

NUCLEOELECTRIC WORKING GROUP

THE NUCLEOELECTRIC OPTION IN CHILE

September 2007

REVISED EDITION

**Incorporates corrections and observations made by
The International Atomic Energy Agency – IAEA
September 2008**

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PRESENTATION

On March 13 of this year, her Excellency the President of the Republic, Dr. Michelle Bachelet, officially announced the constitution of the Nucleoelectric Working Group, through Decree N° 49, 2007, of the Ministry of Mining. This group of 10 professionals from different fields of specialization, was entrusted with the mission of advising the government “in the evaluation of studies towards the identification of opportunities, advantages, challenges and risks that would be involved in the use of nuclear energy for production of electricity in this country, within the framework of international treaties that rule in this matter” (Article 1° Decree N° 49, 2007).

At the moment of their appointment, each member of the group declared not to have any links of interest with areas that might benefit from or be harmed by the introduction of a nuclear option, or having a previously formed opinion on either the convenience or inconvenience of it. Even though they received institutional support from the Ministry of Mining and the National Energy Commission, the group worked autonomously and independently from the government.

This report gathers the consensual opinion that honestly and faithfully has been reached by the group, through a free and independent analysis of all information available to them. Drafting of this document was based on interviews with representatives of different bodies of State administration related to energy, environment, nuclear energy, health and radioprotection, international relations and defense, including a meeting with the Senate of the Republic. Meetings were held with national and foreign specialists in nuclear energy, electric planning and regulation, as well as with operators of nucleoelectric generation (**NEG**) plants.

Likewise, the vision of the civil society, the business and academic worlds, and representatives of the environmental movement was also considered. Finally, several visits were made, where members of the group held interviews with officials of different governments, in charge of the regulation and follow-up of nucleoelectric activity around the world.

What this report does *not* intend

This report does not intend to give any final verdict on the convenience of the NEG option in Chile. It documents the information that reflects international knowledge about NEG, as well as addressing certain aspects pertaining to the current situation in Chile. Nevertheless, from this information, it is possible to recommend adoption of certain measures that are necessary to move forward in the discussion of the problem, among these are highlighted a series of studies to be performed. These studies refer to territorial, environmental, institutional, regulatory, economic and social aspects of our country.

The conclusion on the convenience or not of the nucleoelectric option in Chile should be the result of examining the background information obtained by these studies in the coming years. It will be the Chilean society that should make the decision when the time arises.

Santiago, September 2007

Note on the second edition

After this report was completed and handed to the President of the Republic, it became apparent that it be made available to the public at large in printed form. In the following months we received a number of observations, including several comments and observations by the International Atomic Energy Agency. Most of these criticisms were well directed, improving the clarity and precision of the report without changing its spirit or the conclusions. This second edition takes into account these comments and contributions, which we sincerely thank, as in most cases these corrections help make the presentation more transparent and the conclusions better founded. We hope to have made justice to all of the observations and, although needless to say, any error or misunderstanding is only our responsibility.

In the meantime, the Nucleoelectric Working Group was dissolved and the National Energy Commission, under the direction of Minister Marcelo Tokman, has undertaken the task of producing the studies recommended in our report. These studies are meant to assess the feasibility, the costs and the challenges that the Chilean society would face if it decides to embark in a nuclear power program. The result of this effort should be the basis for the next administration to make a knowledgeable commitment to start or not a nuclear power program in Chile.

**J. Zanelli, editor
October 2008**

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1 INTRODUCTION

Energy from traditional sources is showing growing signs of relative exhaustion. So-called fossil fuels have increased their prices significantly and most experts coincide that prices will remain at levels much higher than those which supported industrial growth in the 19th and 20th centuries.

Although the future is by definition uncertain, no in-depth analyses are needed to realize that a significant number of countries are growing at an accelerated rate and that the resources that sustain this growth, energy in particular, have not been able follow this rhythm. China and India are especially conspicuous, for their impressive demographic size and because their accelerated growth is generating inflationary pressure on many of their so-called commodities. Furthermore, given the lag of emerging economies and their growth potential, it is relatively simple to predict that these essential products will remain scarce.

Successive record-breaking oil prices are a symptom of this fossil fuel-based energy exhaustion and are repositioning the energy issue as a world concern. With increasing prominence, topics such as renewable and non-conventional energies (RNCE), energy efficiency as well as nuclear energy are becoming part of the worldwide debate. None of these issues are new, and in one way or another they have been present for a long time, in the concerns in almost all countries, with perhaps more clearly since the first oil crisis in 1973. However, we are witnessing an intensifying energy problem, from which Chile is not excluded. On the contrary, our country is going through a tightening of the supply of electric energy that has intensified this debate.

Global warming is another element to be considered in this context, in addition to exhaustion of fossil fuels. In fact, it is not only the sources of energy that matters, but also their quality. In this sense, the scenario set for the energy challenge adds more pressure to the scarcity and the prices increase.

The empirical evidence arising from the simple observation of what has been done in the more developed countries, suggests that we are adventuring towards a multi-energetic future. The solution is likely to come from diverse energy sources, from improvement of technologies, and from more efficient application of them, consistent with the vital importance of this resource for modern societies.

Within this complex and concerning scenario, no reasonable option capable of mitigating or reversing all of the problems we are facing can be discarded. On the other hand, the seriousness and urgency of the situation demands a scrupulous analysis in which all effects -positive and negative- for each option are duly pondered and contrasted. In such analysis, nuclear energy appears as an alternative to be considered, whose costs and benefits must be carefully analyzed, in order to know whether or not the country should include this source as one of the components of its future energy matrix.

The international experience shows that nuclear energy correctly handled and administered, is a trustworthy and efficient way of producing abundant electricity at a competitive cost and low CO₂ emissions. However, it is also evident that inadequately

managed, it can produce damage to the health of those working with nuclear power, and cause considerable environmental disasters with serious risk to the general population.

The crucial point is that nucleoelectricity is not like any other form of electricity generation, and has essential differences with other energy sources. Among other peculiarities, it establishes long-term commitments, which the country must consciously and responsibly assume, it also requires a State role different from the current one, and demands the application of complex technology.

The objective dangers of nuclear energy originate from the use of nuclear fuel, a highly radioactive material, capable of causing serious harm to the environment and to persons in case of direct exposure to such radiation. Besides this, after its use in a reactor, nuclear fuel must be removed and stored in a safe place, as it remains radioactive for thousands of years. Moreover, the fact that reactors function near a critical point, means that normal operation parameters, such as temperature, pressure or vapour flux, have values close to the thresholds at which an explosive chain reaction could be triggered. This makes it imperative for reactors to be extremely robust structurally, as to guarantee fine control of the functioning parameters, despite the extreme conditions at which they operate over long periods of time.

These three difficulties – the use of radioactive substances, management of waste and steady-state operation near critical point, present enormous technological challenges due to their complexity and demanding nature.

Apart from the technological and operative challenges, there are further difficulties which stem from the possibility of using nuclear fuel for the purposes of war and terrorism. The implications for international relations are obvious, including the obligation of the Chilean State to play a role of guarantor, a role not required for other industrial activities, with the possible exception of arms production.

While for RNCEs, for energy efficiency, or for the development of technologies for reduced emissions, a traditional sectorial or multi-sectorial approach is sufficient, nuclear energy challenges the society as a whole. The decision to step up on to the “nuclear train” is one that cannot be made solely by a government Ministry, a sectorial authority or an economic team, but must be made by the whole society. Nor should the outcoming answer be based purely on simple acceptance or denial. It must be understood that both, a negative or an affirmative one must be based on assumptions and conditions that come from a methodical study and revision of the facts. This is the only way to guarantee that the decision taken, whatever it may be, will consider the costs involved and the commitments that are assumed as a State.

Changes in era are always accompanied by crises at all levels of society as well as in people’s lives. In moments of crisis, the tiniest of actions may have huge consequences and decisions must be taken very carefully to avoid a situation in which the remedy aggravates the condition of the patient. A rational evaluation of the possible virtues and potential damages of each action in order to have some degree of confidence in the decision, and control over the processes involved.

On the other hand, the heat of a crisis often generates pressures that are poor counselors in the search for efficient solutions that, even when reviewed many years

later, still appear to be the correct ones. It would at the same time be a fallacy, a conceptual error, and possibly, the seed of a more serious crisis in some years, to assume that the solution to our short-term energy problems requires the immediate start-up of a nuclear program in Chile.

For this reason, we are in a fortunate position, in which the evaluation of the nuclear option can be made with the time, seriousness and prudence necessary, allowing a thorough knowledge-based study and avoiding myths or short-term pressures that have nothing to do with the time scales that a decision of this magnitude requires.

2 THE ELECTRIC MARKET AND NUCLEOELECTRICITY

Energy is a fundamental part of the economy, as it is a resource in all productive processes; an essential good for the population, and a critical factor for human development and economic competitiveness. Consequently, the development of a country as well as its insertion in the global economy depend upon its having adequate energy supplies.

2.1 Considerations on the economic analysis

A basic condition for an economic analysis of nucleoelectricity is that it must be made with a long-term perspective, covering at least a period of 30-40 years. This necessarily requires the inclusion in the analysis of the changes that can take place in generation technology (particularly those we know of today as non-conventional), changes in relative costs, in the demand and in the reserves of raw materials for energy production.

Besides management of the inherent uncertainty in the aforementioned factors, possible climatic changes that might be significant over this timescale must also be considered. So, the economic analysis should include a wide range of scenarios that take these variables into account, especially in a country with sizeable hydroelectric production.

Economic signs introduced by nucleoelectricity must also be considered, since it could represent a major perturbation in the energy matrix of the country and a considerable influence on future investments. Factors such as entry barriers, incentives and explicit policies regarding RNCE's must be included in this analysis.

Therefore, a detailed economic market analysis of electric generation must cover aspects such as supply and demand; structure and operation of the electric market and its players; the role of the State; stability requirements; as well as adequate incentives to motivate timely investments. In the specific case of NEG, issues such as human resources; research and development; security; environmental safety; and the global situation must also be considered.

2.2 The Chilean electric system

2.2.1 General characteristics

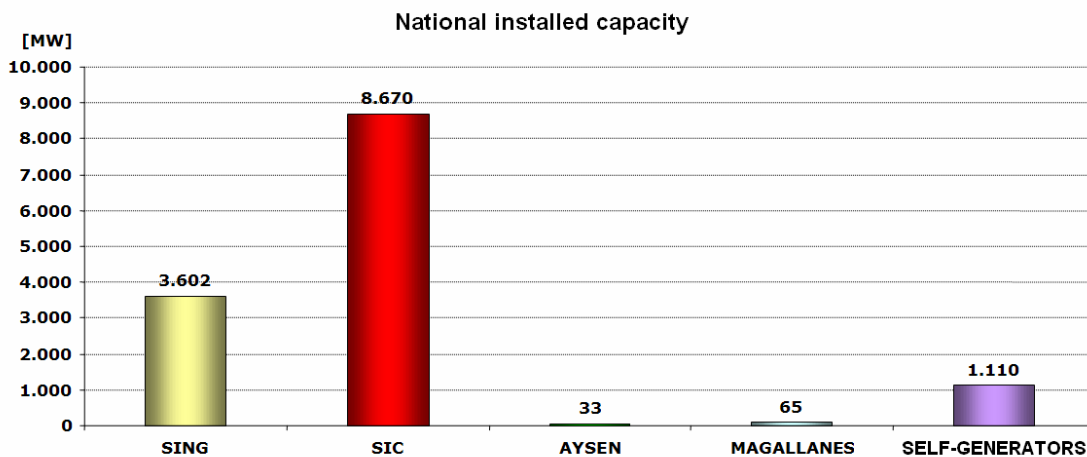
In Chile there are four electric grids. The Northern Interconnected System (*Sistema Interconectado del Norte Grande*, **SING**), that covers territory between the cities of Arica and Antofagasta, with a 29.12% of the national installed capacity; the Central Interconnected System (*Sistema Interconectado Central*, **SIC**), which spreads between Taltal and Chiloé with a 70.09% of the national installed capacity; the Aysén System (*Sistema de Aysén*) that supplies the XI Region, with a 0.27% of the national capacity; and the Magallanes System (*Sistema de Magallanes*), which supplies the XII Region, with the remaining 0.52% of the country's installed capacity.

As of December 2006, the SING had an installed capacity of 3,602 Megawatts (**MW**). Generation is 99.6% thermoelectric, provided by coal, fuel-oil (domestic or household fuel), diesel or natural gas combined cycle power plants, while hydroelectricity represents only the remaining 0.4% of the total.

The installed capacity of SIC rises to 8,670MW as of December 2006 and is the country's main electric system, providing power to over 90% of the population. 55.2% of it is generated from dam and run-of-river hydroelectric power plants, and 44.8% by thermal power plants using coal, fuel-oil, diesel and combined cycle using natural gas.

Approximately 90% of SING consumption is by large-scale clients, in the mining and industrial sectors, typified by law as deregulated clients. The remaining consumption is concentrated in distribution companies that supply customers subject to price regulation. Unlike the SING, the SIC supplies mainly regulated customers (approximately 60% of the total).

The Aysén System supplies electricity to the XI Region. Its installed capacity in December 2006 reached 33MW, with 41.5% and 58.5% from thermoelectric and hydroelectric power plants, respectively. The Magallanes System is formed by three subsystems, those of Punta Arenas, Puerto Natales and Porvenir. By December 2006, the installed capacity of these systems was 65MW, being 100% thermal.



Source: National Energy Balance 2006, National Energy Commission, 2007.

2.2.2 Market system and role of the State

According to current economic policy, our country allows the market to be the main assigner of resources, through free or regulated prices, depending on the specific market.

From an operational viewpoint, the electric market is composed by three clearly distinct types of operators, associated with generation, transmission, and distribution. The market is regulated in order to ensure the supply of electricity to residential and industrial consumers. Operation of the electric market is regulated by the National Energy Commission (Comisión Nacional de Energía, **CNE**), which periodically estimates the future investment projects for electric generation, continually adjusting the expected supply and demand over the medium term, and also calculates the node prices on a six-month basis, from which the regulated prices is defined. These regulations are overseen by the Superintendencia de Electricidad y Combustibles (*Superintendencia de Electricidad y*

Combustibles, SEC)¹. Thus, the State participates in the electric market, mainly through these two institutions.

Under the current legislation, although generation is regulated through its delivery, it is a private business and therefore the decision to invest in a new generation plant is taken by the private sector, considering the expected profit over a determined period.

Another basic principle in current regulation is that at any given time, the generation is covered by the technologies with lowest variable costs. In this type of system, the right moment to invest in a new power plant can be affected by a strategic behavior of the newcomer, who may try to advance or delay its investment in order to influence other planned investment decisions. That is, a standard cost-benefit evaluation does not completely explain the investment in a given year.

It is also stipulated in the current system that energy transactions take place in two markets: The *spot* and the *contract* market. In the spot market the price of the kW-hour is at marginal cost, that is, at the cost of the most recently operating power plant in increasing order of costs. This applies to each separate system, as defined by its connective (transmission) grid, the SIC and the SING respectively. Usually, hydraulic generation has the lowest cost, followed by natural gas, which is predicted to become replaced increasingly by coal, and later by diesel, all three being fossil fuels. The spot price is a function of demand, over the corresponding period, and is also a function of the different types of generation available in the matrix over this period.

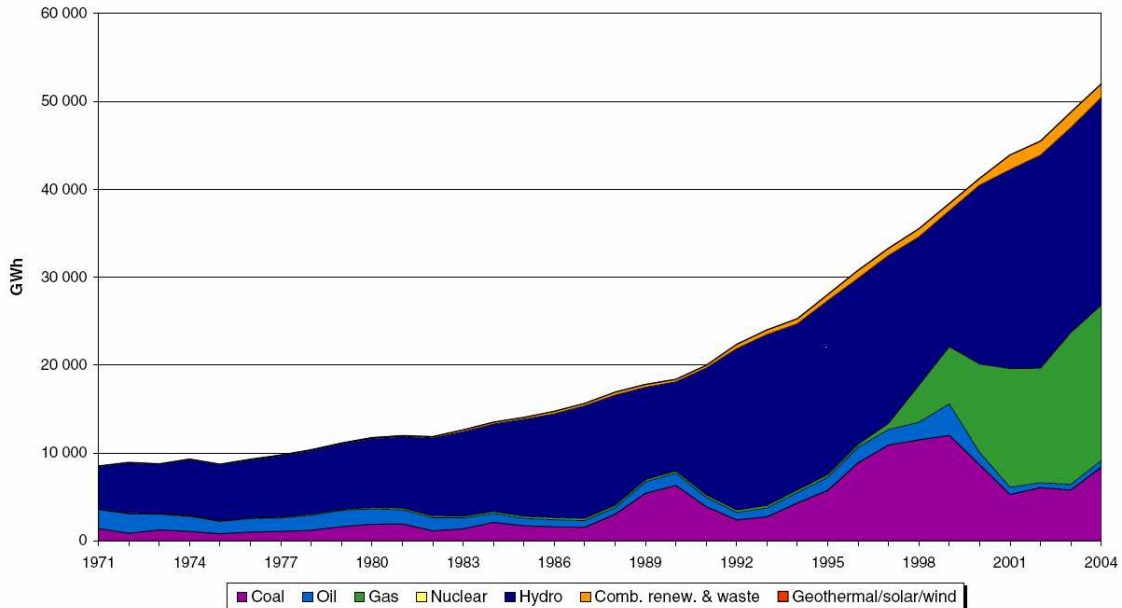
In the contract market, the price results from market forces between present and future participants, in accordance with the new bidding law (Law 20,018, known as Short Law II). In the longer term, however, prices will be affected by the cost of the most efficient technologies, together with environmental restrictions.

2.2.3 Projected supply and demand

In the last 20 years, all forms of energy consumption in Chile have increased at an annual rate of nearly 5.6%, slightly above the growth rate of the economy. Over the same period, there has been approximately a 7.5% average annual increase in electric energy consumption. According to these rates, the country has doubled its capacity to supply electricity approximately every 10 years, as can be observed from the following graph.

¹ Technical Division of the Ministry of Economy. Regulates electrical and fuel services.

Evolution of Electricity Generation by Fuel from 1971 to 2004



Source: International Energy Agency (IEA)

With respect to the future electric supply, estimates by the CNE indicate that by the year 2018, the currently installed capacity of 13,500MW, will be expanded by approximately 10,000MW. Composition by source type shows hydroelectric projects with accumulated capacities of almost 1,100MW, thermal generation would provide nearly 8,500MW, geothermal generation could install close to 260MW and wind generation would generate an additional 150MW, approximately.

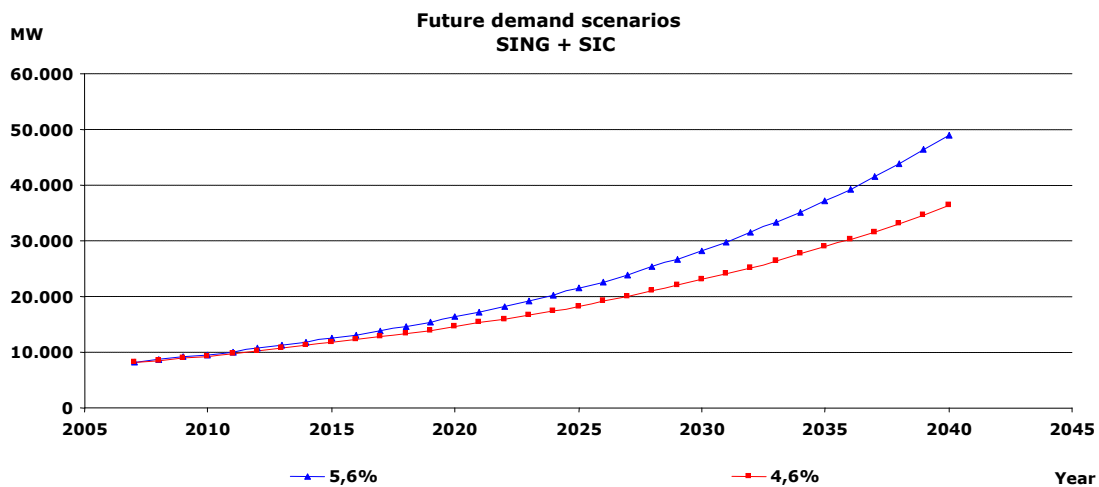
The breakdown for each generator type expected to be introduced by the year 2018 is shown in the following table.

Power Plant	Capacity [MW]	Number of Projects
Coal	4,269	16
Diesel	774	9
Wind	148	6
Gas	3,370	9
Geothermal	260	8
Hydroelectric	1,100	8
Total Capacity	9,645	56

Source: National Energy Commission

In a conservative scenario of 4.6% annual increase in demand, electric energy generation will have to double by 2023 and triple by 2032. If it is supposed that a historic growth rate of 5.6% will be maintained, such timescales will be reduced to 2021 and 2028 respectively. In an intermediate scenario, considering a rate of annual increase of

5% in energy demand, the country will have to double consumption by 2022 and triple it by 2030.



Future requirements could be reduced by improving the efficiency in electricity use. International experience² shows that the growth of per capita energy consumption slows down and in some cases stagnates after a certain level of welfare has been surpassed. Many studies project declining per capita consumption as a result of anticipated policy interventions, but it is far from clear that that will materialize. In any case, in most countries electricity demand per capita continues to grow. In the case of Chile, the limited energy consumption in vast sectors of the population, as well as the need for continued national growth, makes it unrealistic to expect that energy demand will not show a substantial increase.

Satisfaction of the increasing demand will be hindered by a significant lack of low cost energy sources in Chile. It must be mentioned that currently, only around 30% of domestic consumption is covered by our own energy sources. As for electric generation, this figure fluctuates close to 50%, depending on rainfall.

It is probable that in the medium term, oil and its derivatives will keep their large share of world consumption, mainly due to their use in transport and heating. This would occur even if current high prices and direct restrictions were maintained, or if initiatives that discourage use of fossil fuels like or taxes on CO₂ emission, were in place.

Liquified natural gas shipped from different overseas sources could be an interesting alternative. However, the cost of this fuel is likely to stay relatively high due to increased demand by the world economy, limiting its application in activities that are very intensive in energy use such as electric generation.

On the other hand, in a scenario of increasing interaction and interconnectivity, prices of natural gas from the region should reach those of international markets, higher than those enjoyed by the country in the past decade.

² World Energy Outlook 2006. International Energy Agency.

Imported coal is a relatively abundant source which should continue to be available to national users. It could be complemented, on a lesser scale, by national producers, especially if production in Magallanes is reactivated. It is probable that coal will continue to be cost-effective for electricity generation. However, it may become increasingly difficult to use, because of initiatives implemented to reduce CO₂ emissions, or because it becomes more difficult to find possible sites for coal-fired power plants.

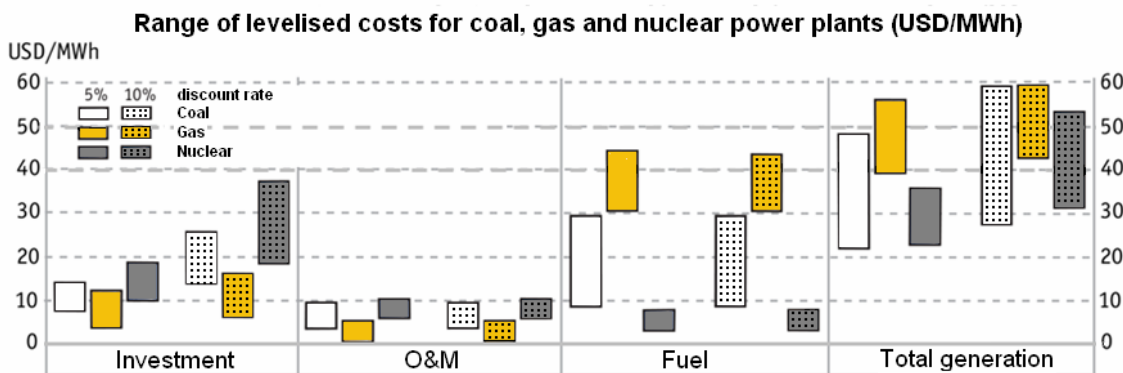
Hydroelectricity should continue to be the main domestic energy source, especially if important large-scale projects currently under consideration are realized. Nevertheless, this expansion will be naturally limited once existing sources with greater potential and lower cost, or those that are nearer to demand centers are used up. Moreover, in the long-term, climate changes that may affect hydroelectric contribution from existing power plants cannot be ruled out.

Non-conventional renewable energies should become more important within the energy matrix, especially if the current high energy prices are maintained, or if measures are taken to encourage their use. But unless significant changes occur in technology and cost, it is unlikely that these energy sources will contribute significantly to national electricity generation in the medium-term.

2.3 Economic aspects of nucleoelectricity

The evaluation of investments in nucleoelectricity must consider the direct and indirect costs of NEG, including those involved in construction, operation, decommission, dismantling, insurance, institutional regulatory framework and the infrastructure required for its development. Since Chile has no experience in NEG, we must rely on international experience.

By averaging figures from countries of the Organization for Economic Cooperation and Development (OECD), it is possible to compare costs of investment, operation and maintenance and total, for different fuels and at different discount rates. The following graph shows the comparative costs and their impact in the final cost of electricity.



Source: *Projected costs of generating electricity*. International Energy Agency and Nuclear Energy Agency, 2005. (Based on prices of 2003/2004)

2.3.1 The nuclear fuel market

The main fuel component of a reactor is natural uranium, a fairly abundant metal in the earths' crust, as abundant as tin, tungsten or molybdenum, and more abundant than cadmium, mercury and silver. There are some 4,743,000 tonnes of uranium in the main known commercially exploitable reserves throughout the world. The largest reserves are found in Australia (24%), Kazakhstan (17%) and Canada (9%). Chile also has some uranium deposits that are not currently mined.

The current rate of world use of uranium is in the order of 66,500 tons/year, from which it is estimated that known reserves are enough to last for some 70 years³. Uranium is an energy source with a low cost of reposition compared to that of oil. Fuel costs in NEG make up about 12% of the final cost of electricity⁴. However, the most critical aspect of nuclear fuel is not the raw material –which accounts for only ¼ of the fuel cost-, but the technology involved. This is an additional advantage of nuclear energy: a 100% increase in the price of Uranium will reflect marginally in the final cost of energy (3-5%).

Both the uranium and nuclear fuel market is highly controlled by the superpowers. Supply contracts are not only agreements between the manufacturer and mining authority of a nuclear power reactor (**NPR**), but are also matters of political agreements between countries under close scrutiny from the international community. Prices, however, are determined quite transparently by market economy.

2.3.2 Effects of incorporating NEG into the electric grid

Under optimal conditions, NPRs are designed to operate on a permanent basis, and therefore, incorporation of nucleoelectricity would necessarily require revision of the current regulatory framework to assure continued output from these base load power plants. Nucleoelectricity would share the grid's base load segment with hydroelectricity, and could even replace part of the electric energy coming from fossil fuels. In a diversified electric grid, nucleoelectricity does not compete with the NCREs, nor does it necessarily have any impact on their development.

One specific feature of NEG is that, based on the international experience, the International Atomic Energy Agency (IAEA) recommends that no individual reactor should have an output above 10% of the grid to which it is connected. This is due to the need to guarantee stable quality the electric supply throughout the grid when faced with an abrupt isolation of a nuclear power plant from the system. In the case of Chile for example, a NPR of 1,000MW could not be connected today, unless the SING and SIC grids were linked together.

Under the current regulatory framework electric generation is efficient, in that investment decisions are made by the private sector in a competitive environment. However, NEG could introduce factors that affect the principles on which the electrical-industrial model rests. Even if the development of nucleoelectricity in the current model should result from private investors, this cannot down play the need for standards to assure inclusion of social objectives (environmental protection, national security, public health, global warming prevention, etc.).

³ <http://www.world-nuclear.org/info/inf75.html>

⁴ *Projected costs of generating electricity*. International Energy Agency and Nuclear Energy Agency. 2005

With respect to insurance and guarantees, it must be taken into account that the risks involved in developing a nucleoelectric project may be extremely high for the private investor. This is particularly important in view of the country's lack of experience in this area and the possible political costs involved, especially in the construction phase and start-up operation. It is also expected that State funds will be required to develop specialized human resources and the research projects related to nucleoelectricity.

Since the technological costs depend on the production scale, if nuclear energy were to be incorporated in a gradual manner, analysis of relative costs should include a wide range of scenarios in order to capture the diversity of variables involved. It is possible, for example, that in scenarios of high priced fossil fuels combined with low rainfall, nuclear energy might be profitable from the start, even on a small-scale. Obviously, the probability of such scenarios should also be assessed. This point is especially relevant when seeking a system that could satisfy future demand and that is sufficiently robust when faced with the usual uncertainties.

Analysis of relative costs of different energy alternatives becomes more complex when new environmental constraints are incorporated by agreements signed by Chile, such as the Kyoto Protocol. Thus, for example, electric generation based on coal-fired technologies could become less economic under new standards, in which the cost of clean production or CO₂ sequestration is included.

In a climate of increasing energy requirements, nucleoelectricity is an energy supply option that should be evaluated in Chile. Several factors lead to this conclusion: limitations in existing domestic sources; possible resource restrictions or greater costs associated to greenhouse gases emissions; maintenance of high international prices and cost disadvantages that non-conventional renewable energies still hold over more traditional energy sources.

3 NUCLEAR REACTOR TECHNOLOGY

3.1 What is nucleoelectric generation?

Nucleoelectric generation (NEG) is a technology that allows transformation of the energy content of nuclear matter into electrical energy, by for example, splitting (fission) of atomic nuclei. A reactor where this transformation takes place is essentially a water boiler that produces steam to drive a turbine for electricity generation. At the reactor core, the nuclear fuel is immersed in water that serves to moderate the energy of neutrons emitted by the nuclear fission, and to transfer heat to the turbine.

The electric generator connected to the turbine is very similar to that of a thermoelectric power plant run on coal, natural gas or oil. Reactor technology has been developed over the last 50 years, based on knowledge of nuclear physics from the first half of the 20th Century. In principle, a nuclear reactor is a source of industrial heat that can be harnessed for other uses such as water desalination or hydrogen production.

3.2 Nuclear reactors

Rather than showing a complete list of reactors and characteristics, we prefer to describe the major trends that reflect currently available options⁵ and those which are expected to become available within the next 15 years. Nucleoelectric technology development distinguishes three types of power reactors:

- Conventional reactors
- Evolutive reactors
- Innovative reactors

3.2.1 Conventional reactors

Conventional nuclear technology has been developed around models that use lightly enriched uranium with less than 5% of the ²³⁵U isotope, and ordinary or light water (Light water reactors, LWR). There are also reactors that use natural uranium and heavy water⁶ (Heavy water reactors, HWR) as a coolant and moderator.

Technology and economy have favored designs based on the use of light water which today are the dominant commercially available models. Among these, the pressurized light water reactors (PWR) are the ones that accumulate the longest operation time, which means improved safety standards, an aspect that should be considered when comparing with models that may incorporate newer technologies, but do not have as many accumulated reactor-years of operating experience.

Fifty years of nucleoelectric technology has led to the three currently most common reactor models. These are the pressurized light water reactor (PWR), the low pressure boiling water reactor (BWR), and to a certain extent, the heavy water reactors (HWR) of the CANDU (Canadian Deuterium Uranium) reactor type. Of the 434 operating reactor

⁵ Nucleo-electric generation has shown growth without a significant increase of new reactor units, due to three main factors: a) greater use of units which has raised the rate from 65% during the 70's, to 80% of the time today, b) an increase in reactor power as a result of greater efficiency and c) extension of the lifespan of the units beyond the 30 years planned originally.

⁶ In which the hydrogen atom of the water molecule is replaced by deuterium or tritium isotopes of hydrogen.

units, 252 are PWR-type, 92 are BWR-type and 34 are CANDU-type. There also exist 15 graphite and light water reactors of the RBMK-type (the type used in Chernobyl), and two liquid metal Fast Breeders, LMFBR. There are also over a hundred compact PWR used for naval propulsion. This reflects a clear tendency of PWR as the dominant model.

In Russia, Ukraine, Armenia, Bulgaria, China, Czech Republic, Finland, Slovakia and Hungary, there are 53 VVER units in operation (Vodo-Vodyanoi Energetichesky Reactor), a Russian-design PWR yielding between 400 and 1,000MW.

In Latin America, Argentina, Brazil and Mexico have a nuclear industry. Argentina has two operational reactors, Atucha I and Embalse, and a third under construction (Atucha II). The Atucha I reactor is a PHWR-type with a power of 375MW, while the Embalse reactor is of the CANDU type, of 648MW. Atucha II is of the same type as Atucha I, but of 745MW and is expected to start operating by 2010. Brazil has two PWR reactors in Angra dos Reis, Angra I and II, which generate 657MW and 1,350MW respectively. A third, under construction, also of 1,350MW, is expected to be ready by 2013. In Mexico, there are two BWR reactors of 690MW, Laguna Verde I and II in Veracruz, whose power is being increased by some 400MW.

3.2.2 Currently available evolutionary reactors

These reactors, in general, are those under consideration by countries with large electric networks that are planning to re-launch their nuclear programs. The first reactor in this category is the ABWR (Advanced BWR), of 1,350MW, a development by General Electric with the participation of Hitachi and Toshiba, which has been operating for some years in Japan and under construction in Taiwan. Then there is the ESBWR (Economic Simplified BWR), of 1,500MW, from GE, with new evolutionary attributes. Two analogs are the BWR 90+ from Westinghouse Atom AB, with a power of 1,500MW and the SWR1000 from Areva, of 1,250MW.

Similar development already exists for evolutionary PWR reactors, several of which stand out: the EPR from Areva, of 1,600MW; the AP1000 from Westinghouse, of 1,110MW; the US APWR from Mitsubishi, of 1,700MW; the APR 1400 from KNHP, of 1,400MW; the VVER-1500 and VVER-1200 from Hidropress, of 1,500 and 1,200MW, respectively. Likewise, AECL (Canada) is developing the ACR1000, an advanced 1,200MW, reactor moderated by heavy water and cooled by light water. South Korea developed the APR-1400, a modified version of the PWR reactor developed in the USA, with a nominal power of 1,400MW, a unified design for scale economy (one single model). The costs of these plants are vastly greater than 2 billion USD.

Other models under development are those of the light water Breeder type, or LWBR, using thorium as fuel (^{233}U as fissile material), increasing the possibility of using a fuel different from uranium (that is based on ^{235}U as fissile material).

The main reactor manufacturers around the world are partnerships and consortiums, among them, Areva (France), General Electric and Westinghouse (USA), Hitachi, Mitsubishi and Toshiba (Japan), Siemens (Germany), ROSATOM (Russian Federation) and KNHP (South Korea).

3.2.3 Evolutionary and innovative reactors

Evolution of nuclear technology has led to a new generation of NPRs whose designs include two fundamental advances: 1) incorporation of passive safety systems that do not depend on active controls; and, 2) the combination of smaller possible size and modular capacity.

There are several PWR models developed with powers of between 200 and 600MW, as for example, the IRIS in Europe, the SMART in South Korea, the SPWR in Japan and the CAREM en Argentina.

Reactor models are also being developed that use an oxide mixture as fuel, allowing recycling of the plutonium generated in fission of the uranium found in the spent fuel.

An alternative development is that of gas-cooled reactors, using mainly CO₂ or helium, with power yields under 500MW. There are also reactors cooled by salts or liquid metals, with large heat extraction capacity, whose designs reach 300MW. One advantage of this type of reactors is that less actinide-rich waste is generated.

The Gen-IV Forum, under the OECD's Nuclear Energy Agency, has identified six conceptual designs as the most promising innovative reactors. The response of nuclear operators has been focused on the World Association of Nuclear Operators (**WANO**) that has watched over the sustained increase in operation safety standards, as well as vigilance of compliance of the industry's own standards. Technical and personnel training have been similarly standardized through the World Nuclear University (**WNU**), both organizations being sponsored by the IAEA. This in turn has helped to reduce licensing times for plant operation, and making government regulation and overseeing much easier.

It is very likely that by the 2020-2030 decade, third generation advanced reactors, GEN III+, may be widely available in the market. These will be increasingly safer and will have the benefit of wider world experience, in their construction as well as in their operation and will have the largest technical support network for their entire life cycle, from conception, to decommissioning and dismantling.

3.3 Nuclear fuel

Fissionable matter that generates heat in the reactor, usually called nuclear fuel, is made of uranium with different concentrations (enrichments) of the isotope ²³⁵U. Natural uranium, composed mainly of the isotope ²³⁸U, contains around 0.7% ²³⁵U.

The nuclear fuel market has four components, natural uranium, conversion, enrichment, and fuel manufacturing. Each component in the chain can be bought separately, or aggregated at a certain level, e.g., enriched uranium or fully manufactured fuel assemblies including the enriched uranium. The market is dominated by a few countries that possess uranium enrichment technology and the metallurgy necessary for fuel manufacturing. Countries that enrich uranium commercially are: Germany, China, United States, France, Holland, England, Japan and Russia. All of them, with the exception of Holland, also manufacture fuel. Other countries that manufacture fuel but do not enrich uranium are: Belgium, South Korea, Spain, India, Sweden and Taiwan.

While most countries that have nuclear energy have chosen to buy the different fuel services from abroad, some countries aim to master the complete fuel cycle, from enrichment to the reprocessing of the spent fuel. The reprocessing allows the separations and recovery of the uranium and plutonium that forms around 93-95% of the spent fuel. Discussions are going on at an international level to develop mechanisms that would discourage the establishment of enrichment and reprocessing plants in many countries, in order to reduce the risk of nuclear proliferation. One suggestion in this direction advanced by the IAEA, is that these services be offered by those countries that provide the original fuel and that in a future stage, regional solutions be considered.

A very peculiar feature of nuclear fuel is that, due to its high energy density (high energy potential in a small volume) it offers the possibility of relatively easy storage to generate electricity for many years⁷, something that would be impossible to do with fossil fuels.

3.4 Economic aspects

According to the World Nuclear Association 2005 Report that is in turn based on reports IEA/OECD-NEA (2005), MIT (2003), DGEMP (2003), Tarjanne & Luostarinen (2003), The Royal Academy of Engineering UK (2004), University of Chicago (2004) y CERJ (2004), the cost of nucleoelectric generation has improved compared with that for fossil fuels in the last decades. One of the most uncertain factors in the price continues to be the financial cost, as it is a high capital investment with a slow return⁸.

According to this report, based on the experience of many countries, *“Overall marginal costs of operating nuclear plants are low and can only be beaten by plants that generate electricity without the need for fuel such as hydro and other renewable technologies. In the United States, average nuclear production costs were 1.72 cents per kWh in 2003, the lowest of any generation technology in this country. The trend has been strongly downwards in real terms since the mid-1980s”*. [This estimate does not include capital costs.]

All considered, accumulated experience shows that the advantages and disadvantages are different in every country. The determinant factor in most cases is cost competitiveness compared with that of alternative generation methods. Nuclear plants have a very high construction cost, but relatively low operating costs. Studies carried out in Belgium, Finland, France, and UK, report that, except for an isolated case in UK, nuclear energy is the least cost option.

The general conclusion indicates that: *“The attractiveness of nuclear energy from the standpoint of economic performance can clearly be demonstrated today, against the economics of alternative generating technologies. Over the years, more output is being achieved with each reactor through improved availability and capacity up-rates. Safe reactor operation is set to continue for many years in the future, backed up by all necessary investments in refurbishment. These improvements are now routine and integrated into the new plant designs”*⁹.

⁷ A nuclear plant of 1,000MW consumes approximately 8 m³ of uranium in 1 year. The quantity necessary to feed a coal-fired plant of the same output for the same period, is 2,300,000 m³.

⁸ World Nuclear Association, *Report 2005*. (www.world-nuclear.org)

⁹ World Nuclear Association, *Ibid*.

It should be borne in mind, however, that costs are sensitive to other economic factors like the prices of raw materials and the cost of money, which in turn depend on other commodities like oil.

3.5 Nuclear waste

NEG necessarily involves the entire fuel cycle, from natural uranium mining, right up to the end of its useful life. Throughout this cycle, radiotoxic residues are produced that contain radioactive elements, which must be correctly managed in order to avoid an impact, either on human health, the environment, or both.

The issues of radioactive waste include the management of spent nuclear fuel or high level waste, which is both highly radioactive and long-lived, as well as short-lived low level waste generated by the nuclear power plants. Low level waste is also produced in other parts of the fuel-cycle, from nuclear research facilities and from the use of radionuclides in health care and industry. It is thus important for a country to establish a waste management strategy, indicating how different types of waste will be handled and ultimately disposed of. Conditioning and disposal of low-level waste is established in several countries as a common industrial practice.

At present, there is no solution that can guarantee perpetual segregation of radioactive waste and, thus, up to a point, there is an ambiguity in the cost ascribed to this part of the NEG process. International organizations recommend, to begin with, separation of waste by danger level, based on the radioactivity of waste (high-medium-low) as well as the half-life¹⁰. High-level waste which, in general, has shorter half-life and does not represent a significant risk after a time period in the order of some 10 half-lives¹¹, is stored for some years. In contrast, wastes with half-lives of thousands of years have low radioactivity levels. These are reduced in volume and stored safely until their final destination at some definitive disposal site. The general agreement among the experts on the approach to provide appropriate confinement of the high-level and long-lived waste includes encapsulating and disposing of it in deep geological repositories.

For highly radioactive spent fuel, two avenues are considered in different countries; to regard it as a resource, reprocess it and recycle the remaining uranium and plutonium as new fuel, while conditioning, storing and subsequently disposing of the remaining high-level and long-lived waste, or; to regard it as useless waste product and dispose of it directly after some 40-50 years storage. The reprocessing would somewhat relieve the burdens on the geological disposal. At present, only a few countries send their fuel for reprocessing and the uranium and plutonium is recycled in light water reactors. In the future, recycling in fast reactors (Gen-IV) would improve the usefulness of recycling and thus increase the energy value of the natural uranium 50 to 100 times. This would, however, require multiple recycling. Whatever route is chosen, eventually a geological disposal will be needed.

¹⁰ Half-life is the time it takes for half of the radioactive nuclei in the sample to decay into more stable nuclei. The half-life of an element is inversely proportional to the decay probability of nuclei and thus the most radioactive elements are, in general, those with the shortest half-lives. Usually, a nucleus decays into another, which in turn decays. The decay chains are made up of multiple isotopes of diverse half-lives.

¹¹ On reaching 10 half-lives, the number of nuclei that have still not decayed, is one thousandth of the original population.

Currently, the problem of nuclear waste has a two-sided approach: to try to reduce the generation of waste, and to reduce the waste that has been produced. Both strategies are continuously pushing for new reactor technologies that generate less waste and for prototype systems that can reduce nuclear residues. An example of the first case is the development of the fourth generation (Gen-IV) reactors. A prototype for reducing waste is found in transmutation reactions, a process in which more energy is produced by burning the waste¹². It is hoped that these technologies may be available by the decade of 2040, although the implied costs are still difficult to estimate.

A nuclear plant starts burning fuel the moment the reactor reaches criticality and starts operations. Spent fuel has to be dealt with after the first refueling and few years later. After a first stage of radioactive “cooling” in water pools at the same plant for some 10 to 20 years, the spent fuel can be sent to a reprocessing plant or to a definitive disposal site. In this way, if Chile were to begin to operate a power reactor by 2020, the reprocessing and/or confinement of waste would begin by the year 2040. It is reasonable to assume that by then better solutions will exist for waste management.

Another aspect of the nuclear industry that has no parallel in the electric generation industries is that the final dismantling, at the end of its lifespan, 40-60 years later, must be considered from the planning stage. This operation includes removal of any remaining fuel and parts of the reactor exposed to strong doses of radiation that contain radioactive material; afterwards, all structures must be chemically cleansed of potentially radioactive substances and finally, demolition of the buildings may also be considered.

After 60 years of operation, closure and dismantling of a reactor of 1,000MW, would generate 3,000m³ of spent fuel and high activity waste, 1,000m³ of medium activity, and some 12,500m³ of debris and low activity waste. The cost of this operation is some 4% to 5% of the final cost of the electricity produced and is, in general, financed by plant operators through a closure and decommissioning tax that must be paid throughout the reactor's life. In many countries a central organization takes charge of administrating the decommissioning fund.

¹² This is an alternative under study and it should be made clear that not all residues can be treated in this way. This means that transmutation is, for the moment, a palliative and not a definitive solution to the problem.

4 NUCLEAR EVENTS AND ACCIDENTS

In 1989, the IAEA along with the OECD's Nuclear Energy Agency (**NEA**) established the International Nuclear Events Scale (INES)¹³ as a way of standardizing communication of the severity of events reported in nuclear installations to the public. This scale has seven levels: least severe (lower levels 1, 2 and 3) are denominated "events", while higher levels (4-7) are classified as "accidents". Events that have no safety significance or relevance are classified as "0" and denominated "deviations" or "off-scale events".

Every single nuclear event that occurs in a United Nation member country is reported to the IAEA, where it is analyzed and lessons extracted that are then shared with the international community. This has contributed substantially to improving technology, producing increasingly safer reactors as well as improving operation methods and systems of risk assessment and prevention.

The possibility of a nuclear accident occurring produces a sense of insecurity in the society that does not match an objective analysis of relative risk. This in turn, directly affects the degree of acceptance of nuclear technology. The above-mentioned scale exists to help compare the seriousness of every event, by establishing a framework of comparison between events.

4.1 Nuclear accidents

Examples of accidents are: Three Mile Island (USA, 1979; level 5) and Chernobyl (USSR, 1986; level 7).

4.1.1 Three Mile Island (TMI)

On 28 March 1979, a PWR-type reactor in unit 2 of the plant suffered an accident in the heat removal system. During a routine cleaning operation of a coolant line, the operator received contradictory information coming from two valves. The lack of correct information produced a series of incorrect decisions and poor handling by operators, initiating core reactor fusion. After 13 hours, cooling of the reactor core was re-established, in spite of having already produced severe core damage.

The radioactive emissions released as a result of the accident produced radiation exposures ranging between 0.015 mSv and 0.83 mSv¹⁴; nobody received a radiation dose that could compromise his/her health and there were no fatal victims. From this angle, this accident did not have a significant environmental impact, as quantities of radioactive elements liberated were not sufficient to alter the natural environmental conditions. However, the impact on public perception and financial costs were considerable.

4.1.2 Chernobyl

On 26 April, 1986 an operation was performed in unit 4 of the Chernobyl plant with the aim of testing the ability of an auxiliary turbine to generate electricity. This RBMK reactor, which uses graphite as moderator, was a model whose original design was oriented towards plutonium production for military use. Moreover, the reactor did not

¹³ The International Nuclear Event Scale (INES), IAEA, Vienna, 2001.

¹⁴ As a comparison, natural background radiation corresponds to a dose of nearly 0.01 mSv per day, a chest X-ray, to 0.1mSv, and a cardiac angiogram to a dose of between 6.7 and 13 mSv.

have an adequate containment building and showed signs of design deficiencies and instability when operating at low power. Ironically, the auxiliary turbine was supposed to improve the safety of the reactor.

Normally this reactor run at 3,200 thermal MW (**MWth**) and this was lowered to around 700MWth. However, operational errors together with the deliberate deactivation of all safety measures, removal of control rods and blockage of cut-off signals, caused the power to drop suddenly to 30MWth. In efforts to reestablish a power to some 200MWth, the power rose to about 100 times the maximum design value in four seconds, and the subsequent power oscillations reached 500 times the maximum nominal level. This caused an explosion of the reactor core container, expelling large amounts of radioactive material and causing a large-scale fire.

In the three following months, 28 firemen and emergency cleaning workers died as a result of acute radiation syndrome (**ARS**) and 2 other workers died of injuries not related to radiation. Over the next 18 years, 20 other workers died of various causes including cancer, but it is hard to establish the link to radiation exposure. Those exposed to high levels of radiation include 600,000 liquidators that worked in the contaminated area between 1987 and 1989, who received average accumulated doses (AAD) ~100mSv; 116,000 evacuees from highly contaminated zone, with AAD~33mSv; 270,000 residents of strict control zones, AAD >50; and 5,000,000 residents of other contaminated areas. Under normal circumstances, some 100,000 cases of cancer would be expected to occur in this population. An incidence of 4,000 additional cases was observed in this sample, including some 1,800 cases of thyroid cancer reported among people that at the moment of the accident were under 14 years old¹⁵. The few dozen people who died and the 4% increase in the incidence of cancer, contradicts the widespread vision of the Chernobyl accident as a devastating holocaust with thousands of deaths.

This accident was caused by a combination of poor decisions and safety standard violations, which demonstrated the need for more rigorous operator control. This nuclear installation was not controlled by international organizations, a fact which in large part contributed to the accident.

4.2 Nuclear events

4.2.1 Vandellos

One example of a nuclear event is provided by Vandellos (Spain, 1989; level 3). This was a reactor moderated by graphite and cooled by carbon dioxide. In this case, no radioactive material escaped, nor was there any radiation emitted from the inside, but a fire produced damage to safety systems that significantly compromised reactor safety, which resulted in its definitive shutdown.

4.2.2 Kashiwazaki Kariwa

On July 16 2007, a nuclear event was resulted from an earthquake, which forced shutdown of the Kashiwazaki Kariwa plant on the western coast of Japan. An IAEA mission inspected the plant and its report establishes that although the earthquake

¹⁵ To advance an analysis of sanitary, environmental and socio-economic effects, in 2003 the Chernobyl Forum was created, an initiative of the IAEA and with sponsorship by a dozen international organizations and the governments of Belarus, Russia and Ukraine. See, www.iaea.org/Publications/Booklets/Chernobyl/chernobyl.pdf

significantly exceeded the seismic level expected for the reactor's design, the plant responded safely during and after the earthquake. In response to the earthquake, the plant shut down the four reactors that were active at that time, and there was only a small water leak that had come into contact with radioactive material in the spent fuel cooling pool. The report estimates that the amount of liquid dispersed into the environment would have a radioactivity well below the authorized limit for public exposure under normal operating conditions.

There is another list of nuclear accidents and events associated with the fuel cycle and with the handling of radiological equipment or transport of radioactive materials. For a comprehensive list of these events and an in depth discussion of their significance and impact, see the International Event Scale brochure published by the IAEA, at:

<http://www.iaea.org/Publications/Factsheets/English/ines.pdf>

4.3 Lessons learnt

The TMI accident demonstrated the need for additional back-up control and information systems. It also emphasizes the importance of quality of the components and improved operator training levels to respond to emergencies. The Chernobyl accident dramatically showed the need to respect safety standards and the danger secrecy involved in nuclear plant operations out of IAEA's control.

These accidents show the importance of continuous improvement of safety systems, especially employing operator independent mechanisms (passive type) that ensure core cooling. The main lessons, however, are the need to develop a safety culture among those involved in a nuclear power program, the need to implement a learning culture by which experiences are continuously incorporated in the procedures, and strict operator's adherence to operating procedures and safety standards, including annual renewal of operator licenses. Accumulated experience also reveals the need for permanent risk assessment studies, including deterministic-probabilistic analyses.

4.4 Risks: Real and perceived

In spite of the real nature of the accidents and other events related to nuclear energy, as an industry NEG has a very good safety record compared to all other forms of electricity generation According to a study¹⁶ by the Scherrer Institute, the relative safety of different energy sources, measured by the number of deaths per terawatt-year between 1970 and 1992, which includes the worst accidents (TMI and Chernobyl) is as follows:

Fuel/Source	Deaths	Who	Deaths/tW-year
Hydroelectric	4,000	Public	883
Coal	6,400	Workers	342
Natural gas	1,200	Public and workers	85
Nuclear	31	Workers	8

In the light of this, it can be concluded that the perceived risk has no factual basis in the real historical records.

¹⁶ *Severe Accidents in the Energy Sector*, Paul Scherrer Institut, 2001.

5 PUBLIC OPINION

The presence of the nucleoelectric issue among the relevant topics of public interest in Chile is inescapable. The country is at an energy crossroads, with disturbing projections in the light of gas restrictions from Argentina and its impact on energy supply and prices.

In recent years, different actors, including members of parliament, political parties, environmental groups and entrepreneurs, have made public reference to the nucleoelectric option. Energy as a central issue and the nucleoelectric option has been the focus of technical seminars, professional associations and think tanks associated with political parties.

Although public opinion is always influenced by perception and subjectivity, this is particularly notorious in the case of nuclear energy. The possible start-up of an NEG program is a sensitive public opinion issue, mainly because of the risks –objective and subjective/perceived- posed by these facilities for the environment and public health.

Fear surrounding the impact of a radioactive accident and the threats posed by nuclear waste are real and require careful consideration as a relevant variable in the analysis. The public mind associates nuclear energy with images of Hiroshima, Nagasaki and the Chernobyl disaster. There is also the widespread notion that radioactive waste is an unmanageable problem and a “negative legacy” for coming generations. As discussed in relation to accidents, the risk associated with nuclear energy is real, even if much less than what is often thought (see Sect. 4.2). At any rate, public concern must not be minimized or ignored just because of its misinformed or subjective nature.

Acceptance of nuclear risk represents a problem for society. In the case of nuclear medicine this risk is accepted because the estimated benefits are greater than the potential threats. However, this is rarely the case for NPRs. For society to accept NEG, a permanent effort must be made to communicate and maintain transparency (especially with respect to accidents and events), and a strong independent regulatory authority to oversee the operators¹⁷ is needed.

In order to understand the sociological phenomenon (attitudes towards risk and its subjective scale) it is worth remembering that “the unpleasantness associated with loss is greater than the pleasure associated with a similar-sized gain. This is because the individual tends to overestimate the very low probabilities and underestimate the medium and high probabilities. It is normal for people to overestimate the possibility of disaster occurring, which is in fact very small for a reactor. Gains and losses, in relative terms as for real terms, are evaluated in an asymmetric way”¹⁸.

It can be observed that although the use of fossil fuels also implies serious environmental and health risks from CO₂, SO₂, NO_x, emissions or particles, (even radioactive matter), it does not generate a sense of risk nor does it provoke public

¹⁷ Commissariat à l'énergie atomique, *Nuclear energy of the future: what research for which objectives?* Monograph of the Nuclear Energy Directorate.

¹⁸ Franco Romero, *Nuclear energy, an option for sustainable development?* University Centre for the Study of Energy Problems, CUEPE, University of Geneva (2005).

rejection. Moreover, the *clean* nature of NEG does not seem to motivate the public to prefer this option¹⁹.

Environmental groups have strengthened their opposition to nucleoelectricity, emphasizing, among other things their concern for: the need to consider the global energy balance and the complete generation cycle when comparing different forms of electric generation; final waste disposal; and the relation between NEG and arms.

Within the business world, opinions have focused on the problem of reliable energy supply and its impact on economic activities, particularly in the SING.

Apart from the performance of these social actors, and of a few specific studies and opinion polls, it is true that in Chile there is very little scientifically sound information about public awareness or systematic opinion polls in the context of national energy or of a nuclear option for the country.

Considering the importance of public acceptance in this matter, confirmed by the role the IAEA assigns to it in the process of adopting the nucleoelectric option, it is fundamental to have updated, reliable information regarding public opinion. In order to have a complete basis for analysis and for decision-making, it would be necessary to design and have in place a regular public opinion polling system for energy matters in general and nuclear energy in particular.

Independently of whether or not the country decides to follow the path towards nucleoelectricity, confidence in the decision taken and its public acceptance will only result if the country acts in an informed, transparent way, through participation of independent experts receptive to the opinions from academia and the civil society.²⁰

¹⁹ Franco Romerio, *ibid.*

²⁰ Franco Romerio, *ibid.*

6 ENVIRONMENT AND TERRITORY

6.1 Environment

Environmental issues relevant to nucleoelectricity are: the risk of events and accidents and their potential environmental impacts (basically ionizing radiation and radioactive contamination), global warming, nuclear waste management (transport, transitory storage and final disposal), and natural disasters (seismic, volcanic, tsunami, landslides).

6.1.1 Risk of events and accidents and their potential environmental effects

No doubt the greatest environmental public concern about the nuclear industry is the possibility of exposure to ionizing radiation and radiotoxic substances, which could result from an accident at any stage of the process (enrichment, transport, use, ultimate disposal). Thus, the main environmental sector at risk is the population, making it mandatory to apply extremely rigorous safety measures. This sets an important difference from all other electricity generation mega-projects, where concerns focus on other environmental components such as air, flora, fauna or water.

In more than 50 years of international experience in NEG, the accident rate within the industry is very low, with one serious radiation accident during this period (Chernobyl)²¹, which represents approximately one serious accident per reactor every 10,000 years. Whole-cycle studies performed in the UK between 1972 and 1992²², that compare accident deaths (standardized per generated TW-year of electricity) for different primary energy sources (coal, natural gas, water and nuclear), show that NEG has the lowest number of fatalities (8) and the coal-fired electric industry the highest (342). Even so, and as for any human undertaking, nucleoelectricity is subject to accidents, either due to negligence, third party actions (terrorism), or by forces of nature.

6.1.2 Global warming

There is wide international consensus on the *clean* nature of nucleoelectricity compared to other major forms of electric generation (coal, gas, oil)²³. This is not an irrelevant factor, for one of the most significant environmental impacts from the electric industry is the production of greenhouse gases (**GHG**) and, consequently has an impact on processes such as the global warming of the biosphere.

Growing awareness about global warming underscores the need to restrict the production of GHG emissions. This places value on the *environmental quality* of energy generation processes as for all human activities. It is reasonable to expect that the international community as well as the market will increase pressure for reduction of

²¹ *The future of nuclear power*. MIT. 2003.

²² Ball, Roberts & Simpson, Research Report #20, Centre for Environmental & Risk Management, University of East Anglia, 1994; Hirschberg et al, Paul Scherrer Institut, 1996; in: IAEA, *Sustainable Development and Nuclear Power*, 1997; *Severe Accidents in the Energy Sector*, Paul Scherrer Institut, 2001.

²³ Doubts are raised with respect to whether the *clean* process applies to the complete NEG cycle, from uranium mining to dismantling and ultimate disposal of all components of the power plant. Although international reports exist of studies comparing global and local environmental impact for different methods of electricity generation, in Chile there is still much research to be done. We consider it to be very relevant and necessary to study, from a *whole cycle* perspective, the advantages and disadvantages of each generation method, as well as the role of each as part of an environmentally and economically sustainable matrix.

emissions of GHG, or for their capture and sequestration²⁴, establishing a scenario where the method of electricity generation **does** matter.

In this context, nucleoelectricity, hydroelectricity and the NCREs will have certain advantages over electricity generated from coal and oil, the largest contributors of CO₂ and other GHGs such as methane. The following table shows the whole-cycle analysis (LCA, Life Cycle Analysis, ISO Standard 14040) performed by EDF (Electricite de France). The result (fourth column) is expressed in grams of CO₂ per kW-electric hour.

Relative contribution of several electricity generation sources for NEG production

System	Operation	Remaining life cycle	Total (g/kWhe)
Coal 600 MW	892	111	1,003
Fuel-oil	839	149	988
Gas (turbine combustion)	844	68	912
Diesel	726	159	895
Hydraulic pumping	127	5	132
Photovoltaic/Solar	0	97	97
Hydroelectric	0	5	5
Nuclear	0	5	5
Wind	0	3	3

Source: Nuclear energy of the future: what research for which objectives? Commissariat à l'énergie atomique.

As can be seen, it is not completely correct to say that nuclear, water or wind energy do not produce GHG, because the construction of plants that use these energy resources requires, for example, concrete and steel, whose production uses, fossil fuels that generate GHG. But despite this, the contribution is marginal with respect to that of primary fossil fuel sources.

6.1.3 Nuclear waste

One of the most relevant potential environmental impacts of NEG is the management of nuclear residues, which require great caution, adequate conditions for the transitory storage and ultimate disposal of radioactive materials (spent fuel, dismantled plants, contaminated clothes and other elements, washing water). This matter is particularly delicate for high radiation residues. As already mentioned, perpetual disposal of nuclear residues is still an open question for the nuclear industry worldwide.

Present technology for intermediate and final disposal of nuclear waste²⁵ makes it possible to assure that residues will not come into contact with the environment, and thus will not intrude into human society through food or drink, in a time scale of up to 10,000 years. Technical and ethical discussion continues as to whether or not 10,000 years is a reasonable guarantee for materials with contamination potentials of millions of years. The search for practical technological solutions is an active field of research, and the international scientific community may eventually be convinced of the benefits of fuel

²⁴ Not necessarily economically viable technology at the present time.

²⁵ For example, disposal standards in Yucca Mountain, Montana, USA.

recycling over the associated risks. But it remains a fact, that the main concern regarding nuclear waste is its management prior to its final disposal in deep geological formations²⁶.

Although for Chile, the possible need for management of nuclear waste may seem as a concern for the distant future, it is a matter that should be addressed and evaluated now. As for deciding on geographical location sites for a nuclear power plant (**NPP**), the Chilean State should evaluate whether or not the country is (or will be) able to responsibly take care of management and disposal of nuclear residues, in accordance with the rigorous international standards in force.

One possible way to reduce the waste management problem in Chile may be offered by the Global Nuclear Energy Partnership (**GNEP**), an initiative promoted by the US, and supported by China, France, Japan and Russia and which has been also signed by a dozen other countries. According to this international agreement, fuel supplier countries would take care of the removal of spent fuel from user countries for later reprocessing and/or disposal in final repositories. In this way, the problem of waste management would be resolved for many countries, as well as limiting the possibility of nuclear proliferation in the world.

Finally, regarding the transport of nuclear residues, there is no record in the world, of accidents with resulting ionizing radiation, but this does not exempt us from the obligation to respect the standards that guarantee safe transport of radioactive materials, including waste.

6.2 Nucleoelectricity in a seismic country

When approaching the issue of nucleoelectricity in Chile, an inevitable question arises: Is the installation of a NPP recommended in Chile, knowing that this is one of the most seismic countries on the planet? Or put differently: Could a nuclear plant resist a large earthquake?

National experts insist that the seismic factor be integrated into the analysis, taking the following into consideration:

- Chile is the country that releases the largest amount of seismic power worldwide, with more than 40% of the world's seismic energy in the last century. If we add to this, the number and intensity of earthquakes that occur throughout the country, it can be concluded that Chile is the most seismic country on the planet.
- It is not possible to determine scientifically that there exist seismic cycles or periodicity of events. But it can be certainly said that any part of Chile's territory may be affected by an earthquake in the near future.
- Reliable scientific information regarding is insufficient and coverage of the national seismological network needs to be expanded.
- In spite of the high standard of national experts, scientific capabilities and techniques are still insufficient.
- However, the lack of information on seismic risk at a national level should not be an obstacle for the construction of a NPP, since this risk could be locally determined in relation to potential location site, for which the technology and

²⁶ *The future of nuclear power*. MIT (2003).

- professional capabilities exists in Chile. These on-site assessments should be sufficient for the design of the appropriate engineering solution.
- Anti-seismic technology and engineering in Chile can guarantee acceptable safety levels for a NPP. In other words, it is reasonable to suppose that seismic risk can be controlled with currently available technological solutions. However, international experience shows that, before deciding upon a location site for a NPR, it is essential to have detailed geology and soil mechanic studies available to gauge the seismic response of the site.
 - There are regions in the world that have NPPs which are frequently hit by earthquakes, some stronger and more destructive than those observed in Chile. That is the case of California, where the observed horizontal ground accelerations are greater than those registered in Chile. This US State has two plants with two nuclear reactors each that have been in operation for 25 years. So, the Chilean standard of civil engineering with respect to accelerations need not exceed the standard of California.
 - Finally, the earthquakes themselves should be considered together with other natural risks, such as tsunamis, volcanic eruptions and landslides.

6.3 Environmental impact

If we exclude local thermal impact and the health risks derived from a nuclear accident, environmental impact of construction, operation and dismantling of a NPR are considerably reduced. These impacts remain focused on the expected effects on other environmental components at different territorial levels. Here we address examine these environmental impacts generated by a nucleoelectric plant, which take place at three distinct levels: at a site level (plant location), over an area of regional influence, and at a planetary or global level as already mentioned.

Impacts at site level depend largely on the characteristics of the geographical location, in particular on the vulnerability of environmental components and their basal state condition. The majority of site-level impacts are generated during the plant construction and do not differ much from any other industrial project of this scale. Normally these impacts can be mitigated; they are transitory in nature and not very significant for the project scale.

During operation of a NPR, the most relevant impact is the local thermal emissions to the atmosphere and surrounding water, required by the cooling system. The international experience indicates that NPPs, if located on an adequate site and correctly operated, produce minor environmental impacts at site level and in their immediate surroundings

Local thermal contamination of water bodies is one of the expected impacts of a NPR, as large volumes of water are required for the cooling process. In a typical plant of 1,000 MW, the operation can heat some $60\text{m}^3/\text{s}$ by 7°C . This heat contamination can affect aquatic ecosystems, significantly modifying them, but in a focalized way. Effects can be felt in the feeding and reproduction habits of organisms, in the dissolved oxygen levels, in decomposition rates, etc. Both at start-up and at shutdown of a NPR, sudden temperature changes take place heat reservoir body, which mainly affects the local aquatic fauna. These local thermal effects are of limited impact; they are well understood through the extensive experience throughout the world and can be further reduced by heat dissipation to air, and some of the excess heat can be used for home

heating or for other industrial applications.

The area of regional influence is normally subject to impacts of a social and economic nature. From this territorial perspective, installing a NPR can have an important impact on the economy, the urban environment, territorial functionality and even on the public image of the region. With adequate planning and territorial management, these impacts should be mainly positive.

The potential impacts of dismantling a NPR are still a matter of concern. Consistent with the whole-cycle focus and from a long-term perspective, special attention should be given to impacts during decommissioning of a nuclear installation, for which there is a wide international and successful experience. A total of 107 reactors have been closed definitively, reaching the end of their useful lives. In the last 12 years, 32 reactors have been shut down worldwide²⁷. Based on these figures, the European Commission has estimated that dismantling of an average plant generates approximately 10,000 m³ of material, most of which is concrete and debris of low level radioactivity²⁸.

It is clear that adoption, as well as exclusion of nucleoelectricity, produces environmental impacts. If a country incorporates NEG into its matrix, certain impacts from construction and operation of the power plants will occur. If the nuclear option is excluded, other forms of electricity generation must be harnessed, which will in turn, produce their own environmental impacts. Therefore, a relevant manner to analyze the nucleoelectric option is to evaluate environmental impacts caused by NEG vis-à-vis those produced by alternative generation methods, assessing all of their advantages and disadvantages in an objective and balanced form²⁹.

6.4 Territorial aspects

Certain territorial aspects deserve special attention for the analysis of a nuclear option, in particular the geographical suitability (definition of **where** to install a NPP) and structural territorial impacts, both within an institutional and legal context.

One of the first questions to be addressed, is *whether geographical conditions exist in Chile for installation of a NPP and if so, where*. To begin with, it should be mentioned that the geographical diversity of the country, its extensive coastline and the existence of vast territories with very low population density, are favorable conditions for siting of a NPP facility. Although the seismic features of the country and the risk of tsunamis are important factors to be considered, they are not insurmountable.

Chile has the professional and scientific capabilities to address the question of *where*, as well as being able to transfer experiences from other countries. The IAEA has established guidelines and offers support for nucleoelectric plant localization. But, in order to adequately answer the question requires, at least, knowledge of all locations that would seem apt for NPP sites at a national level.

It is also important to have the legal instruments, the regulatory framework and

²⁷ Myths of Nuclear Energy. www.greenpeace.org

²⁸ Commissariat à l'énergie atomique, *op.cit.*

²⁹ The analysis should be carried out at three levels: local, regional, and global influence area. For each source type, the impact generation cycle (start and end) must be defined. Only projects of similar size (installed capacity) should be compared.

institutions relevant for territorial planning in accordance with the delicate nature of this issue. On the matter of investment locations in Chile, decisions are made by (usually private) entrepreneurs. In the current institutional and legal scenario, the Chilean State has no major influence regarding where the investments are made³⁰; the government can only make sure that the decision complies with the sectorial legislation in force.

Land use planning instruments, can be useful tools to analyze this issue at local or regional levels. However, these planning instruments are only indicative and do not carry legal force. In summary, *the present institutional and legal scenario for territorial issues does not allow rational and correct decision-making with respect to siting of complex infrastructures*. So, it would not be an exaggeration to say that *the environmental and territorial institutional framework requires significant adjustment to be able to regulate and oversee facility siting and operation of a NPP in a scientific and technically efficient manner*. In such an important and sensitive matter as the installation of a NEG facility, a more decisive role of the Chilean State is required for geographic facility siting.

Despite existing scientific and technical capabilities in Chile and the possible available external support, certain areas of knowledge require further development in order to be able to contribute significantly to decision-making, not only for nucleoelectricity, but for all strategic mega-projects, both in production as well as in infrastructure.

Finally, we must know which structural territorial impacts come from installation of a NPP. Just as it occurs with any industrial mega-project, the construction, operation and dismantling of a NPR brings along certain actions and processes that, because of their scale and nature, necessarily produce important changes in their surroundings. These impacts, positive as well as negative, will depend, among other factors, on the natural and specific characteristics of the location, any pre-existing infrastructure, the major economic processes and current institutional framework as well as the opinion of the local communities.

³⁰ With the exception of the urban environment.

7 IMPACTS OF NEG ON HUMAN HEALTH

Nucleoelectric generation, and in general all activity involving the use and manipulation of radioactive materials, pose potential risks to human health. To understand the extent of these risks, it is convenient to distinguish between the normal operation of a reactor and the case of nuclear accident.

7.1 Effects of ionizing radiation on health

With respect to human health, the ionizing radiations are those that raise the greatest concern. If ionizing radiation penetrates on a live tissue, the ions produced can affect normal biological processes. As a result, contact with any of the typical forms of ionizing radiation (α , β , γ , X-rays and neutrons) can seriously affect human health. It is also known that the effects depend on radiation type and dose. For example, γ radiation only produces localized lesions at specific points, in such a way that the tissue can withstand radiation reasonably well and even heal the wounds. However, a heavy and relatively large α particle causes great damage in a small area and is more harmful to live tissue. In general terms, doses of less than 0.1Sv ³¹ do not generate a clinical response. But an exposure to 4Sv is a half-lethal dose (dose at which 50% of irradiated individuals die).

From an operational point of view, it is also possible to distinguish between deterministic and stochastic (or probabilistic) radiation effects. Deterministic effects are those in which the severity depends on the dose received and for which there is a defined range, as for example, radiation-induced cataracts. Stochastic effects, on the other hand, are those which occur randomly, generally without a known dose range and whose probability is proportional to the dose and severity is dose-independent. Genetic changes and cancer development are the most significant stochastic effects of radiation.

Some of the most significant deterministic effects include acute irradiation syndrome (**ARS**), a combination of clinical syndromes (hematopoietic, respiratory, gastrointestinal and neurovascular), which appear progressively from hours to weeks after ionizing radiation exposure. This syndrome is the most serious and is seen in major accidents. As an illustration, after the Chernobyl accident, 237 people were hospitalized diagnosed with overexposure ($>0.1\text{Gy}$)³². Of these, 134 developed ARS (57%) and 28 patients in this group died³³.

The most significant of stochastic effects is the participation of ionizing radiation in the development of carcinogenic processes, particularly in thyroid cancer (through an effect on suppressor genes) and leukemias (effect on oncogenes). Diverse research on possible mechanisms to explain a cause-effect relation between ionizing radiation and cancer have established the need to consider, on the one hand, the quantity and quality of the received dose, and on the other, the tissue type affected together with its recovery capacity. Particularly relevant is the role of the low LET³⁴ radiation (radiation with a low density of ionizations per path unit, such as X-ray, β , γ radiation, and α -particles that can initiate and weakly promote oncogenic processes. The debate on

³¹ Sv, *Sievert*. Unit for of radiation absorbed by organic matter. 1 Sv is represents 1 Joule of absorbed radiation in 1 kg of organic matter.

³² The gray (Gy) is a unit of the absorbed dose of radiation, which gives a different coefficient for each type of organic tissue.

³³ IAEA, *Acute Radiation Syndrome, clinical picture, diagnosis and treatment*, Module XI.

³⁴ LET (linear energy transfer), allows the quantity of deposited energy per path unit to be defined.

whether the effects of ionizing radiation, in particular those from low LET and low doses³⁵, is far from being resolved, as research has not been able to identify the mechanisms or the dose thresholds beyond which they are triggered, given the high number of factors that intervene in the development of carcinogenic processes. It should be emphasized that exposure at very low doses is of little relevance, as all people are exposed continually to natural background levels of radiation. Any exposures to the public due to normal operation of nuclear power stations do not add significantly to this exposure.

7.2 Effects of NEG on human health under normal reactor operation and in the case of nuclear accident

Under currently-defined international safety standards, in the processes of installation, start-up, operation, management of radioactive waste, and dismantling of a nuclear plant, no significant amounts of ionizing emissions are produced to represent a risk for human health. In effect, the recorded radiation levels inside a nuclear power plant are equivalent to exposure to natural radiation. In this respect, it should be mentioned that a person receives an average of around 0.35 mSv of radiation coming from cosmic rays each year, while a passenger in commercial plane receives approximately 0.05 mSv in a transatlantic trip.

Ionizing radiation is also associated with non-nuclear forms of electricity generation. Coal, gas, oil and geothermal generator plants lift radioactive material from the earth's crust to the surface. According to an estimate from the Environmental Protection Agency USA, a person living at 80km or less from a coal-fired plant receives on average a dose of 0.3 μ Sv, while someone within that radius of a nuclear plant receives less than a third of this dose. Both doses are less than that received by an average US citizen from radiographies, and less than one ten-thousandth of that which he receives from natural background radiation.

However, all of the processes related to NEG are subject to undesired events of variable size and impact to human health. These events, characterized and scaled according to the INES scale established by the IAEA were discussed in section 4.1.

In a major accident like Chernobyl (level 7), the spreading of radioactive material can generate serious effects on health over a large area, with long-term environmental consequences. A serious incident (level 4) like the one in Vandellos, would not require measures beyond the plant site, but may severely affect the health of reactor workers.

7.3 Response of Authorities to a radiological emergency

In Chile, there are radioactive sources currently in use that may generate events capable of affecting public health. The possible sources are the research reactors, the medical and industrial equipment. The institutional responsibility in an event of this sort is shared between the Chilean Nuclear Energy Commission (CCHEN) and the Ministry of Health. There is a consensus amongst specialists that the current response capability is limited and insufficient, particularly due to weakness in inspection and early warning systems, as well as in regulation systems.

³⁵ Exposure between 0 and 100 mGy or an exposure under 0.1 mGy/min, are considered low doses.

8 NATIONAL DEFENSE: ENERGY AS A STRATEGIC ELEMENT

Energy is a commodity that has a direct bearing on development. In turn, a country's development is a fundamental factor of national security, in so far as it brings stability, social cohesion and determines its strategic position. It is fair to say that energy is a strategic element since it constitutes a resource that when scarce, jeopardizes the fulfillment of objectives of national interest.

Thus, we know that lack of energy not only compromises and even hinders development of a country, thereby affecting the lives of its citizens. In addition, the scarcity of energy as a resource implies higher prices and thus, lower product competitiveness in the world markets where Chile takes part through its open economy. From this point of view, there is no doubt that energy must be classified as a strategic resource, or better, an asset whose availability compromises most, if not all of our national effort.

On the other hand, the approach to the energy problem establishes a direct link from the dependence, interdependence and the relation between countries, to the possibility of maintaining levels of economic and social development in constant growth. It is clear that the energy issue today largely determines international order. The relation between producers and consumers, exporters and importers establishes the position of each country and, as a consequence, modulates international relations.

In this context, dependence of a country on essentially one energy source and thus on only a few other producer countries, constitutes a vulnerability factor. Thus, faced with dependency and not being a producer country, two basic possibilities are open to us: interdependency and cooperation.

In conclusion, energy is a matter of national sustainability, and its impact on the level of strength or vulnerability should be evaluated in relation to the levels of autonomy and dependence that are derived from the energy matrix.

8.1 Energy and autonomy

Energetic autonomy is understood to mean the *diversification, with a significant share of self generation and interdependence and/or cooperation relations –and not dependency-between States*. In the light of international experience, it is possible to propose that there exists a correlation between levels of self generation, autonomy and degree of national sustainability.

For countries that are net importers of energy, diversification of energy sources is an essential objective, not only for its effects on development, but also because reducing the vulnerability derived from dependence on foreign sources is also a security objective. Net energy exporter countries, on the other hand, have the chance to establish regional cooperation networks and influence through them on the collaboration and integration relations, promoting their own development and stability.

The usual situation is thus to produce energy with own resources to satisfy part of the national demand, and resort to imported energy products to satisfy the remainder. The proportion of one or another component varies depending on several factors, including: availability of hydro/water resources, hydrocarbons, national policies that stimulate electric generation by NCREs (wind, solar, tidal, etc.), accessibility to certain regions,

energy availability in neighboring countries and certainly, the production and distribution costs.

8.2 Correlation between the energy matrix and national security

There is a relationship between Chile's energy matrix and its national security. The defence policy of our country is defined in terms that exceed the purely military aspects. It is also consistent with our policy of international relations, with the aim of creating a climate of cooperation and confidence, mainly at a regional level. This hopefully encourages relations less conditioned by historical agendas and centered more on the construction of a stable future. In this respect, how the Chilean State builds its future energy matrix is critical, as it will mark present and future relations with other countries.

Incorporation of economic and energy variables has made the concept of security a more complex one, and point to what has been called, "complex security"³⁶, defined as the one arising from a group of countries, whose main security concerns and perceptions are so interrelated that their problems of national security cannot be reasonably analyzed or resolved separately.

From this point of view, it must be recognized that nuclear energy as part of the energy diversification, provides greater autonomy and generates new possibilities of alliances and collaboration in our region.

It is in the energy - power relation that the inclusion of nuclear energy in the matrix of a country acquires features that differentiate it from countries without this energy source. Chile, together with Latin American and Caribbean States, share "*a common vision of the peaceful use of nuclear energy. Consequently, this region and our country have sustained that Nuclear Non-Proliferation Treaties (NPT), the Tlatelolco Treaty and the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which constitute the essential legal framework on which the actions of all peaceful countries must be based. For this reason, we have pledged, not only to fully respect these legal instruments, but also to promote them as necessary tools that promote safer and more predictable international scenarios*".³⁷

One of the main threats to security and world stability arises from the fact that terrorist groups may gain access to nuclear installations, nuclear material or radioactive sources with the aim of using them against third parties. This world threat is a challenge for all countries, forcing them to adopt special security measures to prevent access to installations and radioactive material by unauthorized personnel. World concern in this context is channeled through international organizations. It is for this reason that in September 2005, the UN passed the International Convention for the Suppression of Acts of Nuclear Terrorism, and in September 2006, the IAEA released Resolution GC(50)/RES/11, Measures to Protect Against Nuclear Terrorism, introducing further tasks for overseeing installations and the nuclear fuel cycle.

³⁶ B. Buzan, *Security: A New Framework for Analysis*, Rienner Publishers Inc., USA, 1998.

³⁷ *Nuclear Energy and International Policy*. Document compiled for the Nucleo-Electric Work Group by the Energy, Science, Technology and Innovation Division of the Ministry of Foreign Affairs, Chile.

9 HUMAN RESOURCES

The Human Resources demanded by that nuclear technology varies widely and its basis is guaranteed by the maintenance of the engineering, physics, material sciences and other disciplines at local the universities. Similarly, it is required to have institutions capable of training technicians in the different support specialties, with high standards of quality and rigor, familiarized with the technological demands of the nuclear industry.

For a nucleoelectric generation plant around one hundred professionals are employed in the areas of operation, maintenance and regular repairs, risk analysis and troubleshooting. A considerably greater number of technical staff and administrative and service personnel are also needed. In addition to this, an adequate number of professionals are required in the country's health services and regulatory organizations, capable of understanding, collaborating with the operators, and overseeing normal plant operations, and those who should be prepared to handle emergencies.

If a nuclear power program were recommended for Chile, it would be advisable to start early on with training program for human resources to cover the different specialized aspects of nuclear affairs. Specialization could be obtained through an association scheme, currently under development in the international community, sponsored by the IAEA and with support from other networks including the World Nuclear University.

The applications and derivations of nuclear technology could be incorporated through academic graduate programs in nuclear energy at local universities, through study abroad, or by migrations generated by demand according to market evolution worldwide.

In case of having a NEG program, it would be most convenient to have in Chile at least one center for research and development of energy resources, to study all energy forms, –conventional, renewable and nuclear-, over the long-term. In countries such as Sweden, Spain and Korea, such centers provide technical support to the regulatory bodies and also cater for the needs arising from operation and maintenance of a NPP. This is regardless of the status of technology importers and also irrespective of the support provided by manufacturers.

As commented in §4, an important source of accidents are human factors. In most cases, international experience shows that lack of procedural rigor is the main source of risk. The discipline required for nuclear plant operation is demanded from all personnel involved directly and indirectly in its operation. This is why permanent and strict safety standards must be enforced and upheld, even beyond the plants themselves. Based on this requirement, it would be convenient for culture of safety to be a feature of the society at large, and not just restricted to those working directly with nuclear energy. Independent of whether or not NEG is opted for in Chile, it would be important for the whole country to have a security culture, as a pillar of performance for all its citizens.

10 ROLE OF THE STATE AND INSTITUTIONAL FRAMEWORK

As has been seen in the preceding sections and as confirmed by numerous international examples, NEG is a unique industry and is different from all other electric generation industries. This statement is supported mainly by these facts:

- NEG depends critically on social perception and acceptance;
- Decisions made commit the society to time scales for the next hundred years;
- NEG is subject to strict regulation and international treaties;
- NEG is particularly intensive in terms of high risk capital costs.

These characteristics mean that the decision to incorporate NEG into the existing matrix challenges dominant industrial organizational models in the electric sector around the world. Chile is no exception, and the model that has been in force for 25 years, will very probably need to be adjusted or modified to incorporate NEG. The following analysis shows that the current scheme characterized by the technological neutrality of the State, decentralized decision-making and the indicative State role is not compatible with NEG.

Financial model and cost structure

The price system currently in force in Chile makes it difficult to recognize and internalize the total cost carried by NEG, such as, for example, costs associated with treatment of waste left by nuclear reactor operation. In the same way, known traditional mechanisms to secure compliance or legal obligations to generator companies, such as insurance and guarantees, are not suitable to cover the prolonged time scales implied by NEG and the large investments required by this type of technology. Because of the nature of NEG, which must consider the whole reactor lifespan cycle, including its dismantling phase, the operator must give guarantee that he will fulfill these obligations, guarantees that are not considered as part of the current system in force. In addition, there must be regulatory / political certainty that the operator will be allowed to generate electricity over the plant's lifetime (provide it does so safely).

Access to regulated contracts compatible with NEG investment cycles

Regulated customer supply contracts have a maximum duration of 15 years by law, time enough to make profit on a thermal project, but possibly not enough time for an NEG project. Nuclear reactor operators would be starting a service, with uncertainty about placement of production for regulated customers after those 15 years.

Recognition of strategic aspects and international relations

The decision to incorporate NEG involves strategic aspects related to the countries providing the technology and fuel supplies. This is similar to the way in which decisions are made with respect to acquisition of defense material of a country. Consequently, selection of nuclear technology should be evaluated in the context of international relations and the permanent foreign policy objectives of the country. Moreover, there is a number of international conventions on security and safety standards signed or in the process to be ratified by Chile, that must be observed.

Financial definitions of costs associated with institutional development

Prior to declaring NEG available, the State must make its own investments, such as, for example, developments in infrastructure and institutional framework. In addition, it must strengthen international agreements that might compromise its financial responsibility. In

the same manner, basic and indispensable training demanded by international agreements in human resource matters, including installation of a health system appropriate for the requirements of NEG operation, implies large-scale State participation and funding.

As this analysis shows, NEG incorporation should be a strategic decision and one that is made by the State, demanding that its authorities take an active role not only in decision-making, but also during the evaluation process, in selection of technical options, in the design of the global regulatory framework, in the adoption of international regulations and in overseeing at both these regulatory levels.

11 INTERNATIONAL EXPERIENCE AND CONCLUSIONS

International Experience

After half a century of international experience in nucleoelectric generation, the following list summarizes the relevant facts that should be considered in an assessment of the nucleoelectric option for Chile:

- 1 The available nuclear technology offers a number of reactor models by several suppliers, in continuous evolution. Currently, a few reactor types dominate the market, provided by three or four main suppliers in the world. There is relative consensus with respect to the technology and process, with increasingly simpler and safer designs at lower production costs. At the same time, personnel's training has become standardized under sponsorship of IAEA, which has helped to reduce the times for licensing plant operations and is also facilitating regulation and legislation by governments.
- 2 Under normal operating conditions, a NPR does not generate adverse effects on the health of those working at a plant, nor to those living in the immediate surroundings. The nuclear industry exhibits higher levels of safety than those of other forms of electric generation.
- 3 Nuclear technology has reached reliability levels that can be trusted, but demands care, discipline and rigor on a permanent basis. Without these conditions, the risk of accidents with serious consequences is unacceptably high.
- 4 Nucleoelectricity is considerably more complex and delicate than other options for electricity generation due to the potential risk for the population and the environment, for its technological and cultural requirements, and because it is a long-term commitment for the country in question.
- 5 IAEA experience shows that, once the decision to proceed with a NEG program, the country needs between 10 and 15 years to carry it out. It is also recommended that the power of each individual reactor does not exceed 10% of the installed power of the grid to which it is connected.
- 6 It has been observed that nuclear energy can be commercially competitive with fossil fuel energies at current price levels, although the cost of a nuclear plant is more sensitive to interest rates.
- 7 According to the recent technology for intermediate and final disposal of spent nuclear fuel, it is possible to reasonably assure that, with a time horizon of up to 10,000 years, these residues will not come into contact with the environment.
- 8 Fears for the impact of a radioactive accident and for the potential risks from final disposal of residues deserve to be addressed as a relevant variable in the analysis.
- 9 Nucleoelectric generation requires a sanitary authority that can cope with possible nuclear accidents, with capabilities for containment, treatment and follow-up.
- 10 Both, adoption as well as exclusion of nucleoelectricity produces environmental impacts. If a country decides to incorporate nucleoelectricity into its energy

matrix, there will be certain environmental impacts from this decision, which would be minimal under normal operating conditions, but which could be severe in case of accidents. If nucleoelectricity is excluded from the matrix, other generation methods must be developed that will have their own environment impacts, with long-term negative effects in many cases.

- 11 Accidents in the nuclear industry are mostly due to human errors. So, the main effort should focus on training and periodic re-certification of personnel.
- 12 Establishment of a nuclear power program demands an extended culture of safety awareness within the society, beyond personnel directly working at NPRs.
- 13 Nucleoelectricity generates opportunities for the development of technological capabilities, beyond the scope of the nuclear technology itself.
- 14 Nucleoelectric generation offers an interesting opportunity for regional cooperation and integration, not only at an economic level, but also in science and technology.

Conclusions of the Nucleoelectric Working Group

- 1 Examination of all information available to this work group leads to the conclusion that nuclear energy should not be discarded as a future energy option for Chile.
- 2 Faced with the complex national and international energy scenarios, the assured supply of electricity should be considered as a national strategic objective in order to attain higher levels of development. For Chile, this objective requires greater autonomy of supplies that can be achieved by diversification, in which NCRE, nuclear energy and energy efficiency would play important roles.
- 3 The decision to incorporate nucleoelectric generation is strategic, in technical, political and geopolitical terms. In this decision the State must play an active role in the evaluation process, unlike the one observed up to now, as well as a role in the selection of the technical options and in setting up regulatory institutions.
- 4 Chile's legal framework regarding nuclear energy is not adequate for current needs, and even less so, for nucleoelectric generation. The fact that the same institution promotes, operates installations, regulates and oversees activities related to the use of nuclear energy is incompatible with international practice and requirements.
- 5 The institutional and legal scenario for land use planning in Chile is not favorable to correct decision-making on matters of geographical localization of complex infrastructures, like a nuclear power plant.
- 6 The current response capability of the State faced with a radiological emergency must be substantially improved, regardless of whether or not nucleoelectric generation is adopted.
- 7 The establishment of a nuclear power program would require strong support for

- the training of human resources in areas related to nuclear technology, for which domestic capabilities as well as international cooperation should be used.
- 8 Installation of the nucleoelectric option demands a culture of safety-awareness within the society of the whole country, beyond those directly working at nuclear power plants.
 - 9 In spite of the inherent seismicity of the Chilean territory, that generates understandable public concern, the anti-seismic technology and engineering available in Chile can guarantee acceptable safety levels for the installation of nuclear power reactors. However, in order to minimize risks of major seismic events, it is essential to have extensive information about seismic faults, and reliable soil mechanic studies at potential sites.
 - 10 If the country does adopts nucleoelectricity, the necessary public acceptance will only be possible if the society is duly informed with transparency, if work is done with independent experts and with a disposition to consider diverse opinions from the civil society.
 - 11 The energy challenges facing the country make it vital to significantly boost research and development about energy, regardless of whether or not the country adopts nucleoelectricity. In this sense, it would be convenient to have research centers capable of evaluating the country's generation potential, as well as promoting the development of all possible technological options.
 - 12 The formula that Chile will eventually adopt to face the medium- and long-term energy challenges, should not ignore the international context in relation to other problems, such as global warming, technological evolution, the growing energy demands and even, terrorism.

12 RECOMMENDATIONS

From the afore-mentioned conclusions, a number of general recommendations arise, as well as specific studies to be performed in Chile over the next two years.

12.1 General recommendations

- 1 To maintain a multidisciplinary focus on the study of the nuclear option setting the analysis in the context of broader energy challenges of the country.
- 2 To study the electric matrix along with other domestic energy needs to evaluate the best use of the different resources.
- 3 To perform a range of studies oriented to provide relevant information for the decision-making process about the future of the electric matrix in Chile.
- 4 To set up a technical-operative team in charge of defining reference terms for studies on nucleoelectricity, recruiting necessary expert counterparts.
- 5 To design and order the specific studies to define the institutional modifications required if the country were to opt for the incorporation of nucleoelectricity.
- 6 To inform and educate the public about the significance and implications of nuclear energy, with transparency and participation of independent experts, in a process open to diverse opinions from civil society.
- 7 In order to stimulate a diversified and robust development of the energy matrix with long-term horizons, it would be convenient to support the establishment of research centers for the study and development of energy technologies, for the rational and efficient use of energy, and for the promotion of novel applications in a strategic manner.
- 8 To strengthen and/or to establish national information networks for seismic, hydrologic, meteorologic and oceanographic information, as a basis for decision-making with respect to the energy matrix.

12.2 Studies

For practical purposes, the studies recommended below are grouped according to the most relevant areas to be initially tackled. In general terms, these studies aim toward defining institutional, technical and economic viability of NEG; and to gauge the requirements and the impact of implementing a nuclear power program.

1. Institutional:
 - a) Evaluation of the existing legal and institutional framework that governs activities related to the use of nuclear energy, such as technical, economic, sanitary, environmental and international regulation.

- b) Assessment of costs and requirements for the establishment of norms, legal bodies and other costs associated with the regulation of NEG.
- c) Studies for the design and evaluation of the implementation of the agency to oversee and regulate the nuclear energy industry in Chile.
- d) Design and cost evaluation of modifying and adapting the institutional framework necessary for different alternative scenarios, with or without NEG. Determination of the moment in which different modifications should be introduced in order to accommodate the present scheme of electric generation to the needs brought about by NEG.

2. Economic:

- a) Prospective study of the electricity demands for the next 30 years, including the possible effects of energy efficiency programs, separated by geographic zones and by economic sector. The study should include uses of electricity for residential and industrial consumer needs, allowing for the incorporation of technological and institutional changes.
- b) Analysis of supply, structure and functioning of the electric market, its actors and producers.
- c) Study of the relative costs of different electric generation technologies and their dynamics over the next 20-30 years. Particular attention should be paid to the costs of different nucleoelectric technologies and sizes of power plants, considering the whole life-cycle of the projects. Evolution/scenarios of the electric matrix in Chile.
- d) Evaluation of the economic competitiveness of nuclear energy compared to other generation sources. Determination of the impact of NEG on other areas, including environmental and strategic areas (diversification).
- e) Analysis of the financial insurance coverage required in a scenario of adoption of nucleoelectricity.

3. Environmental:

- a) Prospective assessment of the potential of all forms of electric generation in the country.
- b) Comparative analysis of environmental impact by all forms of electricity generation for the entire life-cycle of each form.
- c) Study of the legal environmental instruments and institutional framework; land-use planning and its compatibility with nucleoelectric generation.
- d) Generation of detailed seismic studies to complete the scant presently available data.

- e) General studies at national level to identify potentially suitable areas for sites of nuclear power plants.
- f) Study to gauge to the structural territorial impacts and their costs, derived from installing of a nuclear power reactor.

4. Public perception:

- a) Design and use of methods to poll public opinion about nuclear energy issues.
- b) Design and use of a public information and education programs about nucleoelectric generation.

5. Health:

- a) Study of health legal and regulatory frameworks that cover events, accidents and emergencies, arising from plant operation, transport, and management of radioactive materials.
- b) Study to define institutions and organizations necessary to cope with emergencies in plant operations, transport and management of fuel and radioactive waste.

6. Human resources:

- a) Study to identify the necessary human resources for development, operation and maintenance of a nuclear program and for radiological and nuclear emergencies, quantifying the relevant costs.

ACKNOWLEDGEMENTS

In our work, we received the collaboration of the following institutions: Ministerio de Minería; Comisión Nacional de Energía; Comisión Chilena de Energía Nuclear; Subsecretaría de Marina; Energy, Science, Technology and Innovation Division, Ministerio de Relaciones Exteriores; Chilean Embassy in Austria; Chilean Embassy in Spain; Chilean Embassy in Japan; Japanese Embassy in Chile; Universidad Adolfo Ibáñez (Chile); Universidad de Chile; Universidad de Talca (Chile); Mathematical Modelling Center of Universidad de Chile; Centro de Estudios Científicos CECS-Valdivia (Chile). This group recognizes the permanent support of the Minister of Mining, Ms. Karen Poniachik, and the Energy Minister, Mr. Marcelo Tokman. Special thanks are also extended to Dr. Álvaro Covarrubias and to Dr. Julio Vegara for their collaboration and in the revision of specific technical aspects of this report.

The following is a list of persons who have kindly shared their time and knowledge with the Nucleoelectric Working Group in the task of drafting this report. We extend our sincere thanks to each and every one of them for their kind and willing collaboration. The content of the report is the sole responsibility of the Group members and does not compromise these persons in any way.

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Pablo Zuloaga, Empresa Nacional de Residuos Radiactivos (Spain)

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