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Antecedents and perspectives on the development of nuclear energy in Chile

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Abstract. A review of activities and future prospects of nuclear energy in Chile is presented. It shows that the development of this sector is closely linked to the history of the Chilean Nuclear Energy Commission, CCHEN, established in 1965. We can distinguish three stages in its development: the installation, culminating at the beginning of 1974 with the La Reina experimental nuclear reactor went critical. Then a phase of consolidation, which reduces the activity of scientific research and stresses the application, between the years 1974 and the end of the eighties, and finally the last twenty years, a stage of continuity marked by a loss of importance and leadership of the institution at the national level, despite having important specific initiatives in the 2000s, such as the successful development of fuel elements, the installation of a cyclotron that allows the execution of PET diagnosis for the first time in the country and the consolidation of a research laboratory on plasma and nuclear fusion. At present there is a consensus that nuclear sector in Chile needs to be placed in accordance with the development experienced by the country, and therefore requires a profound restructuring of the CCHEN, reviewing its vision, mission and work program. Here is a proposal in this regard.

1. Introduction

Chile learned of nuclear energy in a relatively early stage, when the Rector of the University of Chile, Juan Gomez Millas, created the Nuclear Physics Laboratory in 1954. This entity was the prelude to the Chilean Nuclear Energy Commission, (Comisión Chilena de Energía Nuclear, CCHEN, in Spanish) founded in 1965 with the aim to "address the problems associated with the production, acquisition, transfer, transport and pacific use of the atomic energy and fertile, fissile and radioactive materials". Chile, like most Latin American countries did not want to be left out of the tremendous possibilities offered by this new form of energy, which was revealed from the boost given for peaceful uses by various international programs, such as "Atoms for peace" in the mid-1950s, driven by the U.S.

At the foundation of CCHEN there was a clear view of the need for a state agency that was concerned of nuclear issues in the broadest sense. The discussions of the time shows that it was perfectly understood that nuclear issues were strategic for the country's development. This refers not only to have an informed opinion on its geopolitical and defense aspects, but especially on the issue of energy sources and science and technology of nuclear applications in health, mining, agriculture, construction, to name a few. "How can we put this enormous energy released by the atom to serve the country?" was the question asked in 1955 by Dr. Eduardo Cruz Coke, well-known scientist,



congressman and the first CCHEN's President. And he concluded that certainly because the diversity of subjects, the degree of specialization, the urgent need for safe operation and their strategic importance for the country, nuclear issues could not be in the hands of a private organization, nor in a purely academic institute. It had to be a specialized agency of the state who took that responsibility on its shoulders.

In this article we briefly review the development of the nuclear sector in Chile, and then describe the main topics that underpin the strategic plan designed for the near future.

2. The Early Years: 1965-1973

The initial design of CCHEN envisaged a vigorous scientific and technological development plan that included the installation of a nuclear reactor and the study of the application of nuclear techniques in health, agriculture and industry, as well as its possible use as a source for electricity production, that is, nuclear power. Interesting groups were formed for research in close link with the universities. Along with this, the formation of expert researchers, engineers and technicians was encouraged: nuclear physicists and engineers, radio-chemists, physician, lawyers and so on. During these early years, these people began to produce radioisotopes and radiopharmaceuticals (1968), to investigate the applications of irradiation (1969), and the effects of radiation on health and environment, addressing topics such as radiation safety. The first applications to industry and environment started with the development of tracers (1969).

In parallel, it began the research related to the fuel cycle, such as working in geology (1969) and establishing a metallurgical laboratory (1969). A highlight of this stage is the acquisition, installation and the critical set up of the experimental reactor La Reina (1969-1974), located in east side of Santiago. During this time several agreements were also signed with a number of national and international institutions for training specialists, and scientific cooperation. Alongside this, that we could call the "exploitation" of nuclear energy, the safety and security activities were also developed, that is, the tasks of supervising and controlling nuclear activities from the standpoint of the physical security of facilities, processes and staff.

This first phase of installation was interrupted by the Coup d'Etat of September 11th, 1973 that overthrew the constitutional president Salvador Allende. Several scientists and technicians had to emigrate, which caused the dismantling of laboratories and cessation of several activities. The institution failed to reach scientific and technological leadership and could not articulate it to national development [1].

3. Application Stage: 1974-1990

Starting in 1974 there was a shift in the activities of the CCHEN. The military took control of it, resulting in important administrative and operational changes, as the annexation of the Nuclear Studies Center of the Army [2], with its facilities in Lo Aguirre and its research reactor, opened in 1978, but that has never been used on a regular basis. During this stage, the applications were mainly boosted, leaving low scientific research and innovative development. In spite of this fact, it is interesting to note that during this period several of the activities planned in the early years were consolidated: since 1975 the routine production of radiopharmaceuticals and radioisotopes (1975) and tracer for mining (1976) and industry (1984) began; a multipurpose experimental irradiation plant (1978-79) was built, and applications in agriculture (1981) were implemented. On the other hand, there was significant progress on the fuel cycle, including the uranium prospecting of a part of the country (1975-85), and the development of hydrometallurgy, obtaining yellow cake in an experimental basis. In addition to the efforts to produce fuel for research reactors, the operation of the fuel elements plant continued. As before, the tasks of regulation, supervision and control went on and advanced. Also, a Section of production and services began to operate, providing isotopes, instrumentation and chemical analysis to public and private sectors.

The CCHEN administrative structure was also consolidated. A Department for outreach and training, as well as a Section of international relations was established. During this time CCHEN

worked significantly in the drafting of laws, decrees and regulations on nuclear activity. This was crowned in 1983, when a Supreme Decree that approved policies and objectives for nuclear development, helped to consolidate the progress in respect of applications, and order the legislation concerning the regulatory aspect was issued. Also, various aspects of nuclear materials, including mining were organized and regulated.

An important aspect developed during these years, which concentrated great efforts, was the studies on the feasibility of having nuclear power in the country: these studies date back to 1969, then 1975-76 and 1983. In all cases, they were dismissed for economic reasons (see [1] for details).

4. The Chilean Nuclear Energy Commission in democracy

Since the beginning of 1990`s, with the return of democracy, the discussion about the role of CCHEN in this new scenario started, but it was not easy at all. During the first years of democracy, there were issues that caused some tension in the Board of Directors, which fortunately, was surpassed later [3]. However, the results of these debates were reflected in the development of a nuclear policy, enacted by Supreme Decree in 1995 under the title "National Nuclear Development Plan". However, this plan failed to bring a new CCHEN, according to the challenges of the new era that opened in the country. Somehow, there was a policy of continuity, and in fact, there was a continuation of the same activities of previous years, with few exceptions, such as the installation of a cyclotron (2002) that enabled the development of PET technology in the area of health; the international certification of the fuel elements plant (2007), and the consolidation of the Laboratory of plasma and nuclear fusion (2000), which returns the scientific research on nuclear issues to the CCHEN.

In recent years, the leadership in Latin American and worldwide of the Laboratory of plasma physics and nuclear fusion (which now become in the Thermonuclear Plasma Department) on various subjects, particularly in the production of dense plasmas in small devices (2000-2009) has stood out. There is also progress on the use of nuclear techniques. Among the main milestones we can mention the environmental application like gases and wastewater treatment (1993); chemical metrology (1993); measurement of trace metals in sea water and aerosols; operation of a tissue bank (2000); putting into operation the SPEED 2, donated by the University of Dusseldorf [4]; landmine detector, (2008); remote monitoring, (2009). With respect to fuel cycle and metallurgy, it stands out the development of vacuum sintering technology (1990-93), the conversion of UF₆ to metal U (2003-2010) and the production of fuel elements for the RECH-1 (1994 - 2000), an initiative that is crowned by the international certification of the plant gained in Peten, Netherlands (2007).

However, despite these achievements, several years ago there was a feeling that CCHEN was without any clear goal: the country had changed, and there was not a vision or mission of CCHEN in accordance with the needs and demands of our society and state in the perspective of the new millennium. These considerations triggered, some years ago, a deep analysis of the situation not only of CCHEN, but also of the nuclear sector in Chile, in order to rethink it and study the decision that should be taken to bring it up to the current times.

5. The Chilean nuclear sector and its perspective for the future

Status review of the nuclear sector was motivated by several factors, one of which was especially important in the recent past years: the growing energy demand in the country. Chile suffered a severe energetic crisis in 2006-2007, with the lack of natural gas coming from Argentina, what put into sharp focus the discussion on the need to develop a national energy plan which considers diversifying our energy matrix and making it compatible with the protection of the environment. That led to seriously wonder about the possibility of incorporating nuclear power, which in turn led to look how we are in that area. And we found that we were actually in a very wrong foot: nuclear energy specialists are no more than 15 people, several of them close to retirement. The discipline is only taught at one university, the University of Chile, but with one facility, once of first order, now operating at minimum capacity. To make matters worse, CCHEN, the state institution dedicated to these activities, was mired in a morass, with clear signs of stagnation and demoralization.

Indeed, in year 2004 when the energy crisis in Chile due to the problems of gas supply from Argentina began to be glimpsed, the need to diversify the energy matrix immediately raised. This led President Lagos to say that "we also need to think about nuclear energy". After that the crisis became more severe, compounded by drought that hurt hydroelectric plants. Given this scenario, President Bachelet designed a robust energy sector plan that would address the demand the country needed smoothly, without improvisations. The main elements of that policy were embodied in the document "Energy Policy, new guidelines," published in 2008 by the Minister President of the Energy Commission, Mr. Marcelo Tokman [5]. There expressed the urgent need to diversify the energy matrix, begin an intensive energy efficiency program and build a new institutional sector, whose starting point was the creation of the Ministry of Energy.

Consistent with this, in 2007 a Working Group on Nuclear Power, led by Mr. Jorge Zanelli was formed. This group issued a report which set out three main conclusions to evaluate the incorporation of nuclear power in the country: 1) Chile must keep all energy options open. Nuclear power is not an option to discard and could cooperate in the security of electricity supply, 2) nuclear energy is reliable at the levels of security that its industry has reached, but it require permanent concern, discipline and rigor, and 3) nuclear power is a potentially competitive option, especially because of the current fossil fuel prices in international markets [6]. The Zanelli Working Group recommended to advance the discussion of the problem, and to do several studies about institutional issues, economic factibility, environmental, health and territorial aspects, as well as human resources and public opinion, among others.

Then, being prepared to incorporate any energy option, regardless of the final decision, requires to be up to date with the requirements of such an enterprise and therefore, to stress all stakeholders. It is important to point out that the current stage in the country (year 2010) is not to incorporate nuclear power, but to prepare the way for it. The final decision, that is, whether the nuclear-power is incorporated or not to our electrical grid is a decision to be taken after a public debate at a national level. However, actions taken now will be beneficial for the country, regardless of the decision taken. Indeed, part of these actions is the creation of a nuclear regulatory institution (like NRC of the USA), to update all relevant legislation, to modernize and regulate the electricity sector, to allow the incorporation of other generators (not just nuclear but also wind, solar, etc.), to perform geological and seismic studies, and to prepare adequate staff, among other tasks [7].

6. Restructuration of the Nuclear Sector

This, then, is the context and the framework of the analysis and projections of the country's nuclear industry and in particular the future design of the Chilean Nuclear Energy Commission, CCHEN. More than four years ago we became aware of the need to develop a comprehensive strategic planning. In order to do that, we reviewed and made a diagnosis with the aid of specialized external consulting companies, conducting assessments, self assessments, focus groups, etc. Importantly, the strategic planning process included the active collaboration of the vast majority of workers of CCHEN, its head staff and the Trade Union, being directed at various stages by the Directive Board of the institution. In July 2010 this analysis, with the diagnoses and recommendations, was presented by the author, as President of the Directive Board, to the Minister of Energy Mr. Ricardo Raineri. Below we point out the highlights of this plan.

The diagnosis showed several interesting findings. The main problems can be grouped into strategic / organizational and cultural issues. We will present each of them.

A) Strategic / organizational problems: the central point was the lack of clear mission according to the needs and demands of society; it was found that it was a multifaceted and complex institution, but one that has lost focus. For example, CCHEN performs public service and scientific research activities at the same time; it is a regulatory and supervisory agency, and it also works in production activities (radioisotopes for medicine for instance), dissemination and training on nuclear techniques, and also

performs some functions of great social impact, such as health applications, which certainly cannot only be assessed by economic profitability. Regarding its internal structure, it is clear that neither organic structure nor its workers framework nor the wages respond to current needs and have no correlation with the country's progress. On the other hand, there is a disconnection with innovation policy and competitiveness that the country leads. Also, there is limited relationship with other agencies in the country, including universities and institutes.

B) Cultural problems: these account for a culture of individual work, hierarchical, and compartmentalized. There is a lack of incentives for creativity and collaboration, both within the CCHEN as well as with the world outside. Much of the activities are performed routinely; important part of the workers is demotivated and demoralized. There is little human capital management, and renewal of professionals is very difficult. Other aspects are the lack of knowledge management and weak internal CCHEN positioning to the national authority and public opinion.

Having an institution in these conditions could certainly mean not only the loss of opportunities, but also unacceptable hazards that could lead to relaxation in supervisory or production activities, with the possible risk of nuclear or radiological incidents. It also means economic waste when having duplication and inefficiency, loss of investment and knowledge gained in research and development over the past 40 years, and weakening of the link to the IAEA and international relations.

However, the analysis also concluded that if appropriate measures are taken on time, the above situation can be resolved and the institution could become a model for other similar public bodies, not only in Chile but perhaps it could also serve to similar countries in Latin America. These decisions require a profound change, both internal and external, of the institution. Regarding the domestic level, it is clearly a need to consider new targets, which implies an institutional redesign. As for the outer level, new laws and decrees are required, beginning with the early establishment of a nuclear regulatory institution. Currently, this function is fulfilled by CCHEN, but obviously a good practice always advises to separate the regulatory body from the operator body (Here there are several schemes that can be taken and it is instructive to dwell on international experience). Another measure needed is a new law for workers' structure, for remuneration, and a redesign of the public-private relationship. Only a renewed institution can fully meet its obligations in a society which is certainly very different from the one of 1965, when it was founded. All these measures mean a complete restructuring of the nuclear sector.

Thus, the **vision** of CCHEN we need consists of the following points:

- to be the reference body of the state in nuclear issues;
- to be a producer of goods and services needed for the country.
- to be a leading institute in nuclear science, technology and radiological issues, at national and international level, whose results, products and services impact positively on the economy and living conditions of the population.

What can be gathered from the above statements is that the **mission** of the new CCHEN

- collects information and is aware of the world state of art in nuclear issues.
- conducts research and development in the nuclear and radiological service in the country.
- acts as a national laboratory in the country by making its unique facilities, specialized professional and technical support available. Trains researchers, professionals, technicians and students.
- produces goods as well as nuclear and radiological services essential for our country and its people.
- associates with other institutions both from the public and private sector and international organizations.

All these activities performed with high standards of quality and safety.

The previous approaches need to be implemented. We propose to do so on the basis of three main areas: I) the work programs, II) the safety culture, and III) a new institutional design. The development of each of these areas should be in parallel and each at its own pace. We will give a brief explanation of each of them.

I) Work programs: this axis determines the daily work of the institution. It aims to develop different aspects: a) radiation for life, industry and environment, b) material science, c) nuclear energy plasmas, and d) the nuclear regulatory body (its creation must be the subject of a special law and its operation will be outside CCHEN, so we will not detail their function here. Let us just say that its mission is to supervise, control and license nuclear facilities, to ensure their safety in the operation.) These work programs were chosen because they represent the most necessary for the future, and also reflects the best practices carried out in the CCHEN during its 40 years of life. Below we will briefly explain the contents of each of them.

a) Radiation for life, industry and environment: its main focus is on enhancing the development of radioisotopes according to their relevance and usefulness. This is, we plan to develop those products that are necessary for the country and that cannot be provided by other agencies (private, etc.) because the complexity of its production. Similarly, once the techniques are mature, the idea is to transfer them to other institutions for their production, and thus the CCHEN is always in the forefront of knowledge. This area is also raised to develop new projects, one of which is to produce fission Mo-99 at industrial scale. This radioisotope decays into technetium-99, which is the most widely used radionuclide in nuclear medicine. The other new project is to boost the creation of a National Laboratory of Molecular Imaging to develop preclinical research in biomedicine and related areas. This is an ambitious but achievable goal. As in the beginning CCHEN pioneered the development of nuclear medicine in Chile, now it corresponds to step forward and to be pioneers in preclinical research with cutting edge techniques.

b) Material Science: this is a key area for the development of the country, both for mining and industry as well as for construction and defense. The CCHEN can play a fundamental role in research, in conjunction with universities, because it has unique facilities and laboratories, as the reactor itself, which can and must be available for the country to study and characterize materials. This area will be developed in three aspects. One is the fuel cycle, from uranium mining to the production of fuel elements for research reactors. This, somehow, has been done, with certain stages more developed than others. What is needed now is to further systematize and professionalize this activity in all its dimensions. Another aspect is the study of advanced materials. Currently, there are groups working on this issue, at analytical chemistry and diffraction laboratories. The challenge is to interact with universities and institutes, both in Chile and abroad, so that the research carried out is in accordance with the needs of the country and its people. The last aspect to be addressed in this area is the creation of an Institute of Lithium. Indeed, lithium is a material of strategic importance not only for its potential future use as fuel in fusion processes, but for its increasing use in electric batteries (Li-Ion and others). It is anticipated that due to the depletion of fossil fuels, the use of hybrid and electric cars is increasing, and therefore the battery can be considered from this viewpoint, a powerhouse. Chile is the world's largest producer and also has the major reservations, but paradoxically, has almost no studies on this material. However, there is an agreement with CORFO that the money from the royalty of lithium should be used to fund a scientific research institute on lithium technology. CCHEN is the place to start these activities.

c) Nuclear energy and plasma physics: this is the most typical activity of CCHEN. There are three aspects involved in the development of this area. First, to support the nation in the necessary studies to make an informed decision on nuclear-power option and to have the necessary preparation if the

decision is positive. This means, exercising the role of CCHEN as a study group and government adviser on nuclear issues at the highest level. A second aspect is related to foster the development of portable non-radioactive sources for use in applications (exploration and detection of landmines), which until now has been successful in CCHEN, together with military institutions and the ministry of defense. Finally, an area where CCHEN has leadership, not only in Latin America but worldwide, is nuclear fusion research. In fact, devices using small and medium-sized plasmas have been successfully developed at CCHEN. Here the objective is to strengthen this research even further, and study fusion-fission hybrid reactor (plasma focus as seed neutron fission) and pulsed power to generate shock waves, with obvious applications in industry and mining. Of course, we see all this activity in the framework of international collaborations, particularly we want to promote a Latin American program of nuclear fusion.

II) The second axis of development is the safety culture. This is based on the requirement that none of the nuclear industry can be developed without being permeated by a highest standard safety culture, which is well defined by the IAEA. This is reinforced by a disturbing internal report of the Head of the Section on Quality, 2007, which stated that CCHEN has not yet reached a reliable safety culture. Fortunately, in its 45 years of life CCHEN has not had any accident or incident involving security. This theme will work as recommended by the IAEA, and includes joint efforts by all stakeholders: political commitment at the structural level, the authorities of CCHEN, structural commitment of operator behavior, and commitment of each official.

III) Finally, the third axis is related to the need of an institutional design to realize the necessary restructuring of the nuclear sector. First, we must establish policies and criteria of the new public-private relationship of the institution as well as basis to discuss how to address the issue of nuclear and strategic materials that depend on CCHEN, like uranium, thorium and lithium. It is a question of making decisions about granting, operation, taxation and other aspects of these minerals, always having these public goods as a precautionary, and ensure the benefit of the state. A second aspect has to do with the new legislation. We need to pass a new law, of which there is an initial draft, on nuclear and radiation safety. Similarly, a law is needed to create the regulatory body and a new law for workers` structure and remunerations. It is also necessary to conduct a detailed human resources plan and establish a new management model.

So, these are the central ideas and approaches to which the nuclear sector in Chile should go the coming years.

7. Conclusion

Since 1965, CCHEN has made immense contributions to the country. Just to name one: there is virtual unanimity among scholars that the discipline of nuclear medicine, with all the benefits it brings to the population is possible thanks to the CCHEN and its workers. However, despite the many important contributions, it is necessary to restructure the nuclear sector precisely to allow to continue at the forefront of knowledge, as it did in its early years. The situation today is different: we live in a context of depletion of fossil fuels, global warming as result of increased greenhouse gases and the certainty that we are in an environment where natural resources are finite, and therefore we must take care of them. This has brought the issue of energy sources to the center of public debate. In addition, fuels we use in Chile are all imported, except hydropower, and we have a growing demand of energy product of our route to economic development. This is the framework to discuss the incorporation of new sources to our energy matrix. The nuclear power is an option. Whatever decision we make as a society to be informed and prepared for it is a must. That is why I have posed the challenge, which is explained in this article, to restructure the nuclear sector to be according to the XXI century. There is a lot much that CCHEN can give to the country, apart from a possible nuclear power: radioisotopes supplies for medicine, food immunization, research of new materials, sources for material

characterization with increasing use in industry and mining, just to name a few. This is, in Chile at least, the use of nuclear energy for peaceful purposes has many pages to be written.

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9. References

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- [2] See the Law decrees DL 1507 (1974) and DL 747 (1976). An interesting account of the military participation in the chilean nuclear development, see A. Cubillos, El Ejército y el desarrollo nuclear nacional, AHM (2004).
- [3] Interestingly, CCHEN is managed by a Directive Board and a CEO. The Directive Board consists of seven members: one representative of the President of Chile, acting as President of the Board, and representatives of the Minister of Energy, Minister of Health, the Council of University Rectors, as well representatives of the Commanders in Chief of the Army, Navy and Air Force.
- [4] The SPEED 2 is the most powerful generator for experiments in dense transients plasmas in the Southern Hemisphere and the only one in operation in Chile that produces currents of mega-ampere.
- [5] M. Tokman, Política energética. Nuevos lineamientos, edited by Comisión Nacional de Energía, Chile (2008).
- [6] These findings should certainly be seen now in the perspective of what happened in Japan with the Fukushima nuclear power plant after the earthquake tsunami suffered there in March 2011.
- [7] See more details in M. Tokman, Núcleo-electricidad en Chile: posibilidades, brechas y desafíos, edited by Ministerio de Energía, (2010).