TECHNOLOGICAL FORECASTING A LONG TIME OF THE SCIENTIFIC-TECHNOLOGICAL DEVELOPMENT OF THE NUCLEAR FUSION

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ABSTRACT

With base in the introduction in long time of the nuclear fusion inside of a system of viable energy, taking in consideration economic factors, would imply on investment in a long period. The objective of this project utilizing the method of the Delphi technique is the technological forecast a long time of the scientific-technological development of the nuclear fusion and its impact. This research project will be carried through different stages of improvement of variables. A questionnaire based on information and analysis of the literature validated for specialists in nuclear fusion becomes this project a tool in the elaboration future of a database contends variables on the theme nuclear fusion and its perspectives. The database will be composed for the answers and suggestions obtained, with exploratory and extrapolatory elements, on the theme a great number of specialists involving in the nuclear fusion area. The database is analyzed for the configuration of variables that represent elements as scientific-technological factors, economical, political, social and environmental among others. As final result of the research with the Delphi technique, different scenes obtained with the variables will be indicated by convergent factors or not on the approached perspectives. The analysis of the data will be possible through of improve of statistical analysis tools. This is the first analyzes of the answers. The questionnaire was validated with nuclear fusion specialists from the Institute of Physics of the University of São Paulo in Brazil and the Center of Nuclear Fusion of the Technical University of Lisbon in Portugal.

1. INTRODUCTION

The fusion process (1) consists in the formation of a more stable atomic nucleus from the joining of two nuclei that specifically have a low mass in the case studied. The fusion of hydrogen atoms in thermal movement is the source of solar energy, the problem is in the Coulombian barrier to be overcome so as to permit fusion which is of a magnitude of 10^6 eV. The fusion in the sun originates from the gravity acting on these atoms, which are an important factor in this process. For a similar fusion process here, we have to consider the density of these atoms obtained from distinct processes presented farther on.

1.1 – Techniques of Nuclear Fusion

Magnetic confinement (2) and the current work in the construction of the largest reactor of this type, ITER (International Thermonuclear Experimental Reactor), is based in a toroidal form with a plasma under high temperatures and pressures in magnetic fields.. The possibility of fusion continues to be highly sustainable, submitting hydrogen isotopes (deuterium and tritium) has been proved possible in researches (3) in magnetic confinement reactors. Future conceptual projects with adaptation of current information(4) and commercial feasibility studies are detailed in the document, "A conceptual study of commercial fusion power plants, a final report of the European fusion development agreement"(5). The chronogram for the development of magnetic confinement reactors (6) proposes a development period of until the year 2050 for the activation of this experimental reactor, with a commercial purpose. Another magnetic confinement reactor that maintains the plasma is *Spheromak*, where they were analyzed regarding their sustainability (7). A *Stellarator* reactor (also a magnetic confinement in the toroidal form) was analyzed regarding its size evolution and its economic aspects(8). A series of experiments involving *Rigatron* magnetic confinement reactors were also analyzed (9).

The Inertial Fusion Energy (IFE) method described by HIPER (10) is based on a laser beam falling on the surface of a small capsule with deuterium and tritium. The external surface of this capsule which is in a cryogenic state heats up and expands and an internal implosion begins with very high density and temperature, making nuclear fusion possible.

Magnetized Target Fusion (MTF) with Field Reverse (FR) is a potential source of energy still in study (11); projected as an intermediate between magnetic confinement and inertial fusion. This technique utilizes a plasma injector to introduce in a linear region with a field-reversed plasma configuration, obtaining a compaction in thermonuclear conditions.

The Reversed-Field Pinch (RFP) method uses high-intensity electric plasma discharges(12). Inertial Electrostatic Confinement Fusion (IECF) occurs in an almost spherical configuration where there is generation of an electric field for confinement that operates with heavier elements, such as lead, boron, as well as traditionally utilized elements, such as deuterium and helium (13). Studies on Sonofusion are based on the superposition of sound waves to obtain fusion (14); the Muon Catalyzed Fusion (15) describes the creation of a muonic element, the magnetic effects and its transfer to ^{3}He. Heating of $LiTaO_3$ generating a Pyroeletric effect makes high-intensity acceleration possible (16) and the production or neutrons from the deuterium-tritium fusion.

1.2 – Delphi Technique

The Delphi technique (17) describes how a communication process of a group of specialists, who are requesting a judgment through a sequence of questions, with approaches derived from an objective with a future vision for the implantation of new scenarios, planning without historical information, new ideas for organizational policies, search for strategies, support of decisions, dates of possible happenings of an event, tendencies and future.

The Delphi technique can be an extrapolated form from which we get prediction of the future based on passed events; an exploratory form in which the analysis of

change is within the alternative feasible ways to a determined future and normatives based on actions that will determine the future through the analysis of values, needs and environmental variables that are related to the anticipated goal.

The Delphi technique presents advantages in terms of a possibility of predictions that is independent of historical variables, with a large volume of information, questionnaires where reflections are obtained from the responses, anonymity that eliminates interfering factors and a low-cost.

Generally, a group of specialists is formed and a prevision of future elements are proposed based on up-to-date bibliography, a questionnaire is elaborated, its validation is carried out within the group and the questionnaire is then passed on to a group of specialists, with a basis on the statistical treatment and retro-alimentation of the same questions, leading to the possibility of a final consensus between the responses.

The information and opinions between the specialists make it possible to review the responses based on subjective probabilities and a strong argumentation of the adopted consensus in the statistical treatment of the information.

1.2.1 – Use of the Delphi Technique for Technology Prediction

The Delphi technique has been widely used in a number of technological researches. New materials (18), sensors in various areas (mechanics, optics, biosensors, electric, magnetic, chemical, nuclear) and the potential for the next 10 years (19), development of nanotechnology (simple nanostructures, production volume, costs and production of nanocomponents, environment, health, security and potential military use) (20, 21), semiconductors (22), future energy and primary sources (23,24), the access to free software (25), evolution in the creation of new software (26), risks of chemical contamination (27) and review of future rules (28) have already been studied with the use of the Delphi technique.

2. COVERED TOPICS – TECHNOLOGICAL ROUTES

For support of the elaboration of the questionnaires, a number of items were based on information and analysis of the literature with diverse “technological routes’, such as basic research (temperature and energy factors, long-duration discharges, control and plasma stability, heat and particle control, energy confinement), reactor project (systems for the integration of involved technologies, TOKAMAK devices, equipment for control and diagnosis, reactor structures, development of operational control methods) material (superconductors for the generation of intense magnetic field, compatibility of the shells and the structure of the material under high irradiation, heating and possible modifications of the components), cooperation in research (international collaboration in the research, shared-use of installations in universities and research centers, development of ITER and DEMO, a program for experimental reactors), computational (simulations involving the theory and system configuration), forms of nuclear fusion (magnetic confinement, inertial, FRX-L – Field Reverse Experiment Liner, Plasma Injection for Magnetic Target Fusion, Sonoluminescence Fusion, Muon Catalyzed - Cold Fusion-, Inertial Electrostatic Fusion, Pyroeletric Fusion), industrial (development of industries for the components of the nuclear fusion reactors), environment and society (energy from nuclear fusion in the future, the effects or environmental problems,

social security, resistance to the growth of nuclear fusion, description to the society, generation of nuclear fusion specialists and researchers).

2.1. Questionnaire validated with specialists

The questions that follow were created based on an aforementioned bibliography and was analyzed together with specialists in nuclear fusion from the Institute of Physics of the University of São Paulo in Brazil and the Center of Nuclear Fusion of the Technical University of Lisbon in Portugal with the aim of making it a tool in the elaboration of a database for nuclear fusion and its perspectives. They are divided according to the area involved. This is the first round of the questionnaire and answers.

2.1.1 Chronograms

– Around the year 2050, a potentially commercial unit of magnetic confinement nuclear fusion reactor, Tokamak, currently cited by DEMO(5,6) may come into operation. Can there be a classification with an optimistic and incoherent date with uncertain possibilities in the future?
• most of researchers adopted that in 2050 the reactor Demo will be a reality

– The joining of nuclear fission and nuclear fusion reactors is currently discussed (hybrid reactor)(29), the first reactors to be potentially commercialized will only comprise the nuclear fusion technique (for example DEMO). From what period will the incorporation of the nuclear fission technique to nuclear fusion reactors be an available technology?
• the date for this hybrid reactor will be superior to 2080

2.1.2. Technological

- The project of ITER and DEMO reactors has a large influence on a diversity of research areas. In a classification of 1 to 3, whereby 1 is considered to be the most important, 2 of medium relevance and 3 of least relevance, how would the following items - control and movement of particles within the magnetic field(30,31); analysis of the first wall(32);diagnosis techniques(33),reactor configuration(34,34)- be classified?
• 2-Control and movement of particles within the magnetic field(30,31)
• 1- Analysis of the first wall(32)
• 3-Diagnosis techniques(33)
• 2-Reactor configuration(34,35)

2.1.3. Material

– With the development of new material and technology, there can be improvement in the nuclear fusion reactor projects. In ITER, the use of superconducting coils is already a consequence of the introduction of innovative material(36,37). With the coming of the nuclear fusion reactors, from what time period are larger investments in research areas related with the development of material directed towards this future technology possible?
• The investment in materials for use in nuclear fusion will be larger in the next 15 years

2.1.4. Fusion Techniques

– A series of new nuclear fusion techniques are being developed and confirmed, such as: FRX-L (Field Reverse Experiment), Plasma Injection for Magnetic Target Fusion, Sonoluminescence Fusion, Muon Catalyzed (Cold Fusion), Inertial Electrostatic Fusion e Pyroeletric Fusion(11,14,15,16,38,39,40). Can the afore mentioned fusion techniques be considered to be potential for energy generation?
• Most of the respondents works with magnetic confinement and they answered that these techniques could not be considered as promising

– Currently, there are two most promising techniques for nuclear fusion and that are applied in two distinct projects, magnetic confinement and inertial techniques. The magnetic confinement ITER will be in operation in the next few years and has a great potential for the development of commercial stations. The other one, HIPER, which utilizes the laser driven inertial technique(10), has the potential to be commercially developed in the future. What time period would the time difference between the development of these two techniques amount to?
• the difference for the development of the inertial technique in relation to technique of magnetic confinement will be of 30 years

– Currently, the researches on magnetic fusion reactors have a number of resources like computational simulation (approach of material problems, security systems and others) (41,42); experimental tests with great emphasis on material submitted to the operational conditions of the reactors(43,44,45), in theoretical approach (researches with particle movement in magnetic fields, transport and plasma control under fusion conditions and others) (46,47). Considering that researches with the inertial technique are still incipient(48,49) when compared to researches on magnetic confinement reactors, how can we classify its current technological contributions?
• Contributions of low level due to the reduced number of researches published every year

2.1.5. Regiments and normalization

– Presently, elaboration of regiments and rules for operation, security, environment and other factors involving nuclear fusion reactors can be found, especially for ITER(3,50). In what period should normalization, after the operation of ITER and considering the possible implantation of future reactors such as DEMO, be established?
• the normalization will be obtained among the year 2020 and 2030

2.1.6. Environmetal

– The generation of radioactive waste also occurs in nuclear fusion(4,50,51). From the environmental point of view, this would lead to controversies. regarding the items - without great impact; low relevance; relevance of more than 30% of the opinions; high relevance; social groups are against the implantation of this new energy generation system - which one would turn out to be the society’s view on this aspect?
• The answer of larger value was of low relevance

2.1.7. Generation of Researchers

– The future international scenario can be strongly influenced by the impact caused by this technology and by information. After operation and publishing of the results of this magnetic confinement nuclear fusion reactor, ITER, and by the knowledge generated with the development of inertial reactors, like HIPER, a promising growth of research in nuclear fusion(52) can be expected in a number of countries. With regard to the current days, in what period can an increase in the investments in research concerning nuclear fusion and in the development of human resources in this area become wide-spread?
• The largest generation of human resources will be in the next 20 years

2.1.8. Infrastructure

– There are still difficulties and topics to be discussed in the research and development of nuclear fusion(3,4,50,53,54,55). From the items below - lack of compatible material, energy source and adequate capacity, security of the installations, appropriate legislation, investment cost - classifying in a scale from 1 to 5, whereby 1 is considered to be most important and 5 the least important, what would be the greatest difficulty to construct and operate a nuclear fusion reactor?
• 3 - Lack of compatible material
• 4 - Energy source and adequate capacity
• 3 - Security of the installations
• 3 - Appropriate legislation
• 1 - Investment cost

2.1.9. Economic

– The development of other forms of energy and the final values of commercialized electric energy are currently widely discussed(56). In a few decades, nuclear fusion may be viewed just as nuclear fission is viewed today. The nuclear fusion reactor may be seen as a form of long-term investment, involving a capital market with companies committed to the development of equipment and components(57). Considering that it involves the generation of energy at global level, can this future be considered to be promising and not very uncertain for capital investment?
• A promising future for capital investment

– We presently have an economic uncertainty regarding oil, which reflects on the fluctuation, with positive and negative variations in its price and its future availability(24). Is there a possibility of having fluctuations in the price of energy generated using nuclear fusion reactors due to political, environmental and social factors in the phases of implantation and operation?
• there won't be variation of the final price of the generation of energy of reactors of nuclear fusion.

2.1.10. Social

- There is a certain degree of uncertainty about the future predictions regarding energy generation due to many factors that can influence the political, social, environmental, economic and technological development of nuclear fusion(54,58). In the next 50 years,

nuclear fusion can be classified as - very important**;** important**;** important, but of low relevance when compared to energy from other renewable?
• The average of the answers - important

– Factors involving social security(23) can affect the time period of development, implantation and the researches on nuclear fusion reactors. Even with the occurrence of these reactors, can it be that there will be little variation in the investment in nuclear fusion due to the conscience that this represents to development?
• There won't be decreasing variation of investment in researches on nuclear fusion the next years

3. CONCLUSIONS

The consultation of material involving researches on nuclear fusion and the verification with specialists made it possible to form the first round of the an extensive questionnaire on a number of research topics(chronograms, technological, material, fusion techniques, regiments and normalization, environmetal, generation of researchers, infrastructure, economic, social) for the accomplishment of a future research involving the answer of a greater number of researchers with Delphi technique. The future development of a database will occur through cataloging the responses and the possibility to incorporate more exploratory and extrapolated elements on this topic. These questionnaires will be sent by the Institute of Energy and Nuclear Research in Brazil to a "population" of Brazilian specialists (researchers) of the "National Network of Fusion" (coordinated by the National Nuclear Energy Commission (*Comissão Nacional de Energia Nuclear - CNEN*) and to European researchers associated to EURATON by the Center for Nuclear Fusion of the Technical University of Lisbon in Portugal (*Centro de Fusão Nuclear da Universidade Técnica de Lisboa*).

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