutions for low and intermediate level wastes			
2.3.1 Interim storage		3	CM
Current industrial practice in dry and wet storage			
Long-term storage considerations			
2.3.2 Industrial solutions for low and intermediate level wastes		20	CM
· Generic storage options	1		
· Principes de sûreté (Colis + BO + BG)			
• Exploitation center TFA, Morvilliers, France	1		CM
• Exploitation centers FMA, Aube and La Manche, France	2		CM
• Forsmark, Sweden	2		CM
• Disposal sites Konrad/Asse/Morsleben, Germany	1		CM
• Operational and post-closure controls	1		CM
• Environmental monitoring	2		CM or visit
• Example : visit of TFA/FMA center	10		visit
2.3.3 Specific wastes for which industrial solutions do not yet exist: graphite waste, radium-rich wastes, tritium rich wastes		3	CM
Problematics, inventories in different countries and at different producers			

Potential solutions			
State of the art in ongoing research / industrial projects and planning			
Total (2)		**90**	
(3) Geological disposal: phenomenes, evolution, technology			
3.1 Geology, hydraulics of potential disposal sites			
3.1.1 Concepts for geological disposal of intermediate and high level wastes		6	CM
Generic concepts for disposal of high level wastes			
History of the search for disposal sites and evolution of disposal concepts.			
Internationally studied sites (salt, granite, tuff, hard and soft clay) : principal properties, advantages and draw-backs			
Architecture of a disposal site with adaptation of the system of disposal galleries and the design of a suitable engineered barrier system			
3.1.2.Scientific/technical site selection criteria		**2**	
Geomechanic, thermomechanic, tectonic, hydrological, geochemical			
Geodynamic evolution and climatic change			
Absence of resources			
Homogeneity of formation			
Intl. comparison …			
3.1.3 Site characterization		6	
Sismic analyses	1		
Geophysical, hydrogeological and geotechnical exploration drilling programme	2		
Geochemichal and environemental characterisation	2		
Scaling up	1		
3.1.4. Geology of reference sites in clay, granite, salt (undisturbed) : tectonics, volcanism, lithology, mineralogy, geomechanics, hydrogeology, geochemistry, geodynamic evolution, transfer and retention properties, biosphere, climatic change			
• Hard clay: Bure, France	4	8	CM
• Salt: Gorleben, Germany	1		
• Soft clay: Mol, Belgium	1		
• Granite : SKB…	1		
• TUFF: US-DOE	1		
3.1.5 Experience from URLs		6	
Asse (salt, Germany)	1		
Grimsel (granite, Switzerland)	1		

Aspö (granite, Sweden)	1		
Hades (soft clay, Belgium)	1		
Opalinus (hard clay, Switzerland)	1		
Bure (hard clay, france)	1		
3.2 Repository technology			
3.2.1 Development of repository technology		6	
• Specific drilling techniques	1		
• Systems for closure of disposal shafts, disposal galleries and other emplacement locations in salt, granite and clay (examples from Germany, France, Sweden…)	1		
• Systems for waste emplacement (France, Germany…)	2		
• Dripshield, USA	1		
• Systems/instrumentation for long-term monitoring	1		
3.2.2 Materials choices, materials properties and design of engineered barrier system (EBS)		8	
Bentonite			
Cement			
Crushed salt			
Metallic liners			
EBS design in France, Belgium, Germany, Sweden, Switzerland, Japan, United States			
3.2.3 Visit of Bure		10	
3.3 Phenomenology of evolution of disposal system			
3.3.1. Evolution of disposal system during operational and long term post closure phase (host rock disturbed by EDZ, thermal evolution, evolution of interconnected and isolated void spaces, processus of water saturation, formation of hydrogen gaz, thermomechanical evolution, reference to natural analogues)			
• Clay	6	10	CM
• Salt	2		
• Granite	2		
3.3.2 The various phases in the « life-cycle » of a disposal site for high level waste: operational/reversible/post-operational -irreversible / Thermal, geochemical, geomechanic evolution of the disposal site in near and far field for different disposal concepts)		2	CM
3.3.3 Evolution of EBS and waste packages under repository multiples interaction conditions		**12**	CM
• Long-term behavior of nuclear waster glass and spent fuel and associated RN release and models	3		

• Long-term alteration of beton and RN retention	1		
• Long-term RN release from Bitumen and model	1		
• Corrosion of metals: rates and corrosion products	1		
• Interaction between clay and iron and clay/ cement and model	2		
• Production, storage and transfer of gases (in particular hydrogen)	2		
• Overall geochemical evolution of the near field	2		
3.3.4 Migration from EBS to biosphere		6	
• Migration and retention of RNs (phenomenology, mechanism and models)	4		CM
• Impact of biosphère	2		CM
Total (3)		**90**	
□			
(4) Safety and society			
4.1 Performance and safety analyses			
General methods of risk assessment, possibility for and limitation of long term predictions	4	30	CM
• Limits of predictability and the empirical character of science and decision making			
• notion of risk and safety: quantification/perception/acception			
Analytical methods	3		CM
• deterministic/probabilistic			
• fonctional analyses of barrier performance			
• nuclide specific role of barriers			
Safety analysis of the geological disposal system	5		CM
• Safety functions of EBS materials, geosphere and interfaces			
• Normal and altered evolution scenario			
• What if? Effect of failure of one or more barriers on radionuclide release from nearfield and form repository			
Global analyses of the safety of the disposal system	4		CM
• predicted evolution of radionuclide release: key path ways and timing			
• key radionuclides in clay, salt, tuff and granite			
Performance and safety analyses of surface and subsurface disposal	4		CM
• Saftey analyses of a disposal of very low, low and intermediate level short lived waste TFA / FM A			
Modeling and methods for long term simulation	10		TP Visit à l'andra

4.2 Radioprotection		18	CM/TP
• dose/ inhalation/ingestion/			
• Conversion factors Bq/dose			
• dose calculation for external exposure			
• procedures for radioprotection			
• Radiotoxicity vs. Chemotoxicity of radionuclides			
4.3 Institutional framework, actors and responabilities			
• General safety objectifs	1	14	CM
• French situation: Code of environment, PNGMDR, « 3 orientations of research » Actors, responsibilities, organization, financing, planning. . .	1		
• Situation in Sweden, Finland			
• Situation in Germany, United Kingdom…	1		
• United states, Japan, others			
• Role of international organizations: iaea, nea…	2		
Project management, examples from national and European projects	4		Visite?
Preparation of environmental impact statements	5		
4.4 Socioeconomic and ethical aspects			
• Public acceptance/ reversibility/implication of scientific, general and local public	2	19	CM
• Integration of disposal concept and and regional development /socioeconomic aspects of site selection/International examples	3		
• Radioactive waste governance in an international perspective	3		CM
• Intergenerational responsabilities (ethics and memory)	4		
• Cost analyses and financial elements	3		
• Protest movements, example germany	4		
Total (4)		**81**	
GROSS TOTAL		**351**	