Course on "Nuclear Safeguards"

Units and LO Statements

Unit 1 – History of non-proliferation and safeguards (4 hours + case study assignment) ***UU***	**Responsibility / Autonomy**	
	Autonomous capability to account for history of international safeguards	
	Skills	**Knowledge**
• Brief history of nuclear weapons • Historical evolution of non-proliferation and international nuclear safeguards • Different schools of thought with respect to International Relations • Nations staying outside or leaving international safeguards treaties • …	• Analyse the action of different states with respect to nuclear weaponisation, de-weaponisation or adherence to international treaties in the light of international relations and different schools of thought • …	• Be familiar with the historical use of nuclear weapons in military conflicts • Understand the historical development of non-proliferation and international safeguards • …
Assessment criteria: To demonstrate knowledge of the historical background of nuclear weapons and nuclear non-proliferation regimes. To demonstrate skills in the analysis of different state's action with respect to nuclear weapons and proliferation		
Assessment methods: Questions on historical background included in written examination. Additional assignment comprising theoretical case studies of states' historical actions.		

Unit 2 – Legal frameworks (3-4 hours) Jülich/SCK-CEN	**Responsibility / Autonomy**	
	Describe the basic principles of safeguards and its legal basis	
	Skills	**Knowledge**
• Basic principles of safeguards and non-proliferation • International non-proliferation treaties • Safeguards agreements • Safeguards approaches on the facility level and the State level	• Recognize the role of non-proliferation and safeguards • Design a generic safeguards approach for a nuclear facility • Outline a State-level safeguards approach	• Illustrate the basic concepts of nuclear safeguards (e.g. significant quantity, timeliness, ….) • Compare the international treaties on safeguards and arms control • Identify the steps for the development of a safeguards approach • …
Assessment criteria: To demonstrate understanding of the basic safeguards principles and of the main characteristics of the safeguards international treaties.		
Assessment methods: Short essay (1-2 pag. maximum) on State-level safeguards approach for a model country. Questions on the different learning units are included in the written examination.		

Unit 3 – Fuel cycle and non-proliferation (4 hours) UU	**Responsibility / Autonomy**	
	Mastering flows of sensitive nuclear materials in open and closed fuel cycles	
	Skills	**Knowledge**

• Open and closed fuel cycles
• Facilities and technologies involved in each cycle step:
  ○ Mining
  ○ Milling
  ○ Refining & conversion
  ○ Fuel fabrication
  ○ Reactor operation
  ○ Spent fuel interim storage
  ○ Reprocessing / recycling
  ○ Encapsulation
  ○ Final reposition …
	• Capability to account for material properties in each step of the nuclear fuel cycle(s) and to discuss the sensitivity to diversion of each step from a proliferation perspective
	• …
		• Discriminate between fissile and fertile material
		• Distinguish the open fuel cycle from the closed fuel cycle
		• Recognise all steps of the nuclear fuel cycle(s)
		• Understand the need and techniques for enrichment of natural uranium in U-235 for use in most commercial reactors
		• Understand the processes used for reprocessing or recycling of irradiated nuclear fuel
		• Identify possible proliferation issues related to each step in the fuel cycle(s)
		• …

• Sensitivity to diversion of fissile material in the steps of the fuel cycle • …		
Assessment criteria: To demonstrate knowledge of the open and closed fuel cycles and understanding of possible proliferation issues related to each cycle step.		
Assessment methods: Questions on diversion issues for the steps of the fuel cycles included in the written examination.		
Unit 4 – Nuclear material accountancy SCK-CEN (1-2 hours)	**Responsibility / Autonomy** Understand the principles of nuclear material accountancy	
	Skills	**Knowledge**
• Nuclear material accountancy (NMA) in the context of nuclear safeguards • Structure of the nuclear material balance • Principles of statistics applied to NMA • Attribute/Variable sampling • …	• Prepare a general sampling strategy to detect diversion scenarios • …	• Explain the objectives of nuclear material accountancy • Explain the general structure of nuclear material balance in a facility • …
Assessment criteria: To demonstrate knowledge of nuclear material accountancy and basic principles of statistics needed for the NMA evaluation.		
Assessment methods: Questions on different learning units are included in the written examination.		
Unit 5 – Probabilistic and statistical methods for nuclear safeguards (4 lecture, 4 hours exercises) Jülich	**Responsibility / Autonomy**	
	Skills	**Knowledge**
• Basic probabilistic and statistical principles used in safeguards • Measurement errors and their propagation • Random inspection approaches • Inspection verification sampling plans	• Can apply basic probability and statistical methods to simplified safeguards problems • Can thoroughly interpret confidence statements and results from statistical tests • Knows, how error variances are propagated • Can determine the achieved detection probability of random inspection approaches • Can calculate the required number of attribute samples to achieve a required non-detection probability	• Use basic probability rules and explain the differences between discrete and continuous random variables • Describe the components of a statistical test and its use in safeguards • Describe error components and their importance in error propagation • Explain modelling assumptions of random inspection approaches • Explain assumptions for creating an attribute sampling plan
Assessment criteria: To demonstrate understanding of basic probabilistic and statistical principles applied in the field of nuclear material accountancy.		
Assessment methods: Questions on different learning units are included in the written examination and the exercises.		
Unit 6 – Export control (4 hours) JRC	**Responsibility / Autonomy** Understand Export control and how it contributes to nuclear safeguards and non-proliferation	
	Skills	**Knowledge**
• International Export Control Regimes • Export control commitments required by the NPT, CSA and Additional Protocol • Principles of the EU (Nuclear) Export Control Regime • Nuclear dual-use items • Illicit procurement and export control challenges	• Understand export control objectives • Implement parts of the EU export control legal framework • Assess whether items or technologies are subject to export control authorisations	• International Export Control Regimes • Export control commitments required by the NPT, CSA and Additional Protocol • Principles of the EU (Nuclear) Export Control Regime • Nuclear dual-use items • Illicit procurement and export control challenges
Assessment criteria: To demonstrate knowledge of export control and of possible proliferation issues related to dual-use items		
Assessment methods: Questions on export control included in the written examination.		

Unit 7 –Implementation of safeguards (4 hours) Jülich	**Responsibility / Autonomy**	
	Understand how safeguards is implemented in a State	
	Skills	**Knowledge**
• Types of safeguards-relevant information • Types of inspections activities and inspection techniques • Design information verification / Basic technical characteristics • Safeguards Regulatory Authorities • State and Regional Systems of Accounting for and Control of nuclear material (SSACs/RSACs) • Collaboration between regional and international inspectorates • Typical issues during inspections • …	• Distinguish between different types of safeguards-relevant information • Discriminate between different types of inspections activities and inspection techniques • Recognize the importance of collaboration between regional and international inspectorates • Identify possible solutions for addressing typical issues during inspections • …	• Understand the basic procedures and obligations of practical safeguards implementation on the operators' and inspectorates' side. • Understand the process of design information verification / basic technical characteristics • Understand the new partnership approach (NPA) • ...
Assessment criteria: To demonstrate understanding of the practical implementation of safeguards on the States' and inspectorates' side.		
Assessment methods: Questions on implementation of safeguards included in written examination.		

Unit 8 – Containment and Surveillance (C&S) (4 hours lecture) JRC	**Responsibility / Autonomy**	
	Be aware of the existing technological solution for C&S in nuclear safeguards	
	Skills	**Knowledge**

• General presentation about C&S objectives, approaches and technologies
• Sealing technology
  ○ General presentation about seals (what is a seal, different types of seals)
  ○ Passive Seals, e.g. COBRA, metallic seals
  ○ Electronic seals (EOSS, AOLS, etc.)
  ○ Ultrasonic seals (US principles and US seal description)
• Surveillance technologies
  ○ Single- and multi-camera optical systems
  ○ Surveillance review software
  ○ 3D surveillance and change detection
• Smart sensors
• Containment Systems (cabinets, storage containers, conduits)
• Remote Monitoring
• Data encryption and authentication
	• Understand the most effective C&S technology to be adopted depending on the working scenario
	• Design and set-up the solution based on the identified technology
	• Analyse information generated by the solution and draw conclusions
		• Be familiar with C&S technologies:
		  ○ Different sealing technologies
		  ○ Video surveillance
		  ○ 3D technologies
		  ○ Smart sensors
		• Understand the objectives and requirements for C&S in nuclear safeguards, e.g. Continuity of Knowledge, Tamper Resistance, Vulnerability Assessment

Assessment criteria: To demonstrate understanding of different C/S devices for Nuclear Safeguards		
Assessment methods: Questions about different equipments: why they are used and for which specific NS application		

Unit 9 – Non-Destructive Assay (NDA) (4 hours lectures + 4 hours hands-on exercises, if possible) UU	**Responsibility / Autonomy**	
	Autonomous capability to evaluate the use of NDA techniques in safeguards	
	Skills	**Knowledge**

• General principles of non-destructive measurements
• NDA techniques and instruments used in nuclear safeguards
  ○ Calorimetry
  ○ Gamma spectrometry
	• Draw conclusions on adequacy of measurement procedures in terms of accuracy and simplicity
	• Capability to select assessment technique depending on object
		• Be familiar with NDA techniques and equipment used in nuclear safeguards
		• Connect properties of object under study with quantities available for NDA

○ Neutron assay ○ Cherenkov light detection • NDA techniques under development ○ Gamma tomography ○ … • …	• Apply counting statistics to determine precision in measured quantities • Hands-on experience of NDA techniques and procedures • …	• Understand how equipment used must be adapted to properties of the object under study • Understand gamma spectroscopic methods and the influence on data quality from the selection of gamma-ray detection system • Have insight in NDA techniques under development • …
Assessment criteria: To demonstrate understanding of NDA of nuclear materials and capabilities to execute analysis of NDA data.		
Assessment methods: Questions on NDA techniques and equipment included in written examination. Hands-on exercise of a selected NDA technique, including written report of the exercise.		
Unit 10 – Destructive Analysis (DA) ***(4 hours + 2 hours desk top exercise) JRC***	**Responsibility / Autonomy** Acquire knowledge about techniques of high sensitivity, selectivity and accuracy in safeguards and understand quality control concepts	
	Skills	**Knowledge**
• General principles of DA analysis: ○ Dissolution techniques (metals, oxides, etc.) ○ Separation techniques (anion exchange, extraction chromatography, etc.) ○ Hydrolysis (UF_6) • Nuclear material analysis • Environmental analysis (bulk and particle swipes) • DA techniques applied in safeguards (isotope ratios, content/concentration) ○ Mass spectrometry (TIMS, ICP-MS, LA-ICP-MS, SIMS, GSMS, FT-TIMS, etc.) ○ Alpha spectrometry ○ Controlled potential coulometry ○ Titrimetry ○ Hybrid K-edge ○ COMPUCEA • Quality control tools: ○ Method validation ○ Document standards (ISO, ITVs, ASTM, etc.) ○ Reference materials (CRM, RM, etc.) ○ Inter-laboratory comparison (ILC) ○ Uncertainty estimation (GUM, etc.) • …	• Selection of a proper DA approach depending on the type of a sample (environmental vs. nuclear sample) • Special sample analysis and isotopic fingerprinting for nuclear safety, security and safeguards • Instrument calibration (desk top exercise) • Uncertainty budget – top down and bottom up approach (desk top exercise) • …	• Be familiar with DA techniques and instrumentation applied in nuclear safeguards • Be familiar with DA techniques applied in EURATOM/IAEA on-site laboratories • Be familiar with quality in analytical measurements • Acquire knowledge on the estimation of measurement uncertainty in DA • Be familiar with the quality system (international guidelines, ITVs and QC tools) • Be familiar with the significant quantities in safeguards • …
Assessment criteria: To demonstrate understanding of DA techniques for nuclear and environmental materials		
Assessment methods: Questions on DA techniques included in written examination.		
Unit 11 – Novel technologies, approaches and methodologies ***(3-4 hours) Jülich***	**Responsibility / Autonomy** Scanning the horizon for potential technologies, approaches and methodologies	
	Skills	**Knowledge**
• Technology foresight • Instrumentation toolkit for inspectors (“smart inspectors”) • Autonomous navigation and positioning for safeguards • Robots (including UAVs)	• Identify potential technologies, approaches and methodologies from non-traditional safeguards fields • Assess the impact of novel technologies, approaches and methodologies on the effectiveness and efficiency of safeguards	• Understand the need and basic process of technology foresight • Understand the basic principles and potentials of today’s novel technologies, approaches and methodologies • …

• In-situ analysis • Artificial intelligence and machine learning • …	• Consider the safety and security provisions as to the implementation of novel technologies, approaches and methodologies • …	
Assessment criteria: To demonstrate understanding of NDA of nuclear materials and capabilities to execute analysis of NDA data.		
Assessment methods: Questions on novel technologies, approaches and methodologies included in written examination.		
Unit 12 – Physical protection ***(1-2 hours) SCK-CEN***	**Responsibility / Autonomy** Master the objectives and concepts of physical protection	
	Skills	**Knowledge**
• Basic concepts of physical protection • Graded approach: nuclear and radioactive material categorization • Vital areas and access controlled areas • Overview of physical protection systems • …	• Design a general physical protection system for a nuclear facility • …	• Explain the basic concepts of physical protection • Illustrate the graded approach and the differences between areas in a nuclear facility • …
Assessment criteria: To demonstrate knowledge and importance of physical protection systems.		
Assessment methods: Questions on the different learning units are included in the written examination		
Unit 13 –Illicit trafficking ***(3-4 hours) SCK-CEN***	**Responsibility / Autonomy** Master the techniques to detect illicit trafficking of radioactive materials	
	Skills	**Knowledge**
• Introduction and objectives • Legal basis • Detection equipment • Response to an alarm • Authorized uses of radioactive materials • Cases of illicit trafficking • …	• Recognize and compare detectors that can be used for the detection of illicit trafficking • Execute a general approach for the response to an alarm in case of illicit trafficking • Differentiate between authorized uses of radioactive materials and cases of illicit trafficking • …	• Discuss the objectives and risks of illicit trafficking • Explain the legal basis for the detection of illicit trafficking • …
Assessment criteria: To demonstrate knowledge of illicit trafficking and available means to detect potential scenarios.		
Assessment methods: Questions on the illicit trafficking are included in the written examination.		
Unit 14 – Upcoming challenges ***(3-4 hours) Jülich***	**Responsibility / Autonomy** Strengthening non-proliferation and safeguards	
	Skills	**Knowledge**
• Emerging technologies (incl. social media) • Cyber-attacks • Geopolitical developments • Non-State actors, terrorism • Future of legal frameworks • …	• Identify and assess upcoming challenges for the safeguards system • Apply risk analysis with regard to upcoming challenges (…)	• Understand the potential influences on the safeguards system • Understand the possible impact and consequences of future challenges for non-proliferation and safeguards • (…)
Assessment criteria: To demonstrate understanding of upcoming challenges and its implications to the safeguards system.		
Assessment methods: Questions on the upcoming challenges are included in the written examination.		

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

- Official in state authority for supervision of nuclear technology and materials
- Inspector working with in-field verification of nuclear materials and activities
- Employee in commercial enterprise with responsibility for nuclear materials accountancy