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MOOC "NRC for citizens"

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EXECUTIVE SUMMARY

The deliverable titled *MOOC "NRC for citizens"* presents the design and development of an engaging and informative Massive Open Online Course (MOOC) for the general public, designed to empower learners with a comprehensive understanding of nuclear science, radioactivity, and their multifaceted applications. The innovative MOOC course *"Discovering Nuclear Science: Energy and Beyond"* is structured into three sections ("weeks"), with a total of ten modules, each meticulously crafted to deliver an immersive learning experience.

Week 1, "*The Nature of Radioactivity*", kicks off the journey by delving into the world of radioactive elements present in nature and those ones artificially produced by humankind for several purposes. Learners gain insights into the origins of radioactivity, setting the stage for deeper exploration.

Week 2, "*Ionizing Radiation in Action*", offers a closer look at the practical applications of ionising radiation. Modules cover a wide spectrum of topics, from the use of radiation for sterilisation and industrial processes to its pivotal role in healthcare and technological progress.

In Week 3, "*Navigating Nuclear Hazard*", learners confront the multifaceted aspects of the most famous and discussed nuclear themes, including nuclear energy, the environmental impact of radionuclides, nuclear threats, and nuclear waste. This section provides a perspective on the challenges and opportunities associated with nuclear science for energy.

The pedagogical framework underlying the course employs a scenario-based learning approach, fostering engagement and critical thinking through four key steps: "Bring into Play" "From Detail to Understanding" "Food for Thought" and "Self-assessment". This pedagogical structure enhances the learning experience and encourages active participation, ensuring that learners receive a well-structured and informative educational resource.

The deliverable further outlines the course's development process, including content definition, lesson development, and an overview of the course contents.

CONTENT

1 INTRODUCTION

The contemporary landscape of the nuclear sector, as outlined in the EURATOM Work Programme 2019-2020 Nuclear Fission and Radiation Protection Research (NFRP-2019-2020-11), reveals pressing concerns. Foremost among these concerns is the waning interest in specialised nuclear knowledge among the younger generation. Simultaneously, the sector faces the imminent departure of an ageing workforce, creating a potential knowledge and skills gap that must be addressed. Regardless of the future direction of the European Union's nuclear power sector, there remains a steadfast requirement for highly educated professionals equipped with specialized knowledge, skills, and competencies.

In response to these challenges, initiatives to engage and attract new talent are imperative. A pivotal strategy in this endeavor involves cultivating awareness of Nuclear and Radio Chemistry (NRC) topics among individuals with varying levels of expertise. It is from this perspective that a novel initiative has emerged: the development of the "Discovering Nuclear Science: Energy and Beyond" MOOC. This online open course is strategically designed to introduce citizens to the captivating realm of nuclear science, simultaneously enhancing their awareness of crucial nuclear topics. Beyond awareness, it aspires to stimulate interest among younger generations in pursuing careers in the field of NRC.

This document serves as a comprehensive roadmap for the development of the "Discovering Nuclear Science: Energy and Beyond" MOOC. In the following sections, we will detail the vision, objectives, and strategies for creating an engaging and impactful educational experience that not only demystifies nuclear science but also inspires a new generation of learners to explore the limitless possibilities it offers.

1. MOOC Design

Designing a Massive Open Online Course is a complex undertaking, and the first crucial step is to establish the foundation of the educational approach. This process involves thoughtful consideration of the target audience, their educational backgrounds, the course's objectives, and the key topics to be covered. In this section, we outline the key elements that guided the development of the MOOC, with a particular focus on the learning approach.

Target group: general public.

Prerequisites: basic scientific background knowledge, acquired through high school and/or higher education.

General Goals: the MOOC aims to achieve the following objectives:

- **Stir Curiosity**: to ignite curiosity in nuclear themes and their practical applications.
- **Counter Misinformation**: to dispel misconceptions and prevent the spread of false information.
- **Cultivate Interest**: to cultivate users' interest in an unfamiliar discipline.
- **Promote Awareness**: to make users aware of the potential and advancements in the field of radiation science and its advantages in our lives.
- **Enhance Understanding**: to empower users to comprehend news related to NRC and its applications.

The successful realisation and the effectiveness of this MOOC hinges on the careful selection of the appropriate learning approach. Drawing from the experience gained during the development of the "Essential Radiochemistry for Society" MOOC, developed during the previous MEET-CINCH Project, the key characteristics that will define the course have been identified. Of utmost importance is the **communication style**, which will be tailored to be as engaging as possible. This will involve leveraging social networks, stimulating *critical thinking*, and promoting *active user participation*, all while adhering to the principles of *inclusive education*.

To achieve these goals, the incorporation of various multimedia elements into the MOOC has been considered, such as short, informative videos, simple infographics, compelling images, insightful interviews, and current news from newspapers, television, and social media. Based on these considerations, the **scenario-based learning approach** aligns most effectively with these objectives.

In the subsequent sections, we will delve deeper into the specifics of the chosen learning approach, providing a comprehensive roadmap for the development of our MOOC.

1.1 Scenario based Learning Approach

Scenario based learning (SBL) involves, as the name implies, teaching through the use of simulated scenarios which use narratives to guide learners through certain situations which can be adapted based on the choices and responses of the learners.

These scenarios work best when they mirror real world situations [1, 2] that learners are likely to encounter within their subject, i.e. medical students dealing with patients, engineering students dealing with a building project: students are asked to immerse themselves in the situation and solve the dilemma [3]. Scenarios are designed to engage learners in processes of problem-solving, decision-making, critical thinking, generating perspectives, and acting creatively in relation to assumed roles, responsibilities, dilemmas, and challenges of the professional culture [4]. SBL affords learners a more active role in their learning and the opportunity to develop and practice real life skills that they will need to operate successfully in the global state. In teacher education, scenarios permit learners to safely explore situations they might face in their future classrooms [4, 5]; to apply theory to practice; and to help develop learners' professional identities [6].

A scenario is a presentation of a possible future situation in narrative form. One important characteristic of the scenario method lies in its explicit inclusion of uncertainties and its comparison of development alternatives that could shape the course of events [7]. Effective scenarios are realistic, mimicking what would happen in real life as the scenario unfolds. Like stories, scenarios also need to be engaging, so consider using the dramatic arc to help you build action into your scenario. Good scenarios can also be emotive.

To build an effective learning experience using SBL, it is paramount to:

1. **Identify the learning objectives**
   The first step is to identify the performance-based learning objectives that the course is going to address. The learning objectives should form the basis for the scenarios. They can be included in the whole course or just in the assessment phases.
2. **Know your learners**
   Understand learners' needs and their day-to-day struggles at work to identify areas in which they need training. Scenarios relevant to their job tasks help improve their decision-making skills.
3. **Provide scenarios with the use of stories**
4. **Make scenarios true to life**
   Scenarios should be realistic and relevant for learners. Learning in a life like yet risk-free setting takes the stress out of the learning and boosts learning and retention ultimately improving employee performance.
5. **Make scenarios realistic, engaging and immersive**
   Scenarios can be more interesting and immersive by using: images, characters background, challenges, short videos, direct speech, conversational tone and informal language.
6. **Provide the opportunity of practicing decision making, safely and experiencing, albeit virtually, the success or failure of those decisions**
7. **Considering cognitive failures, and how these failures influence our ability to make good decisions**

1.1.1 SCENARIO BASED APPROACH FOR the A-CINCH „MOOC FOR CITIZENS“

The target group selected, along with the general goals adopted, allowed to define the key point of the learning approach tailored for this course. In particular, the course will be designed to:

- Build a **realistic story/situation**, to activate participants curiosity and engagement;
- Put a (multiple choices) **question**, involving the learner in problem-solving / decision-making / critical thinking, / generating perspectives, and acting creatively;
- Provide **feedback / answers / explanation** of reasons;
- Provide **opportunities to go deeper** in the theme (ad hoc didactical materials);

- Provide suggestions to **reliable online resources** (external links).

1.2 Pedagogical Framework

The considerations on the learning approach, communication style and lexicon, along with the Scenario Based Learning style adopted enable the design of the **pedagogical framework** of this course. This is divided into 4 steps as follows (see Figure 1):

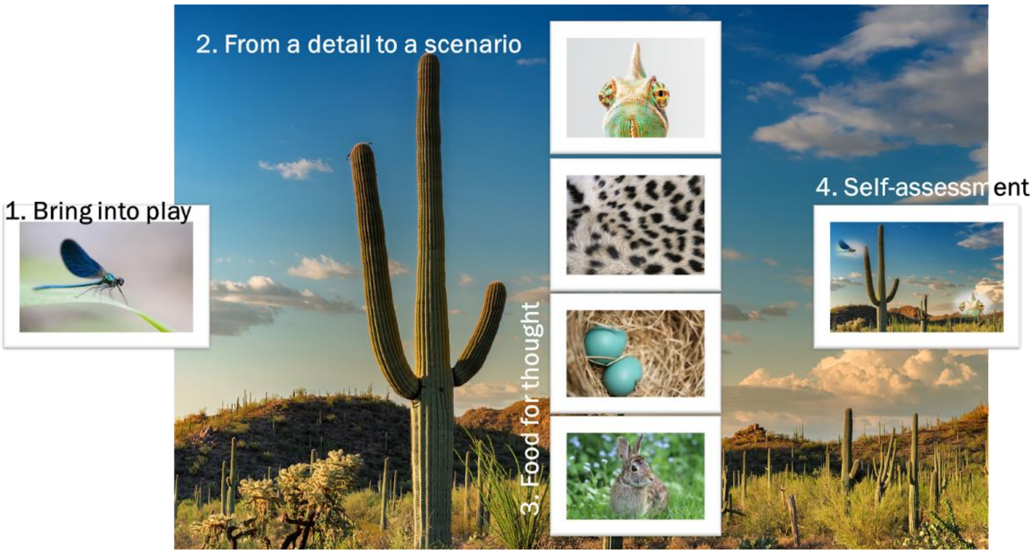

Figure 1 - MOOC "NRC for citizens" Pedagogical Framework

1) **Bring into play**

   Users' interest is piqued by a resource (a news, an image, a short video). Users answer a question about their opinion on the topic. Very easy feedback introduce on the topic.

2) **From a detail to understanding**

   A short 3-minutes video gives the necessary foundation to understand the scenario and the related issues.

3) **Food for thought**

   Users choose among some didactical materials displayed in different formats (an infographic, a short text, an interview, a case study) and explore them for a deeper understanding

4) **Self-Assessment**

   Users answer again to the question or to a new question to realize they have acquired awareness about the topic.

The pedagogical framework will be at the base of each module development, guiding the user into the voyage of discovery of the topic. All the lessons will be subjected also to the guiding principles discussed in the next section.

This pedagogical framework, being at the base of each module development, serves as the cornerstone for the entire course development process. It lays the foundation for an engaging and effective learning journey, guiding users through a captivating exploration of the course topics. These guiding principles will not only be reflected in the course's structure and content but will also permeate every lesson, ensuring that learners receive a comprehensive and enriching educational experience. In the following section, we delve deeper into the guiding principles at the basis of this pedagogical framework, which underpin the course's design and are essential to empowering learners and fostering their genuine understanding of nuclear science.

1.2.1 Guiding principles in course development

Key pedagogical considerations guide every aspect of the course development, serving as the cornerstone for a robust and effective learning experience.

- **Inclusivity: Fostering Diverse Perspectives**

Recognizing the importance of catering to a wide-ranging audience with diverse backgrounds, interests, and perspectives, the course materials are meticulously crafted to promote inclusivity, particularly in view of graphical content. This meticulous approach ensures that visuals are universally comprehensible and resonate with learners from various cultural and educational backgrounds. Such inclusivity encourages engagement and participation from a broader spectrum of learners, enriching the learning environment.

- **Gender Balance: Encouraging Equal Participation**

The course is intentionally developed to establish an inclusive environment where all learners feel equally represented and valued. This commitment extends beyond the composition of course materials to encompass the selection of speakers and experts featured throughout the course. By ensuring gender balance, the aim is to eliminate potential barriers that might hinder learners from fully engaging with the content, fostering an equitable learning experience.

- **Connection with the Public and Accessibility: Bridging the Gap**

A core pedagogical objective is to establish a strong connection with the public and enhance accessibility. Course content is thoughtfully designed to bridge the gap between the complex world of nuclear and radiochemistry and the broader public. Acknowledging that learners come from diverse backgrounds with varying levels of prior expertise, the course employs accessible language, avoids jargon, and maintains a clear and concise communication style. These considerations ensure that even the most intricate topics are comprehensible to all, facilitating broader access to knowledge. Moreover, in case of graphical contents, accessibility text will be provided.

- **Clarity, Neutrality, and Critical Thinking: Facilitating Deep Understanding**

Clarity is a fundamental guiding principle that ensures course content is presented in a digestible manner, facilitating the comprehension of complex topics. The course also maintains strict neutrality, avoiding personal opinions to empower learners in forming their own well-informed perspectives. By steering clear of personal biases and opinions, learners are encouraged to think critically, honing their ability to draw informed conclusions—a vital skill within nuclear and radiochemistry. This fusion of clarity, neutrality, and critical thinking enables learners to cultivate genuine awareness and construct a comprehensive understanding of these subjects.

- **Capturing Interest and Curiosity: The Multi-Faceted Approach**

Within the realm of pedagogy, the primary focus is on capturing learners' interest and curiosity. Indeed, a motivated learner is more engaged and receptive. To achieve this, the course employs a multi-faceted approach that, following the pedagogical framework, includes thought-provoking questions, engaging visuals, diverse speakers, and supplementary resources. This approach not only kindles curiosity but also sustains it throughout the learning journey, resulting in a more profound and enduring educational experience.

1.2.2 Content development

The development of the "Discovering Nuclear Science: Energy and Beyond" MOOC begins with a meticulous selection of topics that are not only essential to a foundational understanding of Nuclear and Radio Chemistry (NRC) but also directly address common misconceptions and in general embrace the wider field of nuclear technologies. In this section, we outline the approach to content selection, emphasizing the significance of dispelling misconceptions that often circulate through various media channels. This process ensures that our course content resonates with learners and equips them with the knowledge needed to critically evaluate nuclear topics in their everyday lives.

By structuring our MOOC content in this logical and pedagogically sound manner, we ensure that learners gain a comprehensive understanding of Nuclear and Radio Chemistry while fostering engagement and critical thinking.

1.2.3 Content definition

The development of this MOOC follows a thoughtful approach aimed at creating an effective learning experience. It began with the careful selection of content topics, eventually leading to the delineation of three distinct macro-areas. The driving idea behind this content selection was a recognition that many individuals often encounter negative narratives surrounding nuclear topics, resulting in misconceptions. To design a comprehensive course that addresses these misconceptions and offers a balanced perspective on nuclear topics, we aim to move beyond negative news and shed light on the positive applications of radionuclides and ionizing radiation. Our goal is to guide learners towards a critical, informed perspective that enables them to decipher complex nuclear and radiochemistry concepts. As part of this educational journey, it became evident that the initial step should involve comprehending the basics of radionuclides and ionizing radiation. This foundational knowledge paves the way for the informed exploration of nuclear topics. This section serves as the cornerstone of the course structure:

Please note that this content selection serves as the initial foundation for the MOOC's development but does not represent the final structure. As the MOOC progresses, new topics may be introduced, and the structure may evolve accordingly.

1. **Radioactive Matter/Radionuclides**

   In this week users will delve into the fundamental aspects of radioactive matter, discovering both natural and artificial radionuclides.

   1.1. Natural Radioactive Elements

   Exploring radionuclides found in everyday environments, such as your kitchen. Understanding the properties of natural radionuclides. Investigating the concept of radioactive decay and its implications. Unveiling the significance of radon in our surroundings.

   1.2 *Artificial Radionuclides*

Examining the role of nuclear power plants in creating new elements and isotopes. Navigating the world of artificial radionuclides. Grasping the concept of half-life and its applications.

Addressing pollution concerns arising from natural and artificial radionuclides, including anthropogenic sources. Discussing monitoring strategies for radionuclide migration and potential remediation efforts.

2. Radiations and Their Applications

This week aims to elucidate the various forms of radiation and their multifaceted applications.

2.1. *Radiation-Matter Interaction*

Investigating the interactions between radiation and matter. Analyzing different types of radiation. Examining sterilization methods for medical supplies and food irradiation. Discussing disinfestation techniques and the preservation of cultural heritage artifacts.

2.2. *Health Implications*

Addressing common misconceptions regarding the radioactivity of medical procedures. Distinguishing between internal and external sources of radiation exposure. Exploring the therapeutic and diagnostic applications of radiation in medicine. Investigating industrial applications, including radiation processing, radiotracing, and measurement techniques.

3. The Risks and Concerns of Nuclear Science

This week highlights the risks and concerns associated with nuclear science while emphasizing its potential benefits.

3.1. *Sustainable Energy Production*

Comparing nuclear energy to other energy sources in terms of sustainability. Analyzing the role of nuclear power plants in addressing climate change and providing clean energy solutions.

3.2. *Safety and Accidents*

Examining notable nuclear accidents, such as Fukushima and Chernobyl. Discussing safety measures, including the function of safety systems in nuclear power plants. Evaluating the risks associated with nuclear materials, including nuclear weapons and terrorism concerns.

3.3 *Radioactive Waste Management*

Investigating the challenges of managing nuclear waste. Assessing the source, radiotoxicity, and potential reprocessing of radioactive waste. Exploring long-term disposal methods and their implications.

1.3 Lessons development

In crafting the "Discovering Nuclear Science: Energy and Beyond" MOOC, the approach to lesson development aligns closely with the established Pedagogical framework. All the key aspects previously defined underpin all lesson development (inclusivity, gender balance, accessibility, avoidance of personal opinions, and maintaining clarity and neutrality). These considerations are vital as they empower learners to form their own opinions and cultivate genuine awareness. The foremost consideration is capturing the learner's interest and curiosity. To achieve this, a multi-faceted approach has been implemented:

Bring into play

Each module commences with a captivating idea designed to pique curiosity rather than test prior knowledge. This introductory component can take various forms, such as a video, a tweet, a picture, a movie clip, or an article, all centred around a simple yet thought-provoking question. For instance, the first module invites learners to contemplate the possibility of finding radioactivity in their kitchen. Similarly, the module on nuclear energy sparks curiosity by asking which energy sources can truly be labelled as sustainable. These initial questions set the stage for engaging exploration. They are not evaluated, and do not judge the opinion of the user, but give an initial consideration that starts the exploration of the contents.

From Detail to Understanding

Following the introductory "*Food for Thought*", a concise video lesson that provides an overview of the module's contents has been produced. These videos typically span 3 to 6 minutes, with more extensive topics sometimes split into two videos. The video content is structured into three sections: narration, graphics, and keywords. Abundant examples illustrate key concepts, making complex topics more accessible. Graphics are meticulously designed to enhance clarity and support the learning process. A consistent speaker throughout all the videos provides a reference presence for the entire course, complemented by a different speaker for each lesson, involving individuals from the radiochemistry and radiation chemistry laboratory team, including PhD students and professors. By featuring a diverse range of speakers, it was possible to create a more relatable and inclusive learning environment. Learners can connect with individuals at various stages of their academic and professional journey, fostering a sense of shared experience and making the course more approachable. This approach not only enhances accessibility but also showcases the collaborative and dynamic nature of scientific exploration, inspiring learners to engage more deeply with the content.

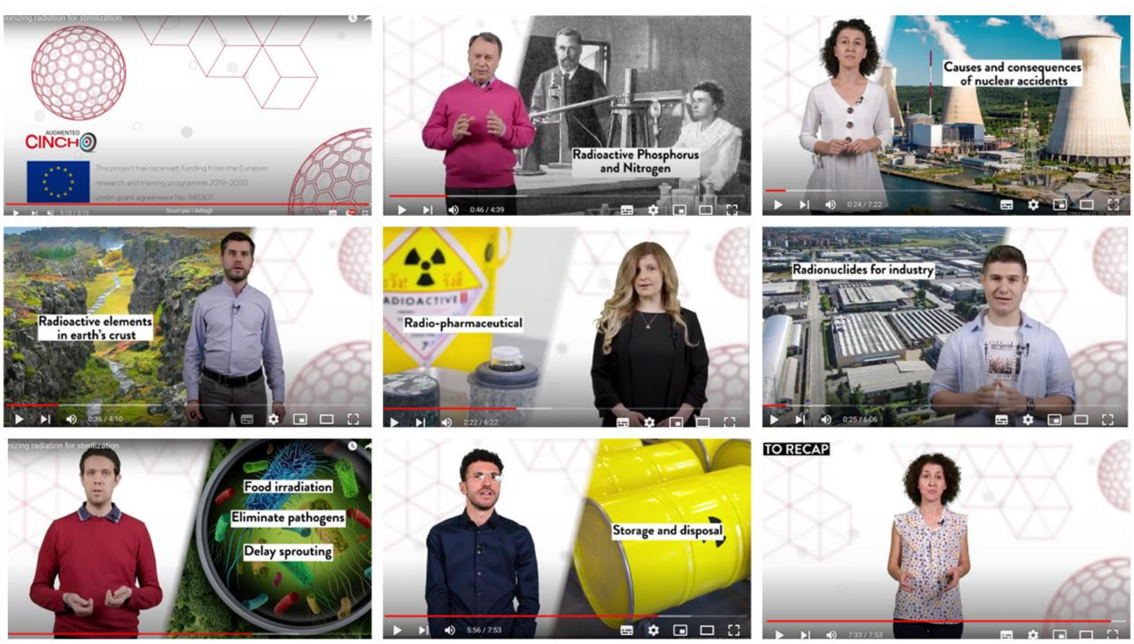

Figure 2 - Video Frames Featuring A-CINCH Project Credits and Various Speakers.

Food for thought

To facilitate deeper understanding, additional resources are offered in the form of infographics, articles, or expert interviews. These supplementary materials provide overviews of various topics without delving into excessive detail or complexity. For example, the module on radioactive waste management includes an article on the reprocessing of spent nuclear fuel, two infographics elucidating the decommissioning of nuclear power plants (a significant source of nuclear waste) and its waste management, as well as an article discussing the final destinations of nuclear waste.

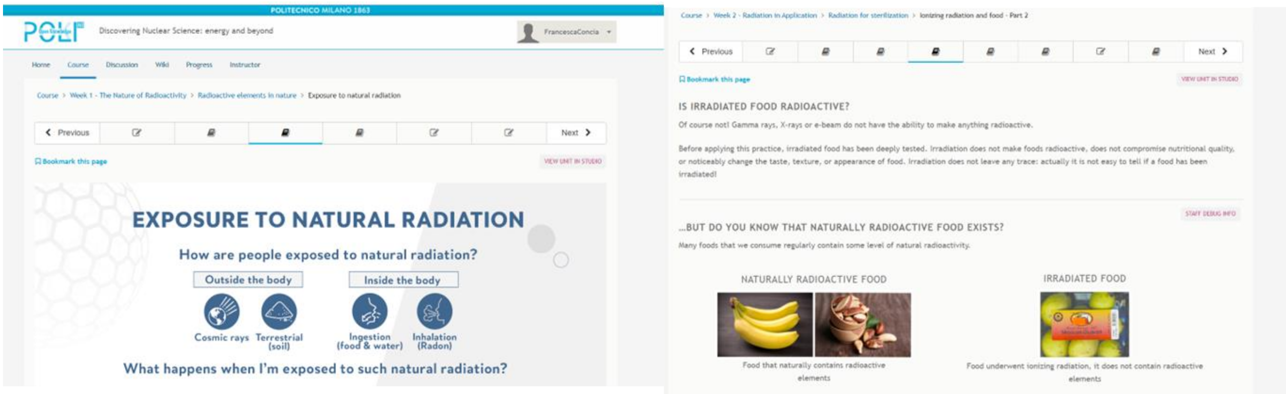

Figure 3 - Example of an infographic and an article format

<u>Self-Assessment</u>

A pivotal aspect of our course design is to foster increased awareness among learners. We incorporate a "*Check Your Understanding*" section comprising two or three questions that assess comprehension of the module's key topics. Additionally, the "*Realize your new awareness*" question encourages users to contemplate their evolving viewpoints without formal evaluation. For example, in the module discussing the applications of ionizing radiation, learners are prompted to consider whether such applications are always inherently dangerous. The nuclear energy module challenges learners to provide feedback on an article strongly critical of nuclear energy. Lastly, in the radiation for health module, users are invited to ponder the safety of a nuclear medicine examination. In general, this question often presents extreme viewpoints from news sources to stimulate critical thinking.

This comprehensive approach to lesson development ensures that learners not only acquire knowledge but are also engaged, encouraged to think critically, and equipped with a nuanced understanding of nuclear and radiochemistry topics.

2 THE MOOC “DISCOVERING NUCLEAR SCIENCE: ENERGY AND BEYOND”

The MOOC is available on the POK platform (Figure 4) at the following link: https://www.pok.polimi.it/courses/course-v1:Polimi+NRC101+2022_M7/about

Figure 4 - Link to the ”Discovering Nuclear Science: energy and beyond” MOOC, available on https://www.pok.polimi.it/.

In the following sections the course and the contents will be presented.

2.1 Course description

The course description is the first presentation of the course to the users and presents all the course characteristics that are the length, the format, the prerequisites, the effort and so on.

*“Welcome to the MOOC "**Discovering Nuclear Science: Energy and Beyond**" This course is designed for learners of all backgrounds and interests, presenting the captivating world of Nuclear Science in an engaging and accessible manner.*

Have you ever wondered about the fascinating applications of Nuclear Chemistry and Radiochemistry in our daily lives? If so, this course is the perfect opportunity to explore the answers to your questions. Through catchy questions and interactive polls, each module will introduce exciting topics that showcase the significance of Nuclear Science in our modern world.

The journey begins with engaging videos providing an overview of each module's subject. As you delve deeper, you will find a series of user-friendly lessons that gradually uncover the fundamental concepts and real-world applications of Nuclear Science and Technology. Fear not, there are no overly challenging lessons here! We've crafted this course to be inclusive and suitable for everyone. Our goal is to ensure that each learner, regardless of their background, can fully grasp the concepts and significance of Nuclear Science. At the end of each module, a final quiz will allow you to assess your understanding and knowledge gained. Additionally, a final lesson will provide valuable insights into the newfound awareness you've acquired throughout the course.

So, whether you're a curious individual with a general interest in science or a student looking to expand your horizons, "Discovering Nuclear Science: Energy and Beyond" promises an exciting and enlightening adventure into the world of Nuclear Science. Join us now and embark on this fascinating journey of discovery. Enrol in the course and unlock the potential of Nuclear Science to shape our future for the better. Let's get started!”

The "*Discovery Nuclear Science: Energy and Beyond*" MOOC is designed to be completed in approximately 10 hours, and it welcomes participants with no prior knowledge requirements. This course, in broad terms, aims to foster skills development across various domains, following the ESCO classification. Learners can expect to gain proficiency in inorganic chemistry, radiochemistry, the application of radioactive substances in diagnosis and treatment, nuclear physics, nuclear energy, as well as decontamination methods and sterilization techniques.

Operated at EQF Level 4, this MOOC spans thematic areas including chemistry (0531), physics (0533), and electricity and energy (0713). Importantly, it's an accessible educational platform that caters to a diverse audience, accommodating individuals from various backgrounds and without any prerequisites. The "Discovery Nuclear Science" MOOC offers an inclusive and informative learning experience, making nuclear science knowledge attainable for all.

2.2 Table of contents

The final course is divided in three weeks and ten modules as shown in the Table of contents:

2.3 Contents presentations

2.3.1 Week 1 – The Nature of radioactivity

In the first week of this MOOC, participants will dive into the intriguing world of natural and artificial radioactivity.

Module 1: **Radioactive Elements in Nature**

This module comprises a series of six lessons to present natural radioactivity and its presence in our environment (see Figure 5):

L1 Where does radioactivity hide? (Picture + question, Ungraded)
L2 Radioactive elements in nature (Video, 4.10 minutes, featuring E. Macerata and E. Mossini)
L3 Exposure to natural radiation (Infographic)
L4 How does Radon get in our home (Infographic)
L5 Check your competences (2 Quiz, Graded)
L6 Realize your new awareness (Picture + question, Ungraded)

In particular, these lessons provide a comprehensive understanding of the following concepts:

- **Radionuclides** and their presence in our **environment**.
- The distinction between stable and unstable atoms, the fundamental concept of **radioactive decay** and its implications.
- **Natural background radiation**.
- The occurrence of **radioactive potassium** in everyday foods.
- **Radon** gas as a significant contributor to indoor radiation and the effective strategies for mitigating Radon exposure in homes.
- The different routes through which individuals are exposed to radiation (ingestion, inhalation, cosmic rays, terrestrial sources). **Natural radiation exposure** for aircrew members.

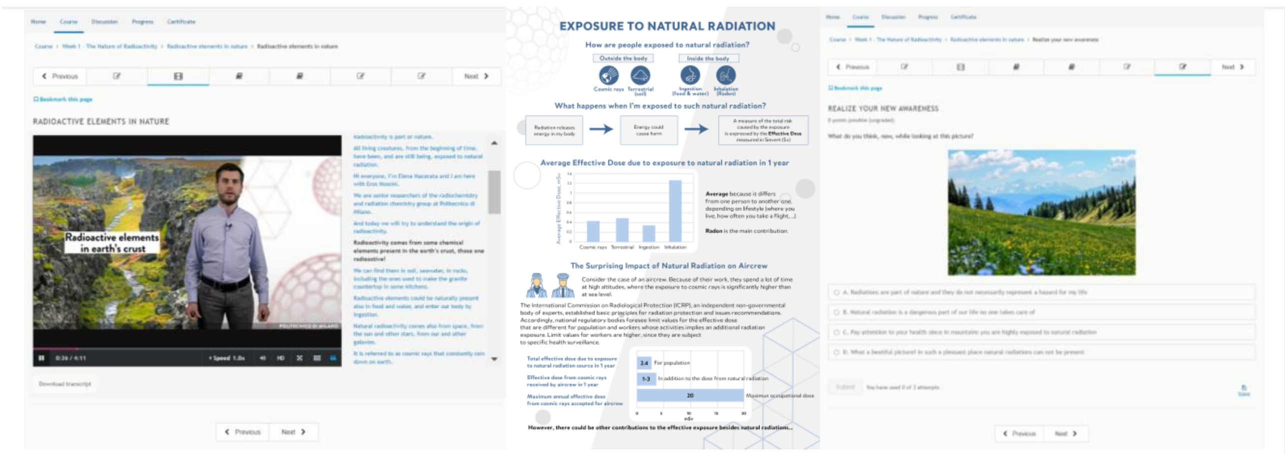

Figure 5 - Snapshot of some lessons of Week 1 Module 1 "Radioactive Elements in Nature".

Module 2: **Artificial Radioactive Elements**

In the second module, learners will delve into the realm of artificial radioactive elements. The module foresees 9 lessons as follows (Figure 6):

L1 Back to the future (Video + question, Ungraded)
L2 Artificial radioactive elements (Video, 4.39 min, featuring E. Macerata and M. Mariani)
L3 Artificial radioactive elements: nuclear power plants (Video, 4.15 min, featuring E. Macerata and M. Mariani)
L4 Reactors in numbers (Infographic)
L5 The very first nuclear reactor! (Quiz + comment, ungraded)
L6 A tour inside a nuclear power plant (external video Link)
L7 Technetium (Infographic)
L8 Check your competences (1 T/F Quiz, Graded)
L9 Realize your new awareness (Picture + question, Ungraded).

These lessons allow users to explore the following essential concepts:

- The concept of **isotopes** and how the same chemical element can have multiple nuclei, the methods used to create **artificial radioactive elements**.
- The pivotal discovery of **nuclear fission**, leading to energy release and the production of fission products, the **chain reaction** and the significance of fission products.
- **Nuclear power plant** operation, **safety** as a paramount factor, different generations of **nuclear reactors** designed to enhance safety and efficiency.
- A look back at the **natural nuclear fission reactor** discovered in Oklo, Gabon, in 1972—that shows that nuclear fission is a natural process.
- The revolutionary discovery of **technetium** and its profound impact on nuclear medicine, enabling advanced diagnostics and treatments.

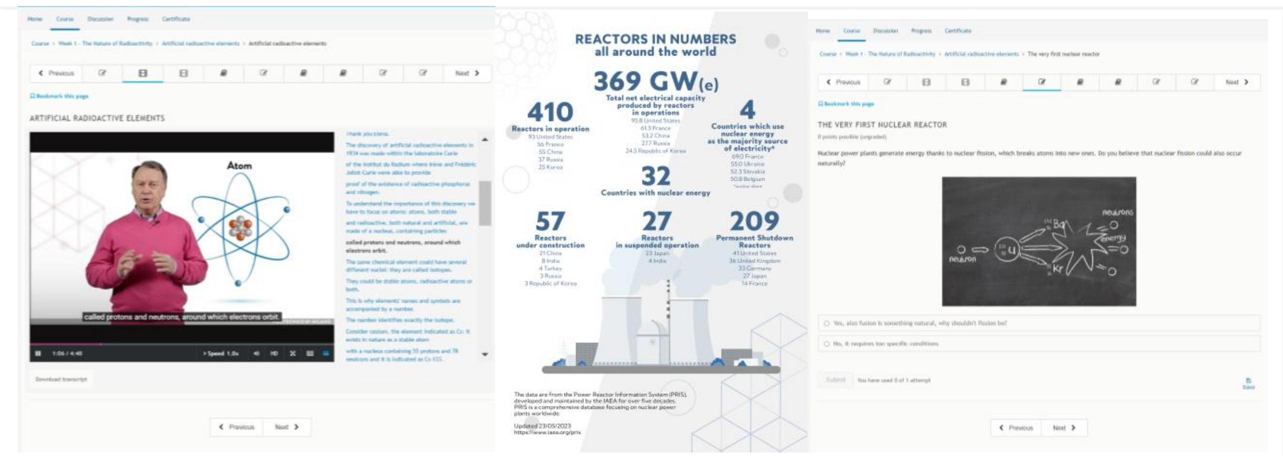

Figure 6 - Snapshot of some lessons of Week 1 Module 2 "Artificial Radioactive Elements".

2.3.2 Week 2 – Ionizing Radiation in Action

In the second week of this MOOC, participants will discover the different types of ionizing radiaiton and their application for society.

Module 1 - **About radiations**

This module encompasses a series of six lessons aimed at introducing the user the world of ionizing radiation (Figure 7):

L1 An unusual tool (Picture + question, ungraded)
L2 The power of ionizing radiation (Video, 3.30 min, featuring E. Macerata and M. Negrin)
L3 How to stop ionizing radiation (Infographic)
L4 Check your competences (2 T/F Quiz, Graded)
L5 Realize your new awareness (Question, Ungraded).

In this module, learners will acquire a comprehensive understanding of various key concepts, including:

- The diverse types of **ionizing radiation** emitted during the decay of radioactive elements, encompassing subatomic particles and high-energy electromagnetic waves.
- An exploration of **alpha and beta radiations**, **gamma rays and X-rays**, as well as **neutrons**, the **ionizing properties** of these radiations, and the **penetration capabilities** of different types of radiation and on what it depends.
- Insights into the **interactions between ionizing radiation and matter**, along with the methods required to effectively attenuate or **block** their passage.

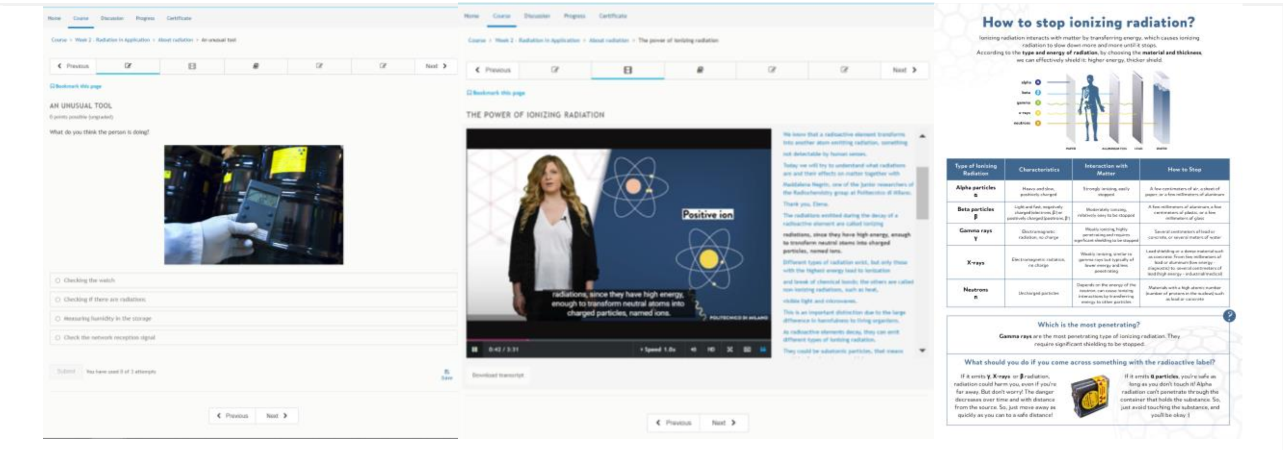

Figure 7 - Snapshot of some lessons of Week 2 Module 1 “About radiations”.

Module 2 - **Radiation for sterilization**

This module consists of a series of seven lessons aimed at exploring the applications of ionizing radiation in sterilization processes (Figure 8):

- L1 Space food! (Picture + question, Ungraded)
- L2 Ionizing radiation for sterilization (5.14 min, featuring E. Macerata and G. Magugliani)
- L3 Ionizing radiation and food (Article)
- L4 Irradiation facilities all around the world (Article)
- L5 Radiation to the rescue of cultural heritage (Written Interview with A. Cemmi)
- L6 Check your competences (Quiz, Graded)
- L7 Realize your new awareness (Text + Quiz, Ungraded).

Throughout these lessons, learners will develop a comprehensive understanding of the following concepts:

- An exploration of various processes used to ensure the **safety** of objects (sanitization, pasteurisation, disinfection, and sterilization).
- How **ionizing radiation** provides an efficient and residue-free method for **sterilization**, enabling precise germ elimination without material degradation. Which ioning radiaiton is used and when (gamma rays, electrons, and X-rays). The **advantages** of radiation sterilization over alternative methods.
- An understanding of **how** radiation energy in matter generates reactive species capable of damaging microorganisms' DNA, leading to pathogen elimination.
- Examples of the **applications** of this method, including healthcare products, pharmaceuticals, and its use in preserving **cultural heritage**, disinfecting artifacts, wood, books, and mummies. Insights into irradiation facilities worldwide
- An introduction to **food sterilization** using ionizing radiation, and the differences between irradiated food and naturally radioactive foods.

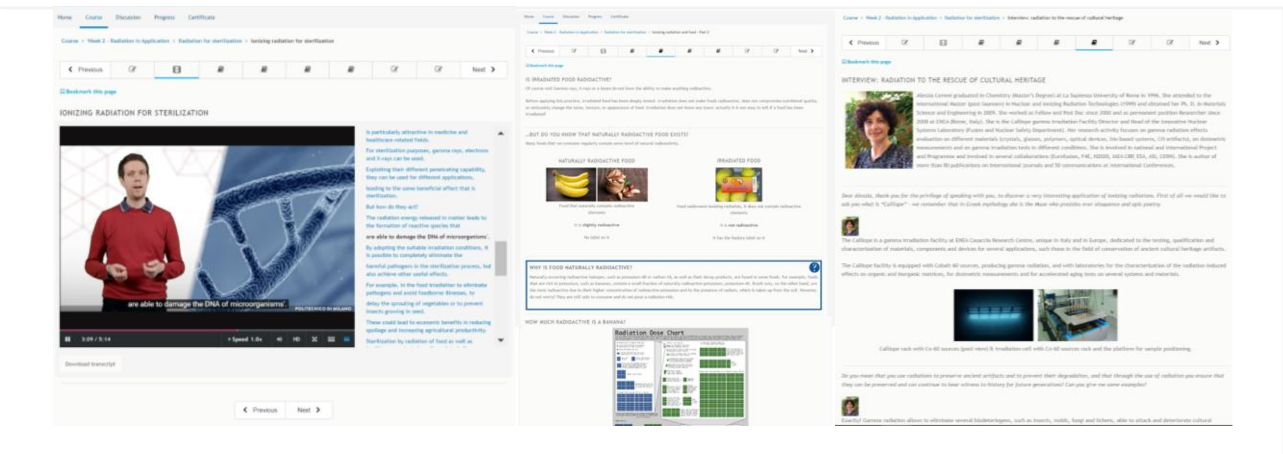

Figure 8 - Snapshot of some lessons of Week 2 Module 2 "Radiation for sterilization".

Module 3 - **Radiations for health**

This module consists of a series of six lessons designed to delve into the applications of radiation in the field of healthcare (Figure 9):

- L1 Having a PET Examination... (Image + Question, Ungraded)
- L2 Transforming Medicine with Radionuclides (6.22 minutes, featuring E. Macerata and M. Negrin)
- L3 Revealing the Unseen with Radiation: Medical Imaging (Infographic)
- L4 Effective Radiation Dose (Infographic)
- L5 Check Your Competences (Quiz, Graded)
- L6 Realize Your New Awareness (Ungraded)

Throughout these lessons, learners will develop a comprehensive understanding of the following concepts:

- The historical significance of radioactive isotopes in medicine, dating back to their first application in 1927.
- The role of radiotracers and their use in **medical diagnosis and therapy**, an exploration of **radioligands** and **radiopharmaceuticals**, with a focus on quality control and **safety** considerations.
- Which type of radionuclide is suitable for diagnostic purposes and which ones for therapy, and **how they are selected**.
- Insights into **nuclear medicine departments.** An overview on the techniques used in medical diagnosis, including **PET and SPECT** scans, and therapy.
- **Radiation exposure in everyday life**, including the concept of the sievert and its comparison to various medical and non-medical examples.

By the end of this module the users will understand how radiation is harnessed for medical applications, from diagnosis to therapy, while emphasizing safety and effective use in healthcare.

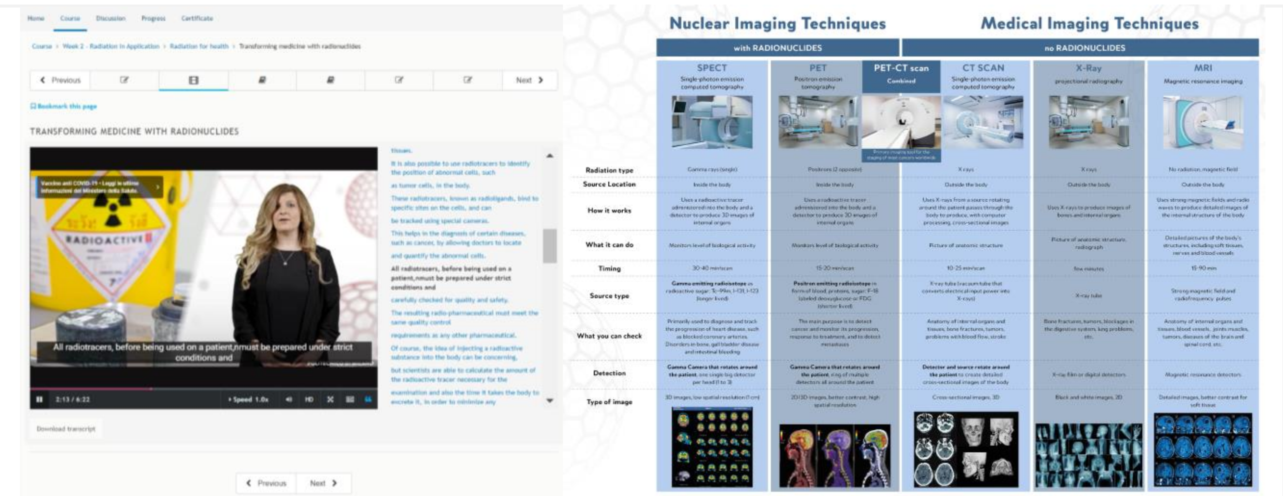

Figure 9 - Snapshot of some lessons of Week 2 Module 3 “Radiation for health”.

Module 4 - **Radiation for industry**

This module encompasses a series of six lessons dedicated to exploring the versatile applications of radiation technology in industrial contexts (Figure 10):

- L1 Security Scan at the Airport (Picture + Question, Ungraded)
- L2 Exploring the Versatile Applications of Radiation Technology - Part 1 (Video, 6:06 minutes, featuring E. Macerata and A. Santi)
- L3 Exploring the Versatile Applications of Radiation Technology - Part 2 (Video, 3:57 minutes, featuring E. Macerata and A. Santi)
- L4 Ionizing Radiation on Gemstones (Article)
- L5 Check Your Competences (3 Quiz, Graded)
- L6 Realize Your New Awareness (Question, Ungraded)

In this module, learners will gain a comprehensive understanding of the following concepts:

- The utilization of **radiotracers** for industrial purposes, including their role in the early detection of leaks, their significant **advantages**, and the underlying principles of operation.
- Their use in **quality control** in industrial processes.
- **Non-destructive testing methods** employing ionizing radiation, specifically gamma radiation and sealed sources, for applications such as assessing building integrity and gauging systems.
- **Gauges** for the measurement of density and levels of gases, liquids, and solids in tanks, even under extreme conditions.
- The role of radiation technology in **clean air** and **wastewater treatment** processes, and its use in textile dyeing wastewater treatment.
- The utilization of **electron beam technology** to enhance the safety and sustainability of everyday products. This section explores the interaction of ionizing radiation with plastics and its impact on product safety and sustainability.
- The **irradiation of gemstones** to alter their color and characteristics, including the underlying principles and applications of this process.

By the end of this module, learners will have acquired a nuanced understanding of how radiation technology is harnessed in various industrial settings, fostering safety, sustainability, and efficiency.

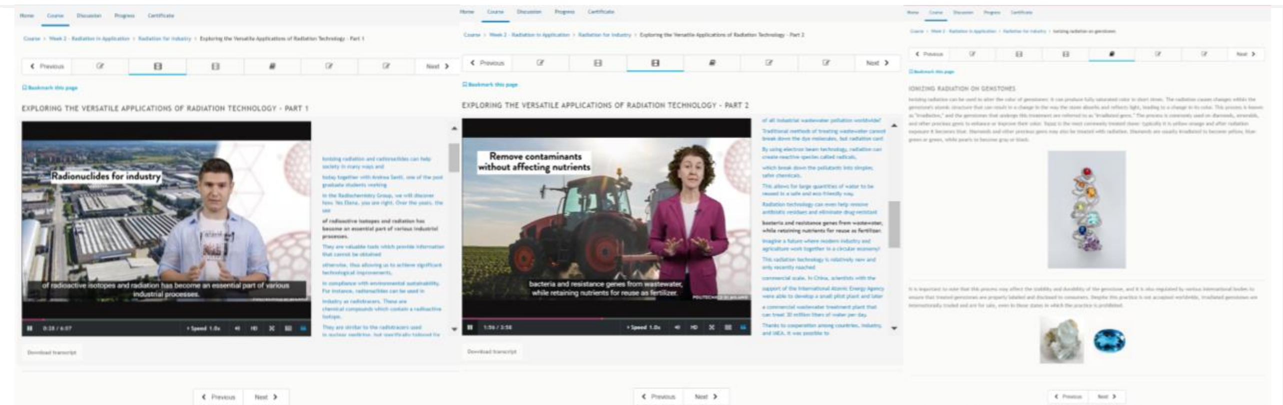

Figure 10 - Snapshot of some lessons of Week 2 Module 3 “Radiation for industry”.

2.3.3 Week 3 - Navigating Nuclear Hazard

In the third week the user will discover in detail nuclear energy, the threats and the benefits, the radionuclides in the environment, and we discuss nuclear accidents and nuclear waste.

Module 1 - **Nuclear energy**

This module features a comprehensive series of ten lessons designed to introduce learners to the diverse aspects of nuclear energy (Figure 11):

- L1 Sustainable Energy (Picture + Quiz, Ungraded)
- L2 Introducing Sustainable Energy (Article)
- L3 Nuclear Energy Unveiled (Video, 7:52 minutes, featuring E. Macerata and F. Galluccio)
- L4 Power Up! A Comparison of Energy Sources (Infographic)
- L5 The Future of Nuclear Energy (Infographic)
- L6 Reactors for the Future (Infographic)
- L7 Ready to Remix Energy? (External Link)
- L8 Nuclear Fusion (Article)
- L9 Check Your Competences (3 Quiz, Graded)
- L10 Realize Your New Awareness (Text + Quiz, Ungraded).

Throughout this module, learners will delve into a variety of vital topics, gaining an in-depth understanding of:

- **Sustainable energy**, the broad spectrum of energy sources, encompassing renewable, non-renewable, and constant power supply options. This lesson lays the foundation for a comparative exploration of these energy sources, shedding light on their respective advantages and disadvantages.
- **Nuclear energy**, its potential benefits, and the challenges it presents, in view of determining if it can be a sustainable energy source: including being a non-renewable energy source, with reduced environmental impact compared to fossil fuels, and minimal emissions during operation, and a small land footprint. The **economics** of nuclear energy, encompassing aspects such as high building costs, enhanced flexibility, longer operational lifespans, and low operating costs. The module also introduces **nuclear waste** generation and toxicity, setting the stage for a more detailed discussion in another dedicated module. Learners will be introduced also to waste volume reduction methods, including **reprocessing** plants, and the objectives and progress of **Generation IV reactors**, which aim to enhance safety and reduce risks.
- A preliminary introduction to **nuclear fusion**, offering a glimpse into this promising and innovative energy generation approach.

By the module's conclusion, learners will have developed a nuanced understanding of nuclear energy's role within the broader energy landscape, its potential benefits, and the challenges it presents. Additionally, they will have laid the groundwork for further exploration of nuclear waste management and the fascinating realm of nuclear fusion.

Figure 11 - Snapshot of some lessons of Week 3 Module 1 “Nuclear energy”.

Module 2 - **Environmental impact of radionuclides**

This module offers a comprehensive series of seven lessons aimed at shedding light on the environmental consequences of radionuclide presence (Figure 12):

L1 From Headlines to Consequences: Risk Perception (Tweet + Quiz, Ungraded)
L2 Exploring Radioactive Pollution (Video, 4:28 minutes, featuring E. Macerata and M. Negrin)
L3 Radioactivity Monitoring in Europe (External Link to Video)
L4 Restoring Balance: Remediation Techniques for Radioactive Releases (Infographic)
L5 Understanding TENORM: A Closer Look at Naturally Occurring Radioactive Materials (Article)
L6 Check Your Competences (3 Quiz, Graded)
L7 Realize Your New Awareness (Article, Ungraded).

Throughout this module, learners will embark on a comprehensive journey to explore:

- **Radioactive pollution** and its implications, with a focus on industrial activities and the release of radionuclides into the environment. Learners will gain insights into **environmental monitoring** and the international networks including the International Radiation Monitoring Information System (IRMIS).
- **Remediation techniques** employed to restore balance and mitigate the consequences of radioactive releases, emphasizing measures taken **in cases of non-accidental leakage**.
- Technologically Enhanced Naturally Occurring Radioactive Materials (**TENORM**), offering an in-depth exploration of these naturally occurring materials, their origins, and their relevance in the context of radioactive pollution.

By the module's conclusion, learners will have developed a profound understanding of the environmental repercussions of radionuclide presence, including monitoring and remediation. This knowledge equips them to engage critically with environmental challenges related to radionuclides and make informed decisions concerning their impact.

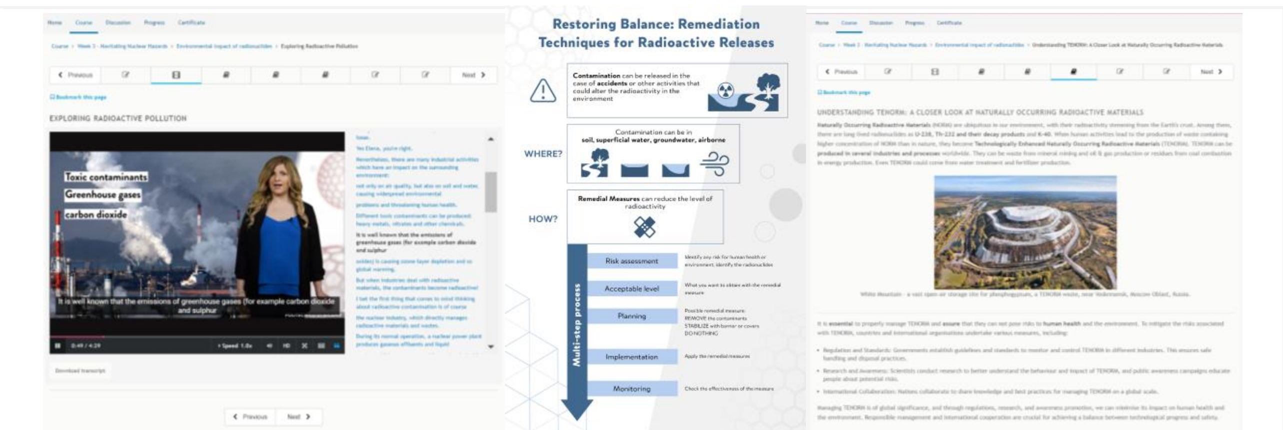

Figure 12 - Snapshot of some lessons of Week 3 Module 2 "Environmental impact of radionuclides".

Module 3 - **Nuclear threats**

This module comprises an extensive series of eleven lessons designed to address the complexities and consequences of nuclear threats (Figure 13):

- L1 Risk Perception (Quiz, Ungraded)
- L2 Nuclear Accidents Unpacked: Causes, Consequences, and Solutions (Video, 7:22 minutes, featuring E. Macerata and G. Magugliani)
- L3 Managing the Aftermath: Steps Taken After Nuclear Accidents (Infographic)
- L4 Nuclear Accidents in the Past (Infographic)
- L5 The INES Scale (Infographic)
- L6 Beyond the Risks: The Stringent Safety Measures of Nuclear Power Plants (Infographic)
- L7 Understanding Radiological Emergencies (Article)
- L8 Decontamination After a Nuclear Accident (Infographic)
- L9 Demystifying Nuclear Bombs (Article)
- L10 Check Your Competences (2 Quiz, Graded)
- L11 Realize Your New Awareness (Article + Quiz, Ungraded).

This module provides learners with a comprehensive exploration of various nuclear threats:

- Risk perception, and a deep dive into **nuclear accidents**, including their **causes**, **consequences**, and the **measures employed to prevent and mitigate their impact**. Notable incidents such as Fukushima (Japan), Chernobyl (Ukraine), and Three Mile Island (United States), are examined. A comprehensive overview of nuclear accidents' consequences, such as environmental contamination, economic impacts, and loss of public trust in the nuclear industry. The significance of transparency and communication in nuclear safety. The role of international organizations like the International Atomic Energy Agency (IAEA) in addressing nuclear accidents, their causes, safety standards, and assistance.
- An introduction to the **International Nuclear and Radiological Event Scale** (INES) to gauge the severity of nuclear events.
- Insights into the stringent **safety measures** integrated into the nuclear industry to prevent accidents, an exploration of the inspections, and regulations in the nuclear sector.
- A focus on **managing the aftermath** of nuclear accidents, including evacuation, medical care, containment, and cleanup efforts, decontamination techniques.
- An introduction to **nuclear bombs** and **radiological emergencies**.

By the conclusion of this module, learners will possess a well-rounded understanding of nuclear threats, from accidents to emergencies and safety measures, empowering them to critically assess nuclear-related risks and their implications.

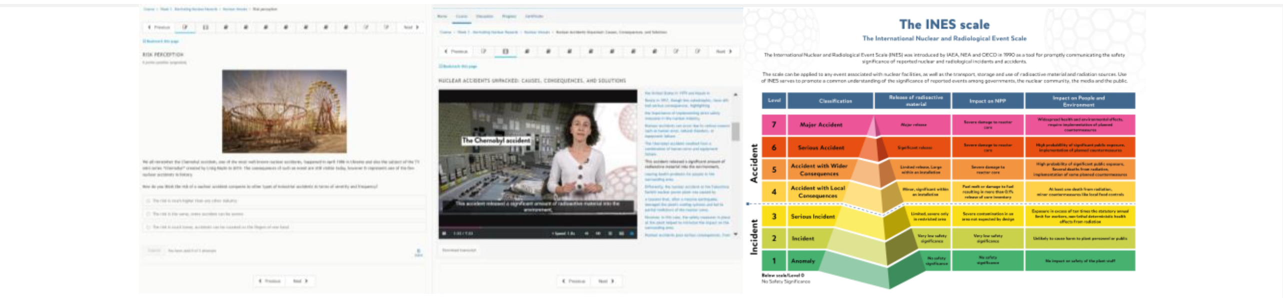

Figure 13 - Snapshot of some lessons of Week 3 Module 3 "Nuclear threats".

Module 4 - **Nuclear waste**

This module delves into the complex world of nuclear waste and its management. It comprises ten lessons designed to provide learners with a comprehensive understanding of the origins, categories, management, and final disposal of nuclear waste (Figure 14):

- L1 Radioactive Waste: Where Does It Come From? (Picture + Quiz, Ungraded)
- L2 The Journey of Nuclear Waste: Origins and Categories (Video 1, featuring E. Macerata and A. Santi)
- L3 Nuclear Waste Management: Navigating the Path Forward (Video 2)
- L4 Reprocessing Nuclear Fuel: A Sustainable Solution for the Future (Article)
- L5 Decommissioning a Nuclear Power Plant (Infographic)
- L6 Radioactive Waste from Nuclear Decommissioning (Infographic)
- L7 Journey's End: Exploring the Final Destinations of Nuclear Waste Disposal (Article)
- L8 Check Your Competences (Quiz, Graded)
- L9 Realize Your New Awareness (Text + Quiz, Ungraded)
- L10 Exploring Academic Pathways in Radiochemistry: Your Journey to Understanding the Atomic World (Bonus Article).

Throughout this module, learners will explore a wide range of topics related to nuclear waste:

- Exploring **nuclear waste classification**, based on the **IAEA** classification system based on radioactivity and decay times, explore all the characteristics and distinctions among waste categories, and gain insights into the safety standards and regulations established by the IAEA.
- Dive into nuclear waste **management** strategies, including minimizing waste amounts through **treatment**, robust isolation and **containment** methods, **transportation** considerations, and exploration of final **disposal** options for each waste type.
- Discover the processes involved in **reprocessing nuclear fuel** and explore potential benefits and challenges, such as waste reduction and resource utilization.
- Gain a comprehensive overview of the **decommissioning** process of nuclear power plants, a significant source of nuclear waste. Understand the unique challenges involved, from waste management to **decontamination techniques** and safety measures.
- A *bonus article* is provided at the end of this module to let the user explore the **academic and career pathways** in the field of nuclear and radiochemistry, providing insights into diverse opportunities for those interested in understanding nuclear science and contributing to innovative solutions.

By the end of this module, learners will acquire a nuanced understanding of nuclear waste, its management, and the crucial importance of responsible disposal practices in the field of nuclear and radiochemistry.

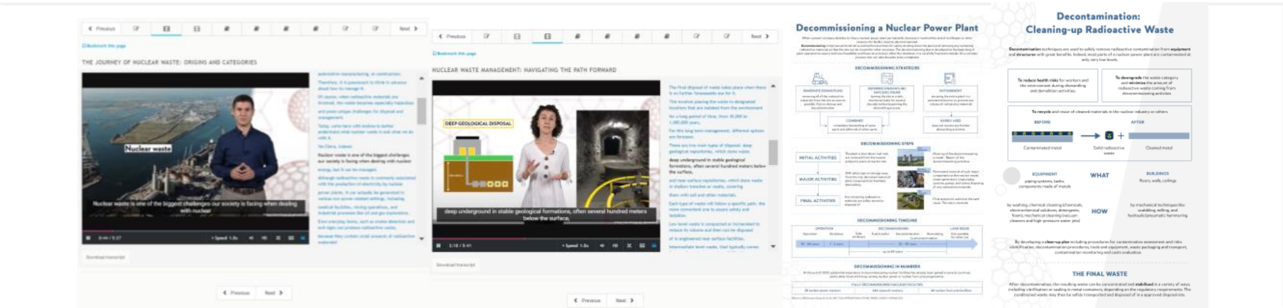

Figure 14 - Snapshot of some lessons of Week 3 Module 3 "Nuclear threats".

3 CONCLUSIONS

In conclusion, "Discovering Nuclear Science: Energy and Beyond" MOOC represents a significant step forward in making nuclear science accessible and engaging for a wide-ranging audience. This MOOC's three-week journey, consisting of ten modules, offers an immersive learning experience that covers the entire spectrum of nuclear science.

The pedagogical framework, based on a scenario-based learning approach, ensures that learners actively engage with the content, fostering critical thinking, reflection, and peer interaction. This approach not only imparts knowledge but also encourages learners to apply their understanding to real-world scenarios.

Throughout the course, learners embark on a captivating exploration of radioactive elements in nature, artificial radioactive elements, the practical applications of ionizing radiation, and the multifaceted world of nuclear science. They gain insights into the environmental impact of radionuclides, nuclear energy and the associated nuclear threats, including the management of nuclear waste.

"*Discovering Nuclear Science: Energy and Beyond*" serves as a valuable educational resource for individuals seeking to expand their knowledge of nuclear science, radioactivity, and their diverse applications. By fostering inclusivity, engagement, and critical thinking, this course empowers learners to explore the fascinating world of nuclear science and its implications for our modern society.

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