Innovations on Nuclear Energy – What Can a Small Country Contribute?

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Abstract

The Slovenian Fusion Association was founded in 2005. The contributions of the participating institutions are based on previous experiences of the scientists involved in the fields of nuclear, atomic and plasma physics, ceramic materials development, mechanical engineering and computer aided design. Contributions in the areas of the Fusion Physics Programme, Underlying Technology Programme and Technology Programme are presented and outlined. It is shown that a small country with limited resources can significantly contribute to tackle complex scientific and technical issues.

Keywords

Energy, nuclear, fusion, ITER, DEMO, Slovenia

1. Introduction

According to the IEA International Energy Agency (IEA), the electricity power consumption is rapidly growing, although the availability of resources is diminishing. It is expected that the energy demand would double by the year 2050 compared to present situation. There are also projections showing that the world population at that time would grow from six to nine billion. Due to fast economic growth in several developing countries such as India and China, where the highest increase is expected, the energy consumption will be strongly enlarged. Industrial production will gradually demand much more electrical energy that can be produced by present sources.

Increased consumption of electric energy leads into even faster exploitation of fossil fuels on which more than 65 % of world energy supply is based, according to the data from 2002. Due to unfavourable distribution of energy stocks, the European Union (EU) has to cover about of half of its energy needs by importation. It is expected that the EU dependence on imported energy would increase to more than two thirds. World natural gas stocks are estimated to be sufficient for the next 60 years and oil reserves for the next 40 years. Nuclear power plants produced in 2002 about 17 % of electrical energy. However, construction of new nuclear power plants in EU is questionable due to relatively low public acceptance of nuclear technology, in spite of substantial technology improvement and increased safety of state-of-the-art plants. Hydroelectric power plants contributed around 16 % energy, and renewable sources such as sun, wind and biomass, around 2 %. The highly growing (about 25 % per year) type of energy production is presently the utilisation of wind. However, due to large geographical areas needed for this type of energy production and relatively low (10 – 20 %) efficiency, wind turbine fields are not a serious alternative for the production of large amounts of electric energy. Similar growth is characteristic for biomass burning, which is also a source of greenhouse gases. In future, it is also expected more efficient exploration of solar energy, but the proportion of such kind of renewable sources will remain relatively small.

The share of renewable energy sources (RES) in the primary energy balance of Slovenia was 10,7 % in 2004, about half of this coming from hydropower. Wood and wood residues are very important domestic energy sources in Slovenia besides coal and hydropower. The share of electricity from renewable energy sources in total electricity production was 29,1%. Current bioenergy sources in Slovenia are dominated by wood from forestry, due to the fact that Slovenia is heavily wooded country with approximately 63 % of the land area covered by forests. There is also energy utilization of other renewable energy sources such as biogas from the anaerobic digestion of sewage, manure or agricultural wastes and landfill gas. The energy policy of Slovenia foresees increase of RES in the primary energy consumption of up to 12 % in 2010. To achieve this goal the share of RES in heat supply should increase from 22% in 2002 to 25% in 2010 and the share of electricity use from RES to 33,6 % in 2010. The share of electricity power produced by co-generation (combined heat and power production) in Slovenia is about 8% and the total installed capacity is about 220 MWe. The target is to double the electricity production by co-generation in 2010. About 41 % of energy production in Slovenia came from the Krško nuclear power plant. This plant is one of the reasons for long tradition in research pertaining to development and utilization of nuclear technology in the country.

Electric energy obtained from commercial fusion power plants can be expected in the second half of this century. However, scenarios for solving global energetic and ecological problems for the future does not take into account fusion as one of substantial and reliable energy sources, as its technical feasibility has not yet been proved. Fusion power plants are expected to provide reliable, cost-effective and safe supply of electric energy from practically limitless sources. They could replace primarily thermal power plants and consequently contribute substantially to reduce emission of greenhouse gases. Appropriately balanced with other accessible sources, the fusion energy should help satisfy mankind energy need in the second half of the century.

2. Slovenia as part of the European Fusion Programme

Slovenian scientists have long been collaborating in numerous fusion-related projects. Therefore, it was a logical step to found the Slovenian Fusion Association (SFA) in 2005 to support to the European Fusion Development Agreement (EFDA). The primary missions of the SFA are to: contribute to knowledge supporting the development of the future fusion reactor, improve public awareness of energy needs, increase the acceptance of nuclear fusion and support the involvement of Slovenian industry in the construction of the International Thermonuclear Experimental Reactor (ITER). The Association was formally established on the basis of a contract between the European Commission and the Slovenian Ministry of Higher Education, Science and Technology. It is organised as a Research Unit, comprised of scientists from the Jožef Stefan Institute (JSI), University of Ljubljana and University of Nova Gorica. The Association is supported by the Slovenian Research Agency, which included the fusion research among priority themes of the Slovenian research programme.

The contributions of the institutions in the Association to the several areas of the fusion programme are based on research and development (R&D) experiences of the particular scientists in the fields of nuclear, atomic and plasma physics, ceramic materials development, mechanical engineering and computer aided design. The major equipment available in the institutions includes the following:

- HVEE Tandetron accelerator equipped with two ion sources and materials diagnostic installations;
- 250 kW TRIGA Mark II light-water reactor;

- Advanced dedicated fully-integrated high resolution microscope facility for nanostructural materials;
- Computer systems for simulations, structural mechanical analyses and computer aided design.

The main areas of the programme comprise:

- Plasma-surface interaction in ITER-relevant conditions;
- Development and irradiation testing of new ceramic materials for fusion reactors;
- Analyses of test blanket module (TBM) neutronics experiments and validation of EFF nuclear cross section data;
- Development and manufacture of a special tool for the construction and production of ITER parts;
- Structural mechanical analyses and evaluations to support the ITER and Wendelstein 7X project.

The Association also participates in the DEMO Working Group, contributing in the topics related to the conventional nuclear power plant technology, in particular in the matters related to nuclear safety and nuclear waste management. There is a substantial expertise available, derived from the long-standing fission programme within the country.

3. The fusion research programme in Slovenia

The scientists participating in the SFA take part in R&D projects related to three main topics: Physics, Underlying Technology and Technology.

3.1. Fusion Physics Programme

The researchers involved in this programme study interaction of vibrationally excited hydrogen with fusion relevant materials. The scientists are concerned with the processes that occur on plasma facing materials and in the edge plasma of tokamak reactors and involve neutral hydrogen/deuterium molecules. These molecules are typically vibrationally excited thus influencing the respective reaction cross-sections. The group developed a special experimental technique for the vibrational spectroscopy of molecules and uses ion beam elastic recoil detection analysis (ERDA) to characterise the hydrogen content on and beneath a material surface. The investigations are also performed in a plasma environment in the linear magnetised plasma facility of the JSI.

Investigations of the surface recombination of hydrogen atoms on fusion-relevant materials, aimed at creating a reliable database of recombination coefficients, are carried out. For this purpose, an experimental plasma reactor has been constructed and tested. The reactor makes use of a catalytic recombination process on the probe-tip surface. Kinetics of the deuterium interaction with the reactor wall material is also intensively studied, making use of precise pressure-gauge measurements and quadrupole mass spectrometry of the up-taken and released gases. It is expected that a better understanding of the deuterium interaction will also help predict tritium retention and the decommissioning kinetics more accurately.

Studies are also focused on the development of appropriate ion beam analysis (IBA) methods for studying plasma-wall interaction processes such as erosion, deposition, fuel retention and material migration in fusion reactors. For this purpose, the relevant specimens from the experimental fusion reactor TEXTOR in Germany are analysed.

Design problems of stellarator Wendelstein W7-X are studied by one of the SFA groups. The investigations carried out pointed to potential problems by providing an insight into zones of excessive plasticity, which might lead into fractions or collapse of the structure. The group involved is providing engineering solutions for the stellarator and manufacturing new tools for producing the vacuum vessel sectors of ITER.

The scientists involved in the DEMO Working Group are contributing to the conventional aspects of the DEMO power station as a nuclear installation. They study neutron transport and activation, the technology of the secondary side, nuclear waste, licensing, safety analysis and emergency preparedness. So far, their main concern was focused on general aspects of radioactive waste treatment.

3.2. Underlying Technology Programme

Appropriate structural materials are of utmost importance for the economic exploitation of fusion power, operational safety of fusion reactors, as well as their low environmental impact. There is a very short list of candidate materials suitable for the first-wall blanket. The most promising material appears to be a composite of a SiC-fibre textile infiltrated with a low-activation SiC-based material, SiCf/SiC. Therefore, a group of materials scientists involved in these investigations is focused on ceramic processing for the production of low-activation SiC-based composites. The work is focused on developing appropriate technologies using the chemical vapour infiltration (CVI) and vacuum slip infiltration (VSI) methods. Besides the technology development to produce the material having properties adequate for use in a fusion reactor, attention is paid to selection of ingredients that would minimally activate after neutron irradiation. For this purpose, the relevant materials are irradiated in the TRIGA reactor of the JSI.

3.3. Technology Programme

The helium cooled pebble bed (HCPB) breeder blanket mock-up benchmark experiment was analysed using the deterministic transport, sensitivity and uncertainty code system in order to determine the tritium production rate (TPR) in the ceramic breeder and the neutron reaction rates in beryllium, both nominal values and the corresponding uncertainties. In order to assess the uncertainty of the TPR resulting from the uncertainty in the basic nuclear data, the sensitivity/uncertainty pre-analysis of a mock-up of the test blanket module based on the helium cooled lithium lead (HCLL) concept is performed. Sensitivity profiles and nuclear data uncertainties, which will be determined for the neutron responses, will be used to guide and optimise the design of the ITER blanket modules.

A group of scientists and engineers is working on analysis, design and manufacture of local machining tool (LOMAC) for the blanket module flexible support housing. They are investigating concepts for both outer and inner manufacturing. After performing virtual presentations, they have focused on detailed stress and deformation analyses, to be able continue with simulations of the manufacturing.

4. Conclusion

Reliable and sustainable energy sources are needed to preserve the living standard in Europe. Therefore, development of environmental-acceptable, safe and sustainable technologies is needed. Fusion offers a possibility for producing large amounts of energy with abundant and broadly distributed sources of fuel. Fusion power stations are expected to meet the basic energy demands in densely populated and industrial areas in the future. Properly combined with other environmental-friendly energy sources, fusion could cover energy needs in the second half of the century, when stocks of fossil fuels are expected to be critically diminished.

Progress in plasma physics, materials, engineering and other technical sciences made in last fifty years has led the development of fusion power station to the key experiment – the ITER that is expected to answer some key scientific and technical questions. Slovenia participates in the ITER project, as well as in investigations and preparations for the next step in the development – demonstration reactor DEMO. Although small in size and consequently limited in resources, it contributes substantially in solving these significant and challenging problems so important for the future prosperity of mankind.

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