ISSUE 6



# alternatives

TALK ABOUT ENERGY DIFFERENTLY

## RADIOACTIVE WASTE A SOCIETAL ISSUE

## FEATURE PAGE 4

# RADIOACTIVE WASTE MANAGEMENT

What are the different categories of radioactive waste? How is this waste managed and who decides what will happen to it? *Alternatives* takes a look at the technical solutions and the decision processes implemented around the world.





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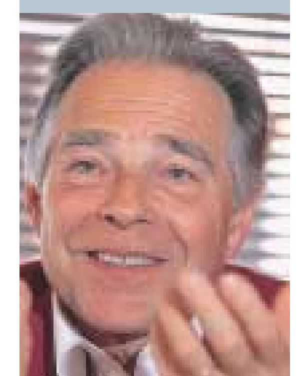
## EDITORIAL

The deadline is fast approaching. In 2006 and 2007, the parliaments of many countries – notably France, the United Kingdom and Canada – will decide how radioactive waste will be managed, and in particular long-lived, high-level waste. We therefore felt that it was appropriate to review the issues raised by this specific waste type, to summarize research in progress, and to describe solutions envisaged by countries that have to manage such waste. The subject is all the more topical in light of the resumption of new reactor construction in some countries – Finland in particular – and recent announcements on the launch of the European pressurized water reactor (EPR), decisions that must be made consensually and for the long-term.

"CONSENSUAL DECISIONS MUST BE MADE ON LONG-TERM WASTE MANAGEMENT."


PIERRE KOHLER
Editor-in-chief of *Alternatives* magazine.

In other areas, world news is marked by sweeping debate on energy policies to be implemented by the end of the century and the role of renewable energies in the overall energy mix – some like to use the term "energy bouquet" – that has become a fundamental principle for the future…
A rising number of debates and conferences has thus been seen in many countries over the past few months, with several decisions imminent.
As always, we will do our best to provide detailed analysis and explanations on a subject that concerns us all: energy.

*Pierre Kohler*

## WHERE DOES RADIOACTIVE WASTE COME FROM?

The nuclear power industry generates most of the radioactive waste (two-thirds of it by volume), largely from the combustion of fuel assemblies in nuclear power stations. The waste is processed in fuel cycle facilities. There are three categories of such waste:

- waste originating directly from used fuel, consisting primarily of uranium fission products formed when the fuel is in the nuclear reactor;
- "technological", or dry active waste produced during the operation and maintenance of fuel cycle facilities, including nuclear reactors (spare parts, tools, protective clothing, overshoes, gloves, rags, etc.);
- waste resulting from the dismantling of decommissioned nuclear facilities.

The remaining one-third comes from the following sources, in order of quantity:

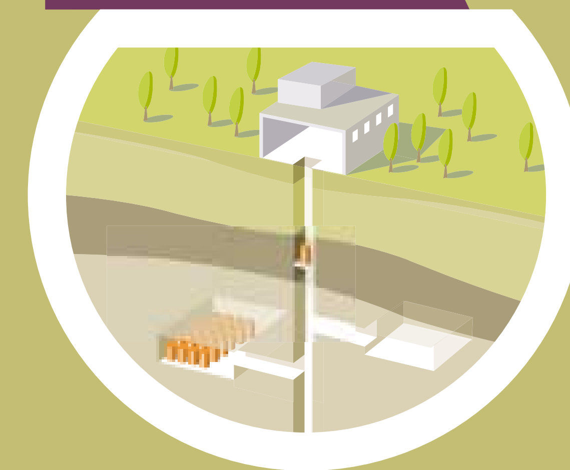
- research;
- national defense activities;
- nuclear medicine in hospitals, especially for radiation therapy and medical imagery applications;
- industrial activities such as quality control of pipe welds by radiography.


Radioactive waste containers to be sent to the Centre de l'Aube waste disposal facility.

### SURFACE DISPOSAL

Short-lived, low- and medium-level radioactive waste goes into surface disposal.

### DEEP DISPOSAL



Deep geological disposal is used or under study for long-lived, high-level radioactive waste.

# RADIOACTIVE WASTE MANAGEMENT

Radioactive waste management is more than just a technical question. Though the waste is not a health threat, its disposal has become a societal issue with a blend of ethical and political considerations. Technical solutions exist for every waste type. They must be clearly explained.

Aside from very low-level waste (VLLW), radioactive waste is classified according to two criteria for purposes of long-term management: the activity level (number of disintegrations per second) and the half-life (see inset, page 7). For although the half-lives of some radioactive elements can be counted in mere seconds, they can be millions of years for others, whose activity levels are accordingly very low (these radionuclides being practically stable). The activity level of waste indicates its toxicity and therefore its potential impact on humans. Four activity levels are recognized: very low, low, medium and high. The radioactive half-life is split into two categories: short half-life waste (essentially containing beta and gamma emitters) and long half-life waste (containing alpha emitters).

# TRUE OR FALSE

**Legally speaking, used fuel is not considered to be waste in Europe.**

**TRUE**

The Organization for Economic Cooperation and Development (OECD) does not include used fuel in its definition of waste, since it still has usable energy potential (unused uranium and plutonium).

## DISTINGUISHING BETWEEN STORAGE AND DISPOSAL

In the nuclear industry, storage and disposal mean completely different things. For the former, the situation is temporary, pending waste packaging or the shipment of packaged waste. Disposal, on the other hand, is a situation that will ultimately become permanent, even when a certain degree of reversibility is possible. In fact, radioactive waste management starts at a very early stage, during the design and operation of nuclear facilities, whether they be industrial, medical or otherwise, to reduce waste volumes as much as possible.

And significant progress has been made in this area, with greater treatment efficiency leading to a five-fold reduction in long-lived waste volumes and a ten-fold reduction in their radiotoxicity. Each category of waste is then packaged according to a specific process. Short-lived low-level waste – which accounts for most of the volume – is compacted and packaged in metal drums, encapsulated in concrete, bitumen or special resins. This waste is generally isolated until its radioactivity has fallen to its natural level.

The French have built a special surface disposal facility in the Aube department for this type of waste. Other countries have opted for a near-surface solution, i.e., slightly below the surface.

The question is more complex for long-lived high-level waste, as their potential toxicity is greater and, depending on the specific case, remains significant for periods of up to several tens of thousands of years. Moreover, their radioactivity results in significant heat generation requiring special precautions. This final waste is packaged when the used nuclear fuel is treated, through vitrification and compaction, and is then placed in monitored storage pending permanent disposal. Testing and evaluation of the latter are currently being conducted under the law of 30 December 1991 (see inset, page 9), which will be supplemented by legislation expected in 2006 or 2007 at the latest. The need for an adequate level of reversibility will be defined in this legislation, if the parliament deems it necessary.

Reversibility is also being studied in the United States, Germany and Sweden, but so far nothing has been decided. Countries are conducting research into permanent disposal methods based on their specific geology.

**Vitrification:** **Stabilization technique for long-lived high-level waste. The waste, consisting of fission products from used fuel treatment, is incorporated into an unalterable glass matrix.**

## POSSIBLE SOLUTIONS

A variety of solutions have been considered for radioactive waste disposal from the very beginning, including disposal under the polar icecap or burial on small desert islands. Undersea disposal was viewed as more realistic, and, in 1967, eight European countries created a nuclear repository in the Atlantic 700 km from the Gulf of Gascony and 4,000 m beneath the ocean surface. Low- and medium-level waste immersion operations complied with the London Convention on the Prevention of Marine Pollution and with the recommendations of the International Atomic Energy Agency (IAEA). The former USSR also deposited large quantities of waste in the Kara Sea. The slow rate of migration from the ocean bottom to the surface confers a certain safety to immersion. In addition, the dilution effect ensures that any radiation remains below allowable thresholds.

Nevertheless, European countries abandoned this option several years ago.

For high-level waste, the solution currently recommended by the experts (IAEA, OECD) is deep geologic disposal. In this case, waste packages are buried at a depth of several hundred meters in structures for which it is certain that there will be no geological upheavals for millions of years. A principle of functional complementarity is then applied to ensure radioactivity retention. These functions are physical and mechanical mechanisms, the main one being radionuclide migration.

To limit migration, the designer of the disposal site often reasons in terms of "containment barriers" between the waste package and the immediate environment, including man-made barriers (encapsulation of radioactivity in a glass matrix, bitumen or cement; steel container) and natural barriers (geologic formation). The latter is the principal protection, for many millennia.

Indeed, the geologic formation must meet very rigorous requirements, such as the absence of free water and very low permeability. To characterize suitable rock, two criteria apply: it must be geologically and hydrogeologically stable. In other words, to prevent radionuclide migration, water must not flow through the rock.

## ESSENTIAL LABORATORIES

For research on deep geologic disposal, researchers are interested in understanding the physico-chemical mechanisms that affect the behavior of waste packages, firstly through mathematical modeling, but also by observing natural analogs (volcanic glass, elements found in the Oklo natural reactors in Gabon) and by performing full-scale experiments. The main phenomena studied are those involving water (in liquid or vapor form), heat and radiation from the package itself.

Every country faced with finding a solution for the disposition of their radioactive waste acknowledges the necessity of creating dedicated laboratories to test the performance of various soils as geologic barriers, the migration of radioactive elements in the ground and the interactions between materials that have been disposed of and the natural environment.

These underground laboratories are essential tools for determining the conditions under which a repository could be developed and operated. About twenty such laboratories are currently either under construction or in operation around the globe.

The main ones are in Belgium, Canada, the Czech Republic, Germany, France, Hungary, Japan, Sweden, Switzerland and the United States. Research is being carried out on various types of terrain, including clay in Mol, Belgium; salt at Asse, Germany; granite at Grimsel (Switzerland), Stripa (Sweden) and Pinawa (Canada); and shale in Japan. Surface disposal of low- and medium-level waste is currently practiced in Canada, the United Kingdom, United States and France.

**GERMANY**
Waste from the dismantling of a nuclear power station is stored pending transfer to a final disposal facility (Wuergassen nuclear power station).

**FRANCE**
Short-lived waste is placed in surface disposal (Aube facility).

**UNITED STATES**
Waste from the civilian nuclear power program will be stored at Yucca Mountain, Nevada, beginning in 2010.

## RADIOACTIVE HALF-LIFE

All radioactive elements are defined by their "half-life", which is the time it takes for the radioactivity of its constituent radionuclides to be reduced by half. For cobalt 60, for example, half of its elements will naturally disintegrate within five years. Cesium 137 has a half-life of 30 years, which means that after 60 years its radioactivity will have fallen to one-fourth its initial amount, then to one eighth after 90 years, etc. After ten half-lives (three centuries), the radioactivity of cesium 137 will have fallen to one thousandth its initial intensity. Half-lives vary considerably from one atom to another and cover a very wide range of values. A few examples: 24 seconds for silver 109, 10 minutes for argon 13, 6 hours for cobalt 57, 8 days for iodine 131, 53 days for beryllium 7, 1,600 years for radium 221, 5,730 years for carbon 14 (used for dating archaeological objects), and 24,110 years for plutonium 239.

## WORD FOR WORD

**ACTINIDES:** chemical elements whose nuclei contain more than 88 protons, starting with the element actinium. There are 14 actinides, but only four of them (including uranium) are naturally occurring, the others being radionuclides created artificially in the core of a reactor. The most abundant actinide in used fuel is plutonium 239, produced in the reactor from uranium 238.

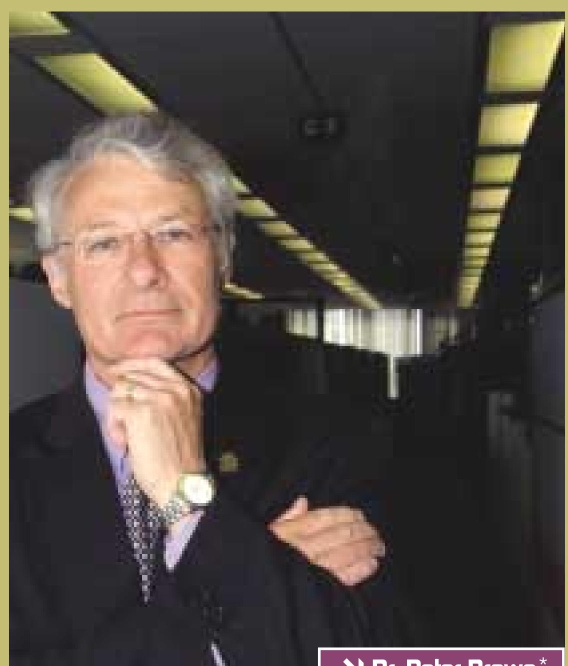
**ALPHA, BETA, GAMMA:** these are the three types of radiation emitted by atoms as they disintegrate. The first type is easily stopped by a little air; a simple sheet of foil can stop the second; but the energy of the third type is stronger than X-rays and can penetrate metal.

**TRANSMUTATION:** this is the process by which a long-lived radioactive nucleus is transformed into one or two short-lived (or unstable) nuclei. The transmutation occurs through nuclear reactions triggered by neutrons (mainly capture or fission) and through natural disintegrations.

EXPERT OPINION

# Taking public opinion into account

For every country, public acceptance is a key challenge, particularly when geologic disposal is the issue. Canada is no exception to this rule. Although decisions have yet to be made, the importance of consensus building has not been overlooked.



Dr. Peter Brown*

**Alternatives: What was Canada's approach to the radioactive waste challenge?**

**Dr. Peter Brown:** In Canada, all radioactive waste, whether low-level or high-level, is currently kept in short-term storage. For low-level radioactive waste that pre-dated the regulations, things started to change in March 2001. The Canadian government and the region of Port Hope, Ontario, where almost all of the waste is stored, came to an agreement on site cleanup and the long-term management of the radioactive waste in storage there. This decision will pave the way for construction of the first safe surface disposal in new tumuli in the Port Hope region. This 260-million Canadian dollar program will span a total of 11 years.

**Alternatives: Who is responsible for implementing Canadian policy in this area?**

**Dr. Peter Brown:** The Canadian Nuclear Safety Commission strictly regulates nuclear disposal. The Commission's personnel review work now in progress to develop and implement long-term solutions for the management of this waste. The Canadian Ministry of Natural Resources (NRCan) develops Canadian policy on radioactive waste management. In this role, NRCan was the architect of legislation on nuclear fuel waste, which provides a legislative framework for a long-term solution. Also, the nuclear operators formed the Nuclear Waste Management Organization (NWMO) on 15 November 2002, whose mandate is to recommend various approaches for long-term nuclear waste management to the government. NWMO must include approaches based on both interim storage and final disposal, and must also build consensus with the public, particularly members of the Amerindian population. It is only after this that the recommended solution will be implemented by the government.

"Approaches based on both storage and disposal."

* Director of the Uranium and Radioactive Waste Division, Canadian Ministry of Natural Resources.

## MANAGEMENT ORGANIZATIONS

Operators in every country with a nuclear power program are confronted with the problem of radioactive waste management. With the exception of Finland, where operators themselves assume responsibility for disposal, each country has an organization or agency dedicated to this mission.

Their mandate is to design, build and operate disposal facilities for existing and future radioactive waste. In Belgium, for example, the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF) has fulfilled this role since 1980. In Canada, the Nuclear Waste Management Organization (NWMO) began performing this task more recently, in 2002. In Switzerland, it is the National Cooperative for the Disposal of Radioactive Waste (NAGRA) and the Commission on Waste Management (CGD), while it is the Swedish Nuclear Fuel and Waste Management Co. (SKB) in Sweden. In France, the National Radioactive Waste Management Agency (ANDRA) created in 1979 manages the Centre de l'Aube disposal facility for short-lived low- and medium-level waste in Soulaines, which is currently in operation. ANDRA also operates the Morvilliers disposal facility near Troyes, a few kilometers away from the Soulaines facility, for very low-level waste. In most countries, radioactive waste management policy is defined in legislation introduced by the government and passed by parliament. This is notably the case in Belgium (law of 8 August 1980), Japan (voted by the Diet in May 2000), Finland (May 2001), Sweden (April 2003) and Spain. In the United Kingdom, long-term waste management will fall under the responsibility of the Committee on Radioactive Waste Management (CoRWM) formed in late 2003 following the national debate on this subject that began in September 2001, with a final decision to be made by 2006. ■

## Radioactive waste categories

Radioactive waste is divided into five categories: mine tailings resulting from uranium extraction (quantified separately as they are naturally occurring and are left on site); very low-level waste resulting mainly from the dismantling of nuclear facilities; and low-, medium- and high-level waste, referred to as types A, B and C.

**A — Type A waste**

Short-lived low- and medium-level "technological", or dry active waste. Represents about 80% by volume of all waste, but less than 1% of their total radioactivity. Three-fourths of it comes from nuclear facility operations and one-fourth from research centers or hospitals. Mainly beta- and gamma-emitters. The radioactivity of this type of waste returns to natural levels within three hundred years.

**B — Type B waste**

Essentially waste from used fuel assembly structures separated during treatment operations. This waste does not generate heat and may be compacted for volume reduction and placed in interim storage pending deep geologic disposal, given that the alpha-emitter content is above the threshold for surface disposal. This waste type represents 5% by volume of all radioactive waste in France.

**C — Type C waste**

This waste represents 99% of the radioactivity in French waste and about one thousandth of the total volume. It consists exclusively of vitrified waste (see vitrification).

BRIEFING

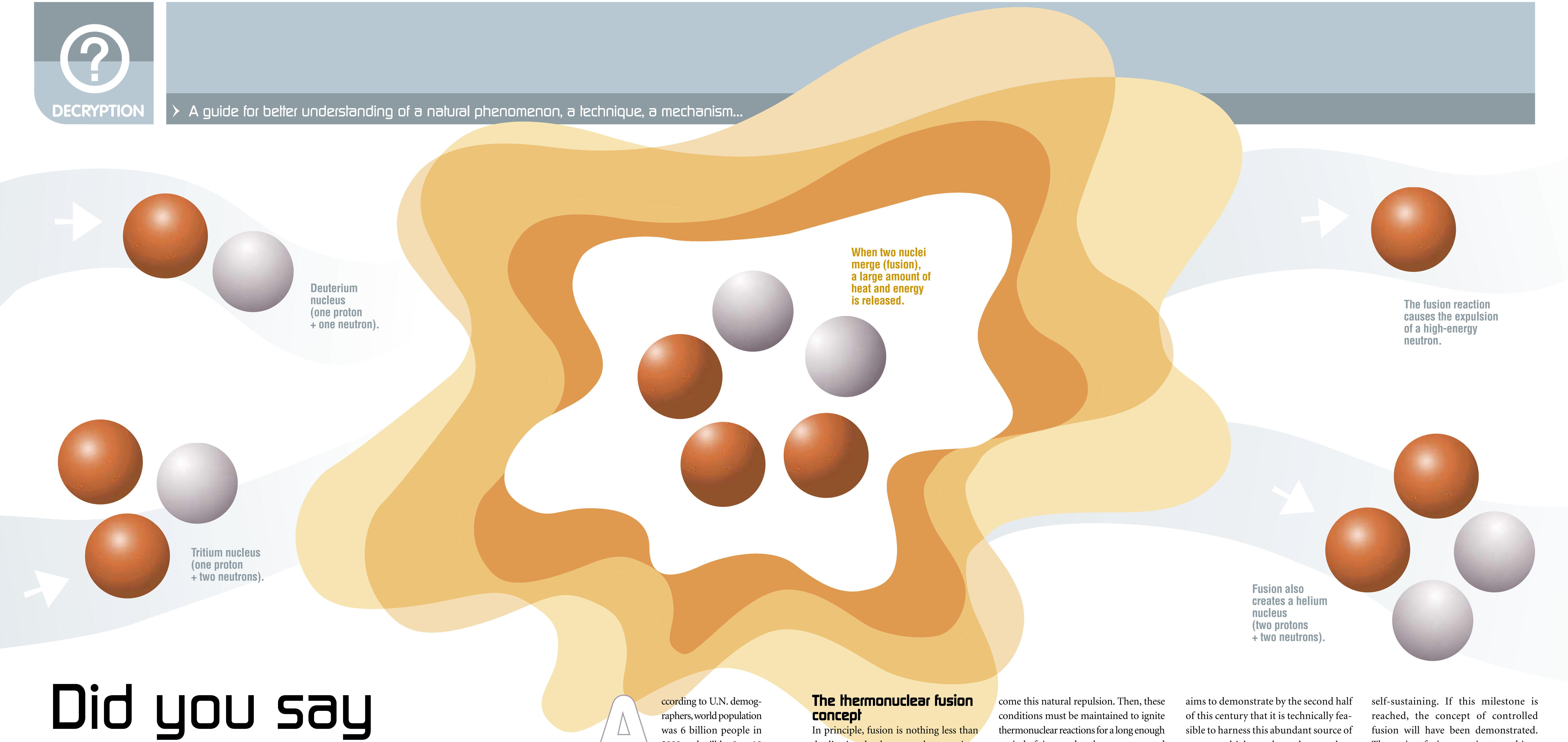
## Research mandated by the "Bataille law"

Under the French "Bataille law" of 30 December 1991, three major areas for research on long-lived high-level waste are being carried out in parallel and will be the subject of a parliamentary debate in 2006.

- Research on solutions for the separation and transmutation of long-lived radioactive elements present in waste so as to reduce its half-life.
- The study of reversible and irreversible disposal options in deep geologic formations, in particular by building underground laboratories. Research is currently in progress at the clay-rich site of Bure, on the border of France's Meuse and Haute-Marne departments.
- Research on waste packaging processes and long-term surface storage.

In 2006, a combined assessment report on this research will be presented to the parliament, together with draft legislation enabling the creation of a disposal facility for long-lived high-level radioactive waste if deemed necessary.

WHO DECIDES? In most countries, radioactive waste management is the subject of legislation passed by the parliament.




# Did you say FUSION?

According to U.N. demographers, world population was 6 billion people in 2000 and will be 9 or 10 billion in 2050. It therefore follows that the energy needs of mankind will continue to increase. Fossil fuels, which currently supply 80% of our primary energy needs and generate two-thirds of the world's electricity, will no longer be adequate to meet demand, hence the necessity to search for new sources of energy. In this respect, controlled thermonuclear fusion is proving to be very promising.

## The thermonuclear fusion concept

In principle, fusion is nothing less than duplicating the thermonuclear reactions that occur inside the sun and stars right here on earth – in other words, recreating a micro-star on earth to harvest its energy. To do this, two atomic hydrogen nuclei must first be brought sufficiently close together – to within 1/100th of a picometer. But they naturally repel each other because they both have a positive electrostatic charge. A massive amount of energy in the form of heat – some 200 million degrees of it – is needed to overcome this natural repulsion. Then, these conditions must be maintained to ignite thermonuclear reactions for a long enough period of time so that the energy created by fusion is greater than the energy expended to start the reaction. There are two ways to achieve this: magnetic confinement, in which a very strong magnetic field acts as a container for the process, and inertial confinement, in which photons emitted by a laser are compressed.

## The ITER project

The International Thermonuclear Experimental Reactor project, or ITER, aims to demonstrate by the second half of this century that it is technically feasible to harness this abundant source of energy, which produces less nuclear waste that nuclear fission. The depth and breadth of this joint research program – which brings together Europeans (France, Germany, the U.K.), Russia, the U.S. and Asians (China, Japan, Korea) – is unparalleled.

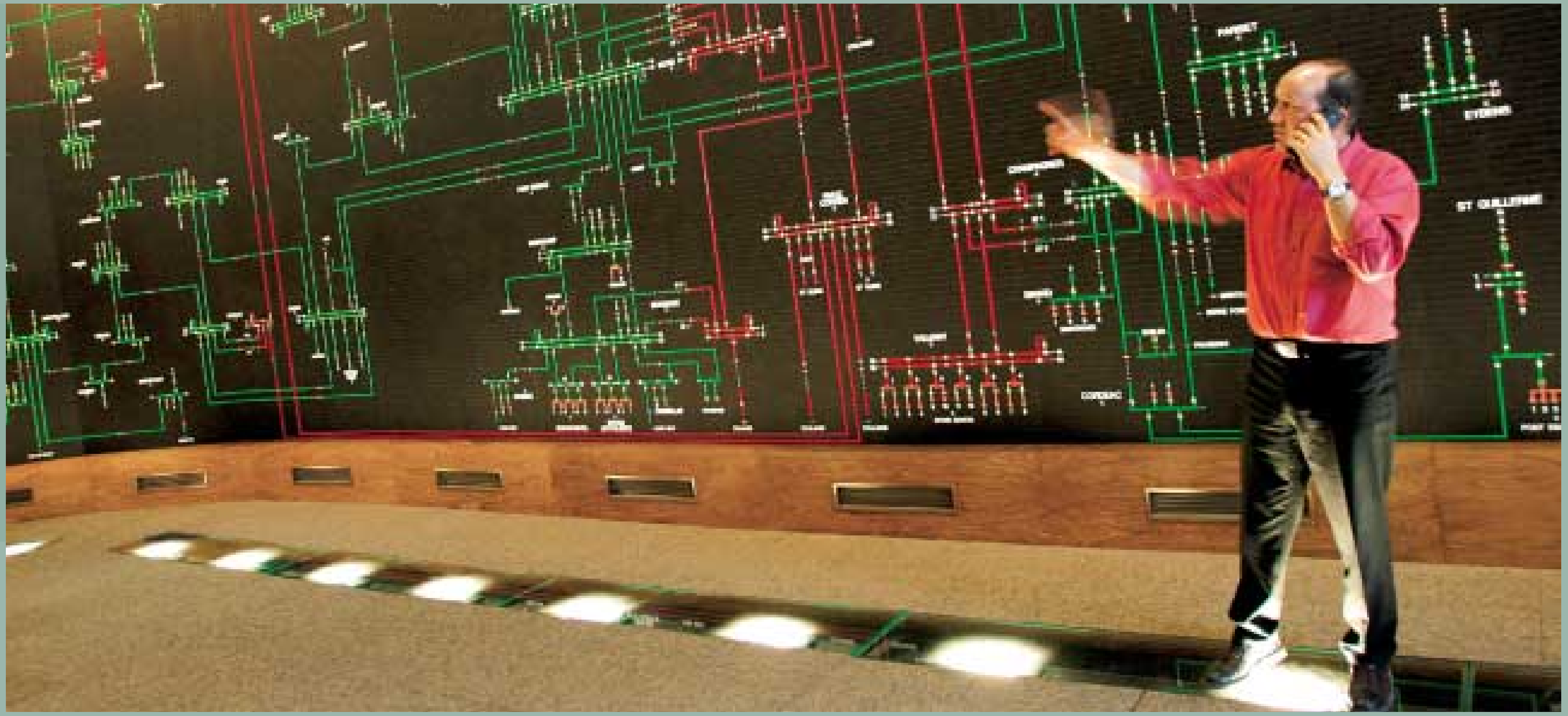
Up to 50 megawatts of heating power will be injected into ITER, with scientists hoping to get back 500 megawatts in fusion power for the 400 seconds required for the fusion reaction to be self-sustaining. If this milestone is reached, the concept of controlled fusion will have been demonstrated. The easiest fusion reaction to achieve uses a mixture of deuterium and tritium, the two isotopes of hydrogen. A single gram of this mixture releases 100 MWh, or the energy equivalent of 8 metric tons of oil, and it only takes 300 liters of sea water to get 1 gram of deuterium. ■

VIEWPOINTS

# The strengths and weaknesses of interconnected networks

› Major blackouts in North America and Europe › At the mercy of the weather, technical glitches and human error › Several ways to protect networks

A look at a map of Europe shows that each country has major extra high voltage networks, veritable electric highways forming an enormous spider's web. But it doesn't take much for an electric grid to fail through a domino effect. Practically every country has experienced this situation at least once. The major blackouts that hit New York in November 1965, August 1977 and August 2003 have gone down in history. Nor has Europe been spared from such blackouts: France in December 1978, London in August 2003, Denmark, Sweden and Italy in the following month... Electricity can take a variety of paths in going from the power station to the consumer. If the most direct route is not available, another one is used without the consumer noticing anything. The grid structure of the network is what makes this continuity of service possible. ■



## Know how to manage real-time load-shedding.

↘ Prof. Chen-Ching Liu's opinion

University of Washington Department of Electrical Engineering.

“Major electric grid failures, such as the one that struck the eastern United States in August 2003, are caused by a series of events, more often that not corresponding to line defects, equipment failure or human error. These events occur one after the other in a domino effect and are rare, but they are catastrophic when they do happen. It is precisely because they are rare and involve several simultaneous events that they are extremely difficult to predict. To avoid them, real-time defensive action and monitoring is required during system operation. The technology to protect electric grids from the causes of these major blackouts exists and has the capacity to cut electrical power where and when required. This selective load shedding is used when the system is found to be unstable and therefore vulnerable, or when it has exceeded its operational limits. In the case of an interconnected grid, the location and degree of power loss is computerized based on different operational scenarios. By voluntarily sacrificing a small part of the load, viable operational conditions can be restored to the entire network. Real-time computer control on a vast scale and the electrical load control technology still need some fine-tuning, and this is the challenge for future grids. A reference document – the 'Strategic Power Infrastructure Defense', or SPID – has been developed jointly by the University of Washington, Arizona State University, Iowa State University and Virginia Tech under the auspices of the Electric Power Research Institute (EPRI) and the U.S. Department of Defense. This wide-ranging framework document covers information and measurement, failure analysis, vulnerability assessment and self-healing actions.
The Advanced Power Technologies Center (APT) of the University of Washington has its own research and development activity on grid configuration control through self-healing actions. Again, the goal is reduce the vulnerability of interconnected grids. The other technologies developed by APT are for electricity price forecasting, the computerization of transfers to available interconnected grids and qualitative analysis of electricity distribution-related events.” ■

## Strengthen backup capabilities between neighboring countries.

“An electric line is, by nature, at the mercy of the weather: lightning can create a power surge, which will result in an overload, a storm can uproot trees or break off branches, which can fall on power lines, an ice storm can deposit tons of ice on the line and weigh it down to the breaking point. All of these risks are well known and controlled, and the lines are of course monitored constantly. France, like most other European countries, has a grid type system. This represents a significant advantage: if there is a fault on one line, the power will be sent via another route, ensuring continuity of supply. Balanced distribution of production sites, nuclear power stations and hydroelectric dams around the country also ensures optimum distribution of available power. France's Electricity Transmission Network (RTE) is connected to neighboring countries via interconnecting extra high voltage lines. On balance, France is an electricity exporter, but if needed can import electrical power. During the 2003 heat wave, imported Spanish electricity helped avert blackouts in France. In fact, interconnections are an essential asset for bolstering mutual backup capabilities between neighboring countries in the event of a fault or power shortage in either one. The specific case of Norway, on the other hand, demonstrates its vulnerability: the hydroelectric dams are in the north and the main consumption centers in the south. These are connected via very long lines that are vulnerable to bad weather. Because it is not a grid-like network, it is difficult to overcome breakdowns quickly.” ■

↘ Hervé Laffaye's opinion

Director of the French national electricity distribution network operations center.

The water movements caused by tides generate an enormous amount of power. Yet only one major installation has operated up to now: the Rance tidal generator in France. But other projects – with more originality than just a dam – are starting to take shape, especially in Norway.

# Undersea tidal power farms

"A TIDAL-STREAM TURBINE IS MORE POWERFUL THAN A WIND TURBINE OF COMPARABLE SIZE AND SPEED."

Several tidal-stream turbine projects are currently underway in Europe. The backbone of this new terminology is a generator beneath the surface of the sea that operates much like a wind turbine, with the ebb and flow of the tide turning the blades… In the United Kingdom, for example, Marine Current Turbine Ltd. (MCT) has installed an experimental marine turbine close to Bristol in Cornwall. There is one major drawback, however: the masts break surface, meaning that they must be marked and indicated on maritime charts. In France, a small Quimper-based business has also developed a system for generating electricity from tidal currents. All the project needs now are investors to start building a 10-kWe demonstrator. Currently, one of the most advanced installations is in Norway, where an entire village is powered by a tidal-stream turbine.

## Tidal-stream turbines more powerful than wind turbines

The site selected for this installation, Kvalsund, is a narrow stretch of sea separating the island of Kvaloya Fala from the country's extreme northern point, 1,000 km north of Oslo. At this location, the speed of the current (about 10 km/hr) offers a considerable amount of energy, given that the power generated by the turbine blades is proportionate to flowrate cubed and fluid density. And water is 800 times denser than air! At the same speed, the energy captured by a tidal-stream turbine is therefore much higher than that of a wind turbine of comparable diameter. In other words, a tidal-stream turbine one-sixth the size of a wind turbine generates the same amount of electrical power. The Norwegian system is anchored to the seabed at a depth of 50 m and fitted with 20 m diameter blades. Its generator produces a relatively modest 300 kWe of power, but the high and low tides are known in advance and, unless there is a mechanical failure, the manufacturer can say with certainty that his tidal-stream turbine will produce 700 MWh per year.

The investment required was about 10 million euros, which is a lot considering the relatively low power output. But it is only a prototype and the manufacturer, Hammerfest Strom, is already planning to build more at the same site. The only unknown is how well the materials will stand up to the corrosive conditions of the sea… ■

1 Assembly of the tidal-stream turbine nacelle.

2 Loading the unit onto the crane barge before immersion.

3 Anchoring the unit to the seabed.

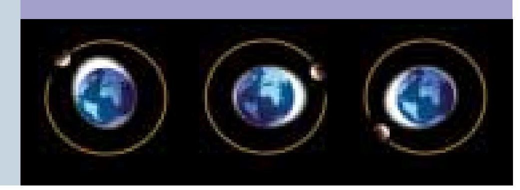
## REPORT

**Bjorn Bekken**
**Director of Hammerfest Strom, Statoil office, Norway.**

"Our idea of installing a turbine under the surface of the sea to capture tidal energy is quite an old one, but this concrete realization started in 2000. We chose to locate the tidal-stream turbine in the Kvalsundet strait, which is 600 m wide and 50 m deep. It is situated 30 km from Hammerfest, which is best known for being the northernmost town in the world! The installation is 300 m from the coast and connected to the transformer station by an underwater cable, but its electricity is not exclusively used to supply the village as it goes into the general power grid. The main technical challenge was to master the force of the currents, which have a speed of about 10 km/h, which is a lot. We also had to find a solution to prevent turbine freewheeling in the event of a loss of grid load. Divers used to working in very cold water carry out system maintenance, but the dives are kept to a strict minimum. To reduce the risk of breakdowns, backup systems are installed for sensitive components so that they can take over in the event of a failure. This tidal-stream turbine is a prototype, but we plan to build a commercial model based on our experience. Initially, our goal is to install about twenty others…"

## Tidal power

The earth, moon and sun system generates some 2500 GW of power that is dissipated by the tides. Tides have an average amplitude of 50 cm in the middle of the ocean, but reach several meters on the continental shelf due to resonance. The energy available on Europe's Atlantic coast alone is estimated at 500 GWe per year. *"The exploitation of this energy by tidal-stream turbines is possible but presumes very good knowledge of the distribution of marine currents and prior analysis of environmental impacts,"* says Florent Lyard, engineer with the Laboratory of Studies in Geophysics and Spatial Oceanography (LEGOS).



# The Danish paradox

Since the end of the 80s, Denmark has invested massively in wind power to satisfy its energy requirements. With installed generating capacity of 3,000 MWe in 2003 delivered by some 5,500 wind turbines, the Danes own no less than 12% of the world's wind power generation base!

"DESPITE THE USE OF WIND ENERGY, DENMARK HAS ONE OF THE HIGHEST LEVELS OF $CO_2$ EMISSIONS."

## TRUE OR FALSE

**The Danish land-based wind farms produce more energy than the offshore wind farms.**

FALSE

Multipliers on the offshore turbines increase blade rotation speed by 10% compared with the land-based versions, thus generating more electricity.

Denmark's commitment to wind power is remarkable for a country of only five million inhabitants. And yet the same country has Europe's worst record for $CO_2$ production per capita…

### An early commitment to wind power

Denmark's installed wind power capacity is both land-based and offshore. The largest land-based site, at Syltholm on the island of Lolland, has a cumulative output of 26 MWe from 35 turbines. The next largest is at Rejsby Hede, a 40-turbine site opened in 1995 close to the town of Tønder, a particularly windy region in southern Jutland. Historically, this site was the largest wind farm in Denmark with a total output of 24 MWe. Due to the high population density and the difficulty of finding suitable land-based sites, the Danish authorities were pushed to progressively phase in offshore wind farms, despite the higher construction costs. A wind farm of this type – the first in the world – was thus built in 1991 in the Baltic sea at Vindeby, close to the island of Lolland in southern Denmark. The two largest offshore wind farms, each about 160 MWe, are in Horns Rev and Nysted. The Nysted site, about 10 km south of Lolland island, was built in 2003 and has no less than 72 high-power turbines (2.3 MWe) that can satisfy the electricity requirements of 110,000 homes. The Horns Rev site, about 20 km off the Jutland coast in the North Sea, is the world record


holder for the number of turbines: 80 units! Another offshore site is close to the port of Copenhagen, where 20 turbines produce 3% of the electricity consumed in the Danish capital. It is a paradox that such a significant commitment to wind power has not prevented this small Scandinavian country from being one of the European Union's biggest producers of $CO_2$, with 53 million metric tons of emissions in 2002, i.e., 10 metric tons per year per inhabitant, or 1.5 kg of $CO_2$ per kWh of electric power.

### Paradox and explanation

This paradox can be explained quite simply by the still very high proportion of coal-fired power stations, which by themselves account for 80% of this electricity. The interest shown by the Danish authorities for wind power over the last few decades has neither lowered consumption of other types of energy nor reduced greenhouse gas emissions.

### Future choices

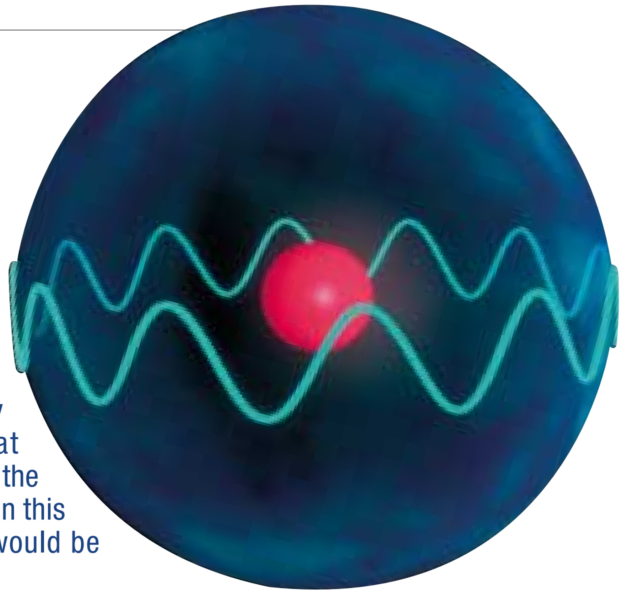
To go further, perhaps an even more ambitious wind power program would have been needed. However – and this is the second part of the Danish paradox – the further use of this type of equipment has been officially halted because increasing the number of wind farms is now considered to be the wrong way to go. Measures to support the use of renewable energies were in the end not enough to reduce $CO_2$ emissions, meaning that other sources of non-polluting energy must be developed. Based on the recommendations in the 2002 report "Forecast of Denmark's energy consumption and emissions", the current government has frozen three of the five offshore wind farm construction projects that were to be built by 2008 for a total investment of 673 million euros and would have produced 450 MWe. The government considered that the initial target of 20% of energy consumption in 2003 through renewables had already been more than fulfilled with a share of 27% of electricity production. Denmark can therefore afford to pause temporarily to avoid the impact of additional expenses on weighing down business competitiveness and the financial burden to society. And yet the "Energy 21" plan developed in 1996 wanted to go even further, as it had set the target of 4,100 MWe of offshore energy by 2030. That amount of capacity would have generated some 14 TWh of electricity per year, or practically half of Denmark's energy consumption of 31 TWh/year, but this was unrealistic. ■

## THE FALLING COST OF WIND POWER

The profitability of offshore wind farms has increased over the last few years due to a drop in the price of wind turbines. The cost of wind power is on average €0.048 per kWh, assuming a service life of 20 years, of which 20% are operating and maintenance costs. That is practically twice the kWh price invoiced by Nordpool (€0.025/kWh), the Scandinavian electricity exchange network. However, for wind power, there are very significant variations in value depending on depth, distance from shore and the related connection costs.

SCIENCE

# A plan for hydrogen



On 10 March 2004, the U.S. Department of Energy (DOE) officially launched its "Hydrogen Posture Plan", which outlines technology milestones to be reached over the next decade to achieve commercial applications in 2015 – 2020. Secretary of Energy Spencer Abraham announced that $227 million have been earmarked in the fiscal year 2005 budget for research in this area. A hydrogen-based economy would be a veritable revolution. ■

ENERGY

# Low-speed wind turbines

Rather than installing wind farms at very windy sites, why not try sites that are less windy? The U.S. undersecretary for energy caused a sensation on 29 March at the Windpower 2004 Conference in Chicago by presenting this apparently paradoxical point of view. Up until now, sites considered to be suitable for wind farms were also usually located in areas far from consumption centers, resulting in additional costs to build the power lines needed to transport the energy. As part of the National Energy Plan launched by President Bush, the United States thus intends to work on slow-rotation wind turbine technology. ■

PROJECT

# Coming soon: miniature fuel cells

A long-duration portable fuel cell was presented at the last Hanover trade fair by the Fraunhofer Institut für Solare Energie-systeme (Ise) of Fribourg, Germany. The battery, which is powered by a hydrogen cartridge, is designed for professional television and movie cameras and can produce 40 W of power for eight hours of filming time. The producers of this new battery will develop versions for other applications, such as micro fuel cells that operate with methanol cartridges. They could be commercially available in less than a year for users of cell phones and computers. ■

MEETINGS

# Renewable energy: international community renews commitment

Bonn conference, 2 June 2004.

In its final statement, the International Conference for Renewable Energies held in Bonn in early June used a phrase from the Johannesburg sustainable development summit, saying that it is necessary *"to increase the global share of renewable energies substantially with a sense of urgency"*. The conference, attended by 150 countries, gave the Chinese the opportunity to announce their intention to increase the share of electricity generated by renewable energy sources to 10%. The World Bank announced a 20% increase per year over the next five years for guaranteed loans supporting renewable energies. France and Germany announced their intention to build wind farms together to minimize construction and network connection costs. Offshore wind farms could be built for a unit cost of 250 to 500 million euros. It should be noted that Germany is the world champion in wind power, ahead of the United States, with an installed generating capacity of around 15,000 MW. ■



INTERNET

# THE ALTERNATIVES SELECTION

A quarterly selection of sites where you can get more information about the topics covered.

**THE FOLLOWING SITES ARE WORTH A LOOK FOR MORE INFORMATION ON RADIOACTIVE WASTE:**

www.worldnuclear.org

IN FRENCH AND ENGLISH

Website of NucNet, an international agency headquartered in Switzerland with member organizations in more than 50 countries. Provides nuclear-related information from more than 400 sources at nuclear power stations and other nuclear facilities, government ministries and research institutes. The NucNet database is continuously authenticated and updated.

www.andra.fr

IN FRENCH AND ENGLISH

Website of the French national radioactive waste management agency (ANDRA) presenting the various stages involved in managing nuclear waste. General information on radioactivity is available and a map of France gives an overview of the sites used for waste storage.

www.radwaste.org/disposal.htm

IN ENGLISH


An extremely thorough and well-documented site on radioactive waste management. Gives a list of 9,000 links on nuclear subjects in general, carefully selected but without distinction as to opinion (governments, research centers, companies, pro- and anti-nuclear organizations).

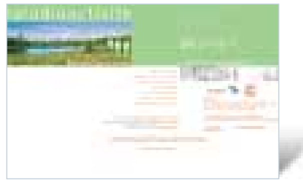
www.nea.fr

IN FRENCH AND ENGLISH

Website for the Nuclear Energy Agency (NEA), part of the OECD (Organization for Economic Cooperation and Development), whose mission is to assist member states in maintaining and developing the scientific, technological and legal bases required for the safe use of nuclear energy. Radioactive waste management is one of about ten themes covered.

www.laradioactivite.com

IN FRENCH



Website developed by EDP-Sciences (Editions of the French Physics Society), with the support of the National Center for Scientific Research (CNRS). The highly educational content addresses the problem of radioactive waste very clearly.

READING LIST

# Should we be afraid of radioactive waste?

The storage and disposal of radioactive waste have a bad public image. And the multitude of articles and scientific work aiming to give a clearer understanding has not been able to change this. Based on a survey conducted by CREDOC on French perceptions of this question, the book integrates contributions from a variety of well-known people, and concludes that the scientific debate on this subject needs to be reopened.

**Under the direction of Michèle Chouchan, ANDRA. 264 pages, available from ANDRA.**


# Does nuclear energy have a future?

The answer from the author, a past director of the French Atomic Energy Commission's (CEA) nuclear physics lab and currently scientific advisor to CNRS and responsible for energy programs at the French Physics Society, is "yes" to the question posed in the title of this book. Mankind, according to Hervé Nifenecker, cannot do without nuclear energy to generate the electricity it needs and to reduce the production of $CO_2$. Deployment of sustainable nuclear energy is, in his opinion, consistent with current technical and economic conditions.

**By Hervé Nifenecker, Éditions Le Pommier, 64 pages.**

# interactive...

Answers to frequently asked questions

### What will replace uranium in nuclear power stations, for which there are currently 40 to 50 years of recoverable reserves?

**Question from Mr. Michel S., Angoulême (Charente, France)**

The International Atomic Energy Agency (IAEA) and the World Nuclear Association (WNA) estimate that there are currently a little over 2 million metric tons of uranium ore reserves recoverable at a cost of less than $40/kg. This corresponds to 30 years of operations of current reactors. However, these resources are underestimated, since there is currently no significant exploration effort in view of the size of available stocks. At an accepted production cost of $130 – which would not be prohibitive, given that uranium represents only 5% of the cost of nuclear-generated electricity – there would then be enough reserves for 60 years. Uranium can be replaced in nuclear fuel by other fissile elements, such as plutonium, which does not however occur naturally. The only source of plutonium is from decommissioned nuclear weapons or from the treatment of used fuel from current reactors. It is already used in this form and mixed with uranium to make "Mox", which slows the consumption of current reserves. Another possibility is to optimize the use of uranium 238 (whose fertile nuclei are only slightly fissile) by bombarding it with fast neutrons: this is the principle underlying fast breeder reactors, whose development is currently on hold but which would allow a factor 50 increase of the fissile materials used.

### A few years ago, we were told that nuclear energy had a future only if fast breeder reactors were developed. If China and other countries continue to develop nuclear power stations, the current uranium reserves will be quickly depleted...

**Question from Mr. Raymond B., Touvre (Charente, France)**

It is true that after the oil shocks of 1973 and 1979 the industrialized nations feared an energy shortage and that, with the prospect of significant development of nuclear energy, uranium reserves appeared to be relatively limited. By enabling these reserves to be multiplied by a factor of 50 to 100 – by using all uranium isotopes – the fast neutron reactor (breeder reactor) appeared to have a bright future. But when crude oil then fell back to its initial price level and the pessimistic forecasts based on crude oil resources in 2000 did not materialize, fast breeder reactors lost their attraction. The cost associated with operations that were more complex than originally foreseen, the risks associated with the use of liquid sodium for cooling and, above all, the pressure of environmentalist movements prompted the French government's decision, in September 1997, to dismantle the "Superphénix" prototype, even though it had already reached the industrial phase by generating electricity for the grid. Regarding uranium reserves, see the response to the left.

### Is there a difference in electricity losses from overhead and underground power lines?

**Question from Mr. Hervé L., Saulieu (Côte-d'Or, France)**

For a given transit capacity (same voltage), in theory a buried cable has fewer losses than an overhead line, at least for low and medium voltages. However, it is difficult to give figures because, as the specialists from the EDF distribution department explain, this varies as a function of numerous parameters (cable type and cross-section, voltage, etc.). Buried cables have their own drawbacks, such as the production of "reactive" energy, which is not directly usable. Due to the "resistance" of the conducting wires, line losses are proportionate to current squared (Ohm's law). This is why current is kept as low as possible, which increases voltage proportionately: by up to 400,000 volts for extra high voltages (EHV). Unfortunately, in the case of EHV, buried cables result in the highest loss in transported energy. To overcome this, substations have to be built every 50 to 80 km for 90,000-volt lines, every 25 to 30 km for 225,000-volt lines and every 15 to 20 km for 400,000-volt lines. In that case, the cost would be 10 to 12 times greater than for overhead lines.

## In the next issue...

Several readers have asked about the operation of wind turbines, their efficiency, etc. *Alternatives* will devote its next Decryption article to this subject to answer as fully as possible.

## SEND US YOUR QUESTIONS

This is your space and your opportunity to send us your questions. We will respond in future issues.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