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Isotopic techniques for environmental monitoring and nuclear waste management at CIRCE

R. Buompane([1])([2]), A. D'Onofrio([1])([2]), L. Gialanella([1])([2])(*), F. Marzaioli([1])([2]), A. Petraglia([1]), G. Porzio([1])([2]), M. Romoli([2]), C. Sabbarese([1])([2]) and F. Terrasi([1])

([1]) *Dipartimento di Matematica e Fisica, Università della Campania "L. Vanvitelli" Caserta, Italy*
([2]) *INFN Sezione di Napoli - Napoli, Italy*

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Summary. — CIRCE (Center for Isotopic Research on Environmental and Cultural heritage) was founded in 2005 as a research center dedicated to the application of isotopic methodologies in environmental and cultural heritage research. Later the spectrum of activities expanded and CIRCE became part of the laboratory hub of the Department of Mathematics and Physics, University of Campania L. Vanvitelli (formerly Second University of Naples), Caserta, Italy. In this context, an environmental monitoring program of the areas surrounding the Garigliano nuclear power plant (NPP) and of the building materials of the NPP was developed. The activities were carried out by involving undergraduate and doctoral students and taking care of communication with local administrations. In this framework, a survey among high school students was conducted to provide an insight into the public's perception of risk connected to NPP. Alongside environmental radioactivity monitoring and material characterization techniques available at CIRCE are discussed. The activities presented here could find interesting applications in the framework of the Italian National Repository for Radioactive Waste and the annexed Technopark.

Introduction

University laboratories have the difficult but challenging task of reconciling the sometimes conflicting demands of research with those of education. This situation makes universities the bridge between scientific research and society. This role is especially important in critical issues, among which the management of nuclear power plants during and after their lifecycle could be an excellent textbook example. CIRCE was founded in 2005 as a scientific department of the regional Competence Center INNOVA. Later, it became part of the laboratory hub of the Mathematics and Physics Department of the University of Campania and its interests expanded to include basic research in nuclear,

(*) Corresponding author. E-mail: lucio.gialanella@unicampania.it

atomic, and molecular physics, together with a broad range of applications in different fields. Remarkably, at CIRCE long lived radioactive ion beams are produced for basic research and applications [1]. However, environment remains a pillar of CIRCE. Several collaborations with Italian and international partners have been established over the years and research is integrated into the training of undergraduate and graduate students of the bachelor and master's degree courses of the University of Campania and students. Besides education and research, CIRCE is committed to providing services to a wide range of public and private clients. In the following sections the activities relevant to the subject of the Italian National Repository for Radioactive Waste and the annexed Technopark are presented in a general overview, referring to the references for details.

1. – Environmental studies using Accelerator Mass Spectrometry of Actinides

The assessment of the radiological impact of any nuclear installation requires detailed environmental analyses not only along the operational life, but also before, during and after the decommissioning process. It is then important not only to assess the radiological status of the surrounding environment and of the plant structural material as a consequence of the operation activity, but also to monitor the radionuclide releases due to the decommissioning activities themselves. The University L.Vanvitelli started its collaboration with SOGIN 25 years ago performing several environmental campaigns to estimate the radiological signature of the activities of the Garigliano Nuclear Power Plant (GNPP) in the area surrounding the plant and in its structural materials. Additional campaigns have been carried out as service to different companies involved in the decommissioning of the GNPP: The sensitivity of these analyses has been greatly enhanced since the installation of the Accelerator Mass Spectrometry (AMS) system at CIRCE [2, 3]. AMS plays a crucial role in the study of the environmental impact of an NPP thanks to the ultrasensitive detection of actinides. The measurement of the isotopic composition of U and Pu in environmental and structural samples is a very powerful tool to gain information about their origin in different matrices. AMS has proven to be characterized by an unparalleled sensitivity for rare isotopes detection via single ion counting [4, 5], while current measurements in Faraday cups are used for normalization to abundant isotopes. Isotopic measurements are capable of distinguishing the contribution from fall-out, due to nuclear tests in the atmosphere, and major accidents at nuclear power plants (Chernobyl, Fukushima) from the possible impact of the NPP. In particular, the measurement of abundances and isotopic ratios of anthropogenic actinides (236U, 239Pu, 240Pu) may reveal the presence of irradiated fuel through the 236U/238U ratio. 240Pu/239Pu gives further information on fuel composition, U enrichment, and burn-up [6, 7, 9-13]. During the period between 2001 and 2021, seven campaigns have been performed in collaboration with Sogin and its contractors in the area of the GNPP under decommissioning, using different methods of analysis on various radionuclides. Environmental matrices such as soil, air, water, vegetables, milk, meat, and fishes have been studied [14-16]. Riverine, sea waters and sediments near the nuclear site were also investigated [17] their study is crucial to assess the radiological status of the seabed and water, and to identify any anomalies or variations from the environmental background values, to ascertain impacts caused by the NPP activities. Finally, a systematic investigation of the distribution of all U isotopes in concrete and metal matrices of the NPP was performed. The behaviour of 235,236U/238U isotopic ratios in the different compartments of the NPP was studied [18] to search for possible correlations of these ratios with 60Co and 137Cs specific activities in concrete and metal samples. These data represent a very valuable information to

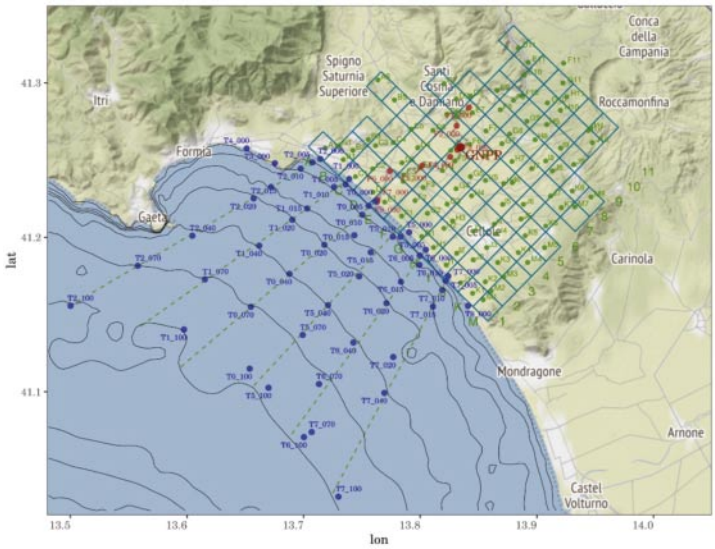

Fig. 1. – Areas covered in the 2001-2020 environmental monitoring campaigns. Only a portion of the onshore camping points are reported. See text for details.

direct the decommissioning procedures under course. Figure 1 reports the area covered by the monitoring and a part of the sample collection sites.

2. – Monitoring and material studies

In addition to the environmental monitoring activities presented in Section 1, there are other activities carried out at CIRCE-DMF that are of potential interest for the Italian National Repository for Radioactive Waste and the annexed Technopark. We shortly present them here. The European project called PREDIS [19] sees the participation of 47 institutions from 17 countries of the European Union. It aims at identifying and studying innovative technologies for the treatment and the monitoring of radioactive waste before its definitive storage in long-term deposits. The University of Campania "L. Vanvitelli" is collaborating to this project jointly with the Istituto Nazionale di Fisica Nucleare (INFN), in the design of read-out electronics for a monitoring system based on SciFi (Scintillating Fibers) and on SiLiF (Silicon detectors coupled to 6LiF converters) for gamma and neutron detection, respectively. These detectors have been developed by INFN in the past years and described elsewhere in these proceedings [20]. The new electronics (shown in fig. 2) has very appealing features: compactness (having reduced dimensions of about 100x140x50 mm3), highly configurability (being based on the ESP32 micro-controller), very low power consumption (with a programmable wake-up of the system, that is otherwise in sleeping mode), very small maintenance requirements and time (modularity of the board and use of long-life rechargeable batteries, as power supply), the possibility of remote control and data transfer via wired (Ethernet) and Wi-Fi connection and, last but not least, low cost, obtained using components widely available on the electronic market. Specially designed and developed intelligent software will enable the use of the detection system in different scenarios, from the radiation monitoring in fixed positions inside and outside a radioactive waste storage to the radiation monitoring

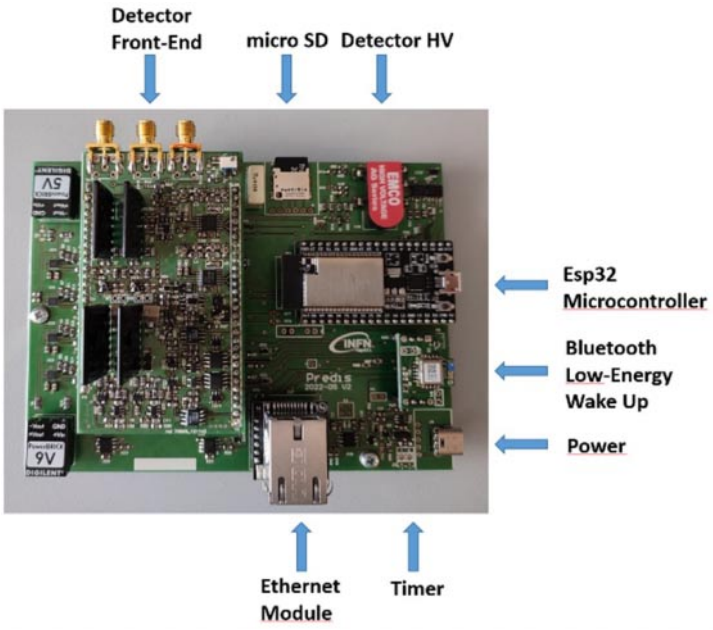

Fig. 2. – The prototype electronic board with indication of the main components.

in mobility during the waste drums transportation. The acquired data will be stored on a cloud database, thus allowing their real-time utilization by different scientific groups collaborating to the project and, in the future, for general safety applications, exploiting the Microsoft Azure platform. Thus, it will be possible to use features such as cloud tiering, synchronization between multiple sites, direct and rapid access in the cloud environment and integration with cloud backup. Using the cloud also simplifies network configuration, with cloud provider guarantees of service reliability and availability, as well as automatic data backup features and lower costs. As a first application, a monitoring system for nondestructive detection of cracks in concrete inside a drum is currently being developed. In addition, the use of the same electronics for different types of detectors (ionization chambers, CsI scintillators, Geiger counters,...) and its integration on a drone for environmental radiation monitoring is studied, in order to be able to use the system even in environments affected by accidental events and/or radiological hot spots.

Another research field of potential interest to this workshop is the use of isotopic methods to characterize materials used in nuclear applications. An example is the investigation of water diffusion, that is important in the modelling of ageing processes of vitreous or ceramic materials or passivation layers for the immobilization of high level radioactive waste [22] and references therein. Based on a project aiming at the production of hydrogen free graphite targets [21], a beamline at CIRCE is equipped with a setup for Nuclear Reaction Analysis devoted to the measurement of the water diffusion profile in surface layers. Briefly, proton capture nuclear reactions are initiated using a MeV ion beam. The observed yield depends upon the hydrogen fraction in the sample and eventually on the water diffusion in samples exposed to water. Of course, the material's hydrogen stoichiometric content may limit the application of this method.

3. – Public engagement

Vanvitelli University's strong ties with its host territory have led over the years to the development of various initiatives to disseminate the results of scientific investigations and study the factors that determine the perception of issues related to nuclear power plants and radioactivity in general. Obviously, the public's perception of risk is a critical aspect. Understanding it is critical when making decisions, providing valuable insight into people's concerns. Here we present a survey conducted in the Garigliano Plain (Italy), around the nuclear power plant (GNPP), to quantify young people's perceptions of risk, particularly in relation to the nuclear power plant itself. The Garigliano plain is an area of significant concern by population, as evidenced by the numerous articles, leaflets, and websites that can be found discussing issues regarding nuclear power. The GNPP is often linked to the Chernobyl and Fukushima accidents. The survey aimed to provide insight into the public's perception of risk. Its findings provide valuable information about public perceptions of risk, in particular relating the GNPP. The analysis of the collected data and the key findings are discussed here, as well as an introduction to the concept of risk perception and how it is influenced by various factors. Additionally, this paper includes an examination of the specifics of the questionnaire, data collection and processing, and other results such as dependence on social and geographical factors. The survey was completed in the years 2011 and 2012 among high school students in the Garigliano Basin area. The results of the project are reported in details in a master and a PhD work [23, 24], and are shortly resumed here. Risk perception is the subjective judgment that people make about the characteristics and severity of a risk. Cognitive biases and heuristics play a fundamental role in the level of risk perception in individuals [25,26]. Thus often the layman feeling about a risk is uncorrelated to the opinion from experts in the field [27]. Aim of the poll was to relate some personal factors (scientific knowledge, concern toward environmental issues, quality of the information channels, social background and so forth) to various aspects of risk perception. Psychological research shows that individual socio economic status, knowledge, confidence in institutions, and local context are the main factors influencing the perception that people have of dangerous activities, and the controversial role of compensatory measures [26]. The factors influencing risk perception are well resumed in a document from World Health Organization related to electromagnetic field, which can be well extended to nuclear risks [28].

3˙1. *Survey of risk perception.* – The questionnaire has been developed in the framework of a Master's degree thesis [23]. It includes 29 questions and some anonymous personal information (area of origin, occupation of parents, age and sex) and submitted to 187 students attending the last year of three secondary schools. The 29 answers were used to produce the eleven indicators in table I.

The analysis of the data is rather complex and beyond the aims of our contribution. However, we report here the main results of the analysis of single indicator distributions:

- The compilers of the questionnaire possess less scientific knowledge than they think. Indeed, the values of A1 (self-perception) are, in average, higher than those of A.

- There is much concern toward social and environmental issues but this concern is not well perceived, as is shown by the indicators B and B1.

TABLE I. – *Indicators exploited in the analysis of the results of the survey.*

A	technical and scientific skills
A1	self-perception of technical-scientific skills
B	level of attention to social and environmental issues
B1	self-perception of attention to social and environmental issues
C	perception of nuclear risk
D	tendency to deepen the knowledge on the subject
E	risk perception in general
F	quality of information channels
G	alarm level toward the radioactivity
H	alarm level toward the GNPP
I	trust in institutions and technology

- Among other possibly risky technologies and activities, nuclear energy has been frequently considered the most dangerous, as is shown by the indicator C, which has a peak very close to the theoretical maximum.

- The quality and quantity of information sources (indicators D and F) is medium to low.

- There is a considerable degree of alarm, which become higher as we focus toward the power plant (indicators E, G and H: perception of risk in general, alarm level towards the radioactivity and alarm level towards the GNPP).

- There is no general trust in institutions and technology. Indeed, the value of I is considerably lower than the theoretical maximum.

- There is a wide variability in the scientific skills, as is shown by the standard deviation of the indicator A, which is larger than that of the other indicators.

- There is a low variability in the alarm level toward the GNPP, which is compressed toward the maximum values.

Interesting assessments arise by analysis of correlations. The results are reported in fig. 3.

Some correlations are fairly predictable. That is the case of the strong positive correlation between G (alarm level for radioactivity) and H (alarm level for the nuclear power plant of Garigliano) or of the positive correlation between C (nuclear alarm), E (risk perception), G (alarm level for radioactivity) and H (alarm level for the GNPP). Some correlations are of great interest to envision a way to a spread a correct and rational risk perception. The modest negative correlation between the indicators A (technical and scientific skills) and G an, similarly, the negative correlation between G and E and D (tendency to deepen the knowledge on the subject). This indicates an important way in lowering the perception of risk: that is by presenting a good information and providing a more active involvement of the population. Indeed, D is positively correlated to A. Finally, a very interesting negative correlations is observed between the indicator I (trust in institutions) and anyone one of the indicators C, E, G and H.

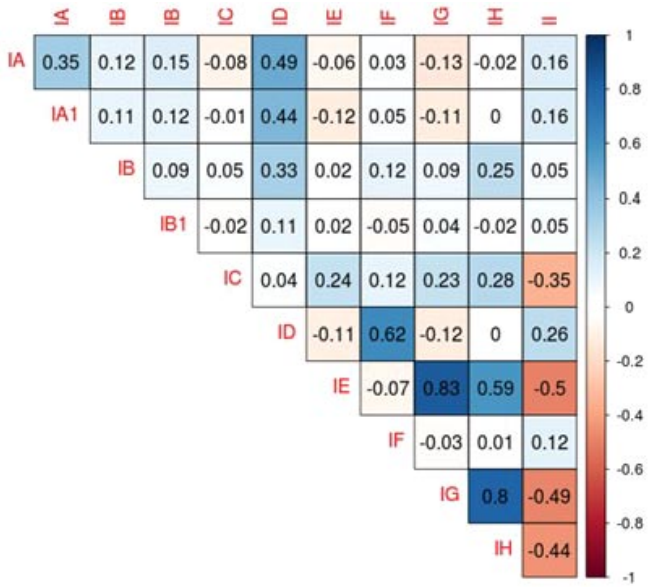

Fig. 3. – Correlation table for the eleven indicators used in the survey. The colour scale on the right refers to the correlation coefficient among pairs of indicators

Conclusions

We presented the research activities at CIRCE of interest to the Italian National Repository for Radioactive Waste and the annexed Technopark. Some of them, are since decades devoted to the environmental monitoring of the area surrounding the GNPP during its decommissioning. Some are just starting out, and some currently have only potential interest. The presentation aimed at giving an overview, details are given in the references. Perhaps the most interesting aspect of the activities carried out at CIRCE is the constant involvement of students. This allowed on the one hand to carry out a well-structured and comprehensive training activity, and on the other hand established a strong communication link with the population. The results obtained show that these aspects more than compensate for some operational difficulties related to the involvement of students and indicate the important role that Universities may have in critical social issues linked to the subject of the Workshop.

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