NEW AND UPGRADED R&D FACILITIES IN FRANCE, IN SUPPORT OF NUCLEAR DEVELOPMENT IN THE XXIST CENTURY

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ABSTRACT

In Europe and North America, most of the R&D facilities, the results of which were essential in developing nuclear power to the point where it supplies 30% of the electricity generated in OECD countries, were built in the sixties, or even earlier. Even in France, where the major industrial development of nuclear power took place during the decade following 1974 and the first oil crisis, many facilities dedicated to nuclear R&D are getting old. This concerns the reactors, their fuel, and the fuel cycle including the management and disposal of radioactive wastes.

In the next century, nuclear energy is expected to play a significant part in the supply of electricity to the world, and certainly to France. To this purpose, we need to keep nuclear power safe, economically competitive, and well accepted by the Public. This, in turn, calls for innovation, fuelled by R&D.

To meet this challenge, France in the next decades, is developing or planning major constructions and upgrading : research reactor, metallurgical and radiochemical « hot » laboratories, laser enrichment facility, etc. Many of these facilities will be used by researchers outside France and outside Europe.

INTRODUCTION

In the year 1996, nuclear reactors throughout the world have generated 2 300 billion kWh of electricity. This may be a far cry from what was expected in the seventies, but it is equivalent to more than the oil production of Saudi Arabia, or to the total world electricity production in 1960. In 40 years only, starting from zero, nuclear power accounts nowadays for 18 % of the world electricity generation, a figure that reaches 30 % for OECD and more than 75 % for France.

This tremendous industrial achievement was built upon a huge and world-wide R&D effort, starting with the Manhattan Project itself, and followed by Atoms for Peace. All this R&D was carried out with an impressive array of dedicated facilities: critical assemblies, research and irradiation reactors, hydraulic and thermalhydraulic loops, component test facilities, hot laboratories for fuel examination, metallurgy and solid state physics, radiochemistry, enrichment and reprocessing pilot facilities, power reactor « demos » and prototypes, not to forget many training facilities. Just to give a measure of this flourish, more than 300 research reactors of one kind or the other were built and operated. Some of these early facilities were built on a scale we could hardly dream of today, like the EMAD hot cell in the Nevada Test Site, able to engulf a full-size railroad engine, complete with its heavy shielding and the rocket propulsion nuclear reactor it was designed to carry, or the more recent FFTF, a 400 MWth irradiation reactor built in Hanford to test FBR fuel assemblies' behaviour.

But many of these experimental facilities are now decommissioned or dismantled, and most of those still in operation are old, and their lifetime will not extend beyond very few decades. Conversely, nuclear power is likely to be with us for a much longer time period, provided, *inter alia*, that continuous improvements are implemented, many of which shall require R&D results, and therefore R&D facilities.

THE NEED FOR NUCLEAR POWER

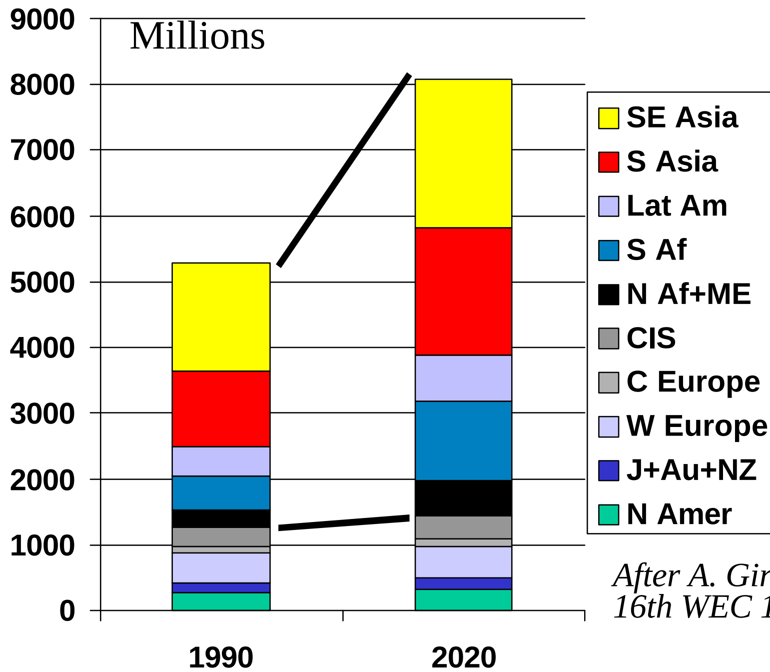
The real purpose of forecasting is not to predict a future that shall always remain uncertain but to evaluate how decisions taken - or not taken - today may affect whatever future lies ahead. This being said, some features of the future are less uncertain than others. Everybody agrees today that the world population, which experienced a tremendous and unprecedented growth in the second half of the XX^{th} century, is bound to grow further during the first half of the XXI^{st}. The size of the population increase is debated but, from the 6 billion people we are today, mankind should probably number 9 billion or so by the middle of the next century, and may still be growing, hopefully at a much slower rate.

Another fact that amounts to a certainty is that we keep depleting fossil energy resources, coal oil and gas, at a rate that is larger by *many* orders of magnitude than the rate at which Mother Earth synthesised them through her own geochemical processes. This is true even though the actual magnitude of these resources remains all the less certain that any figure refers (and usually refers only implicitly) to a given state of the extraction technology and to a given cost of extraction, not to mention the uncertainties linked to geological extrapolations in many places of Earth where actual exploration has been cursory, at best.

Last, but not least, billions of people live today in a state of poverty, that contrasts dramatically with the standard of living in our affluent and sometimes wasteful societies in Europe and North America. This is ethically unacceptable and politically very dangerous. Much is said - more said than done - nowadays about *sustainable* development, and we must hope that their development to-morrow can be less energy intensive - and less polluting - than our own development was yesterday. Nevertheless, from our past experience, and from what we can witness today in the « really developing » countries of East Asia, development needs a lot of energy, a lot of electricity. As was recently quoted by the former Director General of IAEA (H. Blix, 1997), the average Swede uses annually 15 000 kWh, to be compared to less than 100 kWh/y per capita in Bangladesh or Tanzania. And the yearly individual electricity consumption in South Korea rose from 70 kWh in 1960 to 5000 kWh today.

From these premises, all the experts agree than the world energy consumption, presently equivalent to some 9 billion metric tons of oil per year, all energy sources included, should at least double during the next century, even assuming a stabilisation in Western Europe and North America, and a much too limited development in Africa. This was, for instance, made very clear during the last World Energy Conference held in Tokyo in 1995, as illustrated on Figures 1 and 2 (A. Giraud, 1995). As early as 2020, the world energy consumption may be of the order of 15000 Mtoe/y, a huge figure indeed.

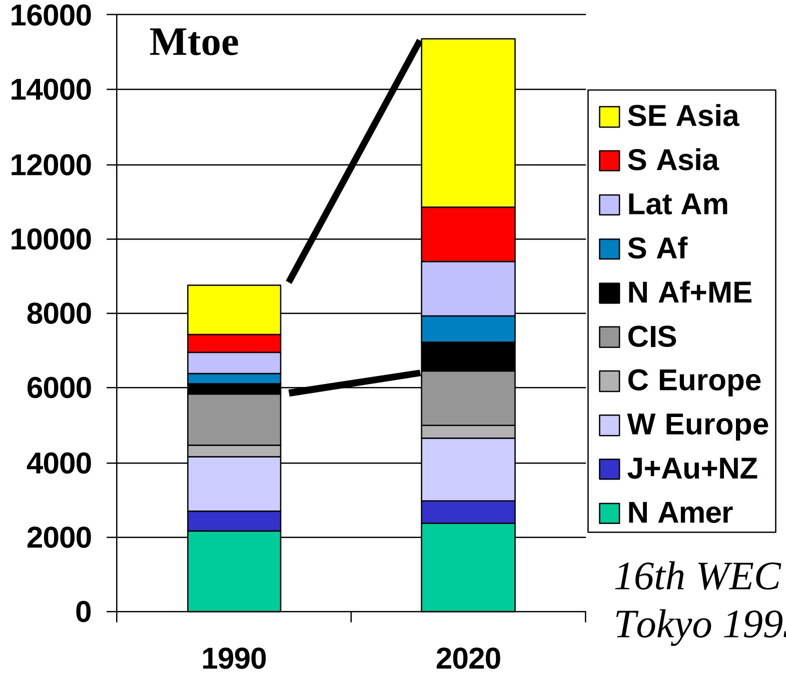
Population Transfer 1990-2020



After A. Giraud
16th WEC 1995

BB/PBNC'98 Figure 1

Energy Consumption Shift



16th WEC Tokyo 1995

BB/PBNC'98 Figure 2

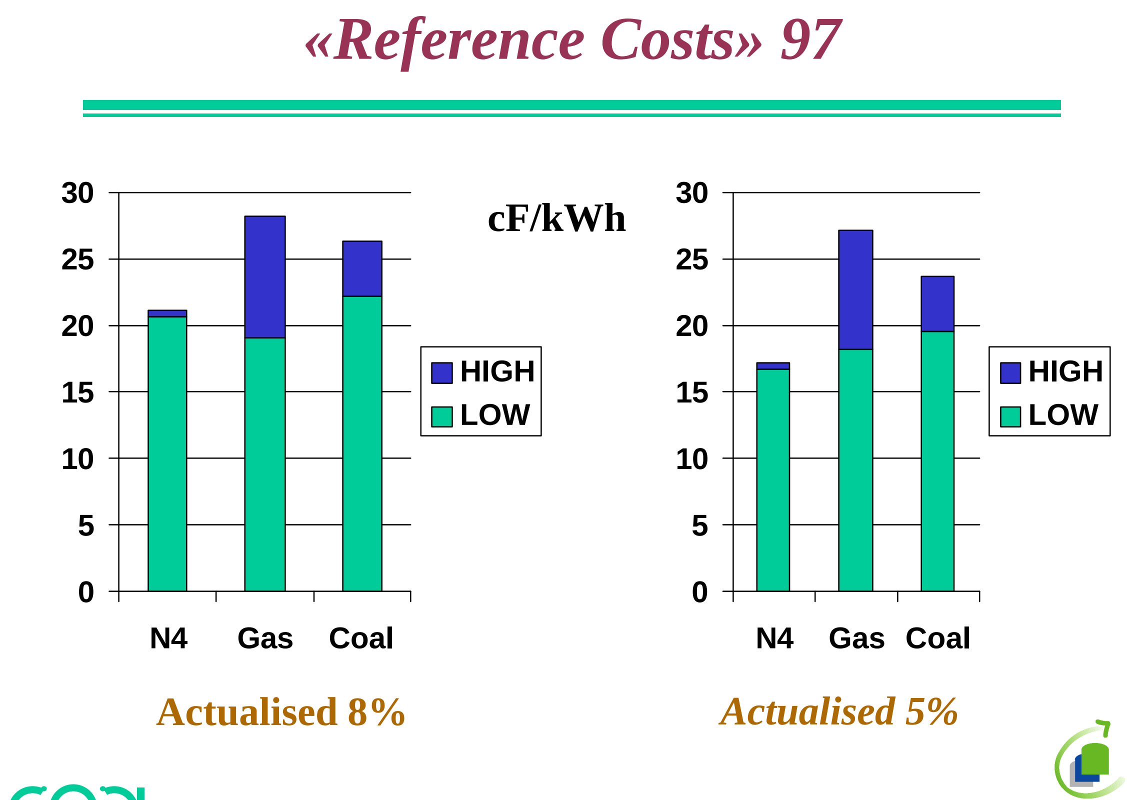
Supplying such an amount of energy to cater for mankind's needs will prove a formidable challenge, so formidable that there is no need to dwell upon the specific merits of nuclear power (reliability and safety, cost almost insensitive to mineral resources price variation, independence from imports, minimal impact on environment, no greenhouse-gases emission etc.) because we shall have to make use of *every* available energy source: coal, oil, gas, hydro, wood, sun, wind, *and* nuclear power. Contrary to what is said by some opponents, it is not a matter of choosing between nuclear power and energy conservation: each TWh not generated by nuclear power will make another dent in the Earth fossil stockpile. If the technologically advanced countries that can implement nuclear power safely and economically elect not to do so, it can only be at the expenses of the less developed countries that do not have the same freedom of choice.

In France, we are very happy to benefit today from this clean, safe and economic source of power, and we certainly intend to keep doing as far as the eye can see.

THE NEED FOR NUCLEAR R&D

The fact that we shall need nuclear power does not, by itself, guarantee that we shall have it. There are at least two hurdles in the way to its continued development: economics and public acceptance. In both cases, R&D should aim at overcoming these hurdles.

Between 1974 and 1986, between the first oil crisis and the « oil backlash », nuclear power enjoyed a fat margin of competitiveness against its fossil fuel competitors. This is no longer the case: oil and gas prices are very low on the world market, and fossil fired plants, especially combined cycle gas turbines, have greatly improved their efficiency, taking full advantage of the technological advances triggered by the aerospace industry. Today, in France, though existing reactors generate very cheap electricity, *future* nuclear power remains competitive only as a baseload source (Figure 3). It is difficult and highly debatable to predict when the so-called « gas bubble » will collapse, but it is easy to foresee that, victim of its own success, gas will follow the pattern of oil sooner or later.



BB/PBNC'98 Figure 3

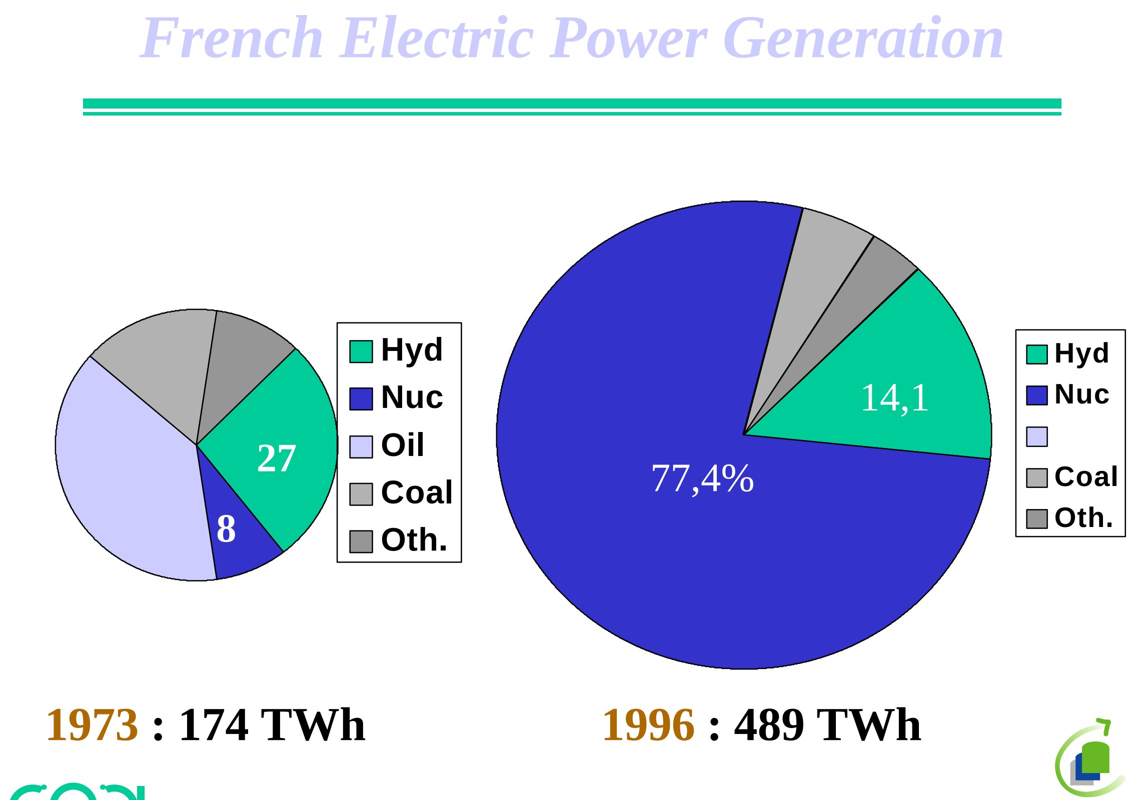
It is therefore of utmost importance for nuclear energy to regain some grounds on the economics battlefield. All the more since it is facing more and more demanding safety criteria and requirements, as expressed in the US Utility Requirements Document or the European Utility Requirements (see EUR).

The battle for competitiveness is fought on two fields, the reactor and the fuel cycle, and on both battlefields R&D can and should help, but there is a basic difference in that reactors, and even more fuel cycle facilities, evolve big step by big step, while the fuel is « disposable » and can evolve and improve continuously.

France and Germany are now designing EPR, the most advanced LWR, to replace older European nuclear reactors in the early decades of the next century. Such a reactor designed in the late 90s, ordered in the early 00s, would still be in operation by 2060, and very little can be done to modify it, once it is built, to improve its competitiveness (gains can and will be realized on the side of O&M, but it is beyond the scope of this paper). On the other hand it is a safe bet to assume that the fuel elements loaded in EPR in 1960 will have much better performances in terms of safety and economics than those constituting its first load.

Therefore, not surprisingly, most of the facilities described thereafter will concern the nuclear fuel: design, fabrication, behaviour under normal, transient and accidental conditions, and fuel cycle, including at last waste management.

This exposé will now focus on France. With 77% of its electricity generated by nuclear reactors, as shown on Figure 4, and being one of the largest supplier of fuel services in the world, France has, among the industrialized countries, the highest stakes in maintaining nuclear energy alive on the medium and long term. That is why provisions are now being made to ensure that new and upgraded facilities will be available to pursue needed nuclear R&D in the next century.



BB/PBNC’98 Figure 4

IRRADIATION FACILITIES

Many experimental reactors offer today irradiation services to test fuel and materials under representative conditions. Even though full size qualification test are more and more performed directly in power reactors with so-called « precursor » fuel elements, dedicated reactors offer some unique features: controlled experimental conditions, full instrumentation and measures, accelerated test with higher neutron fluxes, and irradiation under conditions not allowed in commercial plants, like fast transients, abnormal temperature or chemistry or even fuel disruption or melting.

In the European Union, at least six such reactors are competing on this market, each of them with some specific qualities but with basically similar capacities. Most of them are also used outside the field of nuclear power, like radioisotopes production for medical or industrial purposes for instance, but this too is outside our present scope.

All these reactors were put in operation in the late 50s or early 60s. They have been kept in good shape - the safety authorities look to it! - and have undergone a series of revamping operations, but the fact remains that by 2005, they will be 40 years old or more. One cannot rely upon them to support nuclear fuel and materials development throughout the first half of the XXI^st^ century.

To face this situation, France has launched a two-pronged operation. Just before definitively shutting down our SILOE reactor, in which outstanding research was carried out in Grenoble between 1963 and 1997, we have performed a new revamping of OSIRIS in Saclay (J. Guidez et al., 1996), to make sure it remains state-of-the-art in the nest decade at least. In parallel, we are now performing the basic design of the future « Réacteur Jules Horowitz », RJH, to take the relay from 2005 to 2050.

Previously described as « REX 2000 » (Merchie F. et A. 1996), this new irradiation facility will have roughly twice the performances of OSIRIS. Its site has been selected on the Cadarache nuclear research centre of CEA. As it appears that the RJH may be the only operating Materials and Fuel testing reactor in western Europe in a few decades, emphasis has been given to flexibility of use, accessibility and instrumentation rather than maximum neutron flux. In view, however, of the recent decision by the French government to abandon the SUPERPHÉNIX prototype FBR, more thought is presently being given to increase the capability to carry out in the RJH FBR-linked R&D.

In addition, the experimental value of a MTR lies as much in the loops and facilities around the core as in the core performances. All the know-how acquired in Grenoble - which is now being transferred to OSIRIS - and in Saclay will fully benefit the RJH when times come for it to replace OSIRIS.

DEDICATED REACTORS

Outside of MTR and neutron sources for basic research in physics and biosciences, a few dedicated reactors play a specific part in support of the nuclear energy development. The so-called « critical facilities » are very important to validate reactor physics codes and data. France possesses EOLE for LWR physics and MASURCA for FBR physics. Being zero-power, those facilities do not age, and we simply intend to keep them ship-shape.

Facilities dedicated to research in Safety, like PHEBUS and CABRI-SCARABEE, have also very short period of neutron production over their lifetime. Upgrading are considered, notably to extend the capabilities of CABRI to carry out very fast reactivity transients, representative of strong reactivity insertion, in a water loop, in addition to its present sodium loop. No completely new facility appears needed at this time.

« HOT » LABORATORIES FOR FUEL AND MATERIALS R&D

Hot laboratories constitute an indispensable complement of Fuel and Materials testing Reactors, in order to carry out the post-irradiation examinations.

France used to have a number of such facilities, too many of them and ageing. The CEA has undertaken to concentrate the whole set-up:

- The « RM2 » laboratory, operated from 1968 to 1981 at Fontenay-aux-Roses is presently being dismantled ;
- The fuel disassembly and NDE[1] facility « LSAI » in Marcoule will be kept in operation at least till the dismantling of PHÉNIX and SUPERPHÉNIX ;
- The similar facility « LDAC » in Cadarache is definitely shut down, and will be dismantled.

But in the meantime we have launched (Lefevre M. and Girard J-Ph. 1997) a comprehensive revamping of the remaining facilities:

[1] Non Destructive Examination, or Non Destructive Testing

- In Saclay, the « LECI » which had been used since 1959 for irradiated fuel PIE[2], is, since 1995, extended and renewed to be dedicated to the examination and mechanical characterisation of non-fuel irradiated material samples, with the most advanced techniques available;
- All the fuel examination facilities and equipment will be concentrated on the twin laboratory LECA-STAR. Completely revamped, this renewed facility will perform examination of full size fuel pins, including destructive analysis and « refabrication » of already irradiated fuel for further irradiation/experimentation (to melt preirradiated fuel in the PHEBUS-FP experiments, or to perform power « ramping » for instance). Close to the RJH, it will constitute with this reactor a complete fuel R&D centre for the fist half of the next century.

During all the transition period, the « LAMA » hot laboratory in Grenoble will continue operation and provide the necessary flexibility when other equipment is unavailable, due to revamping operations. Afterward, the LAMA shall be used for the early stages of the dismantling of the SILOE reactor, and then, shut-down.

To complete the picture, one should mention the « warm » laboratory « LEFCA » in Cadarache, dedicated to the fabrication of plutonium bearing experimental fuel : this modern facility is recent enough not to be a part to this revamping operation.

FUEL CYCLE FACILITIES, FRONT END

The present situation of the fuel cycle research facilities can be viewed as a token of the maturity of the nuclear industry which operates an increasing number of large scale industrial facilities, both in the front and in the back end of the nuclear fuel cycle. This means that a second generation of R&D facilities is now appearing or is under development with new medium or long range goals.

The commercially available enriched uranium resources are produced by gaseous diffusion or ultra centrifugation plants which, for most of them, have been in operation for about 20 and up to 40 years.

In France the R&D present situation in uranium enrichment results from the decision taken in 1985 to develop a laser atomic photo-ionisation process, currently known as SILVA, which involves a large program carried out jointly by CEA and COGEMA. The corresponding R&D facility is called ASTER where the physics and technology necessary to implement this process can be tested on a scale compatible with a future industrial enrichment plant.

The goal of the ASTER experimental program (Guyot J. et al. 1996) is to provide in 1997 all the proper data for a general assessment of the SILVA process, along with its economics.

The decision taken in 1985 to develop the SILVA program led consequently to the dismantling of all the R&D facilities which were developed previously for the other processes : gaseous diffusion, ultra centrifugation and also chemical exchange.

REPROCESSING FACILITIES

Three new large industrial reprocessing plants have been put into operation successively since 1990 : the UP3 plant in 1990, the UP2 800 plant in 1994, both in France at La Hague, and the THORP facility in 1994 at Sellafield in UK.

All these industrial realizations are the result of large and continuous R&D programs which started in the fifties. During the 1975-1990 period, much progress and improvements were progressively qualified. The

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[2] Post-Irradiation Examination, non-destructive or destructive.

reprocessing capacity improved from 1t/day to 4t/day with a decreasing amount of plutonium in waste from 1 % to 0.1 %. The feasibility of the reprocessing of FBR fuel, then of the LWR MOX fuel, was demonstrated.

For the period starting schematically from 1990 and onwards new R&D programs are under development to bring improvements or new solutions to different aspects of reprocessing such as :

- waste volume reduction
- vitrification research
- high burn-up and MOX fuel reprocessing
- cost reduction of processes
- partitioning of long-lived radionuclides for transmutation
- chemical modelling techniques (molecules and processes).

The SPIN program carried out in France jointly by CEA and COGEMA is structured into two main parts called PURETEX and ACTINEX. PURETEX is a short-mid term program with the target of waste volume reduction from 1.5 m^3/tu to 0.5 m^3/tu in 2000. ACTINEX is a long term program with the goal to separate selected long-lived radionuclides for transmutation.

Up to 1995 the reprocessing R&D programs were carried out at Fontenay-aux-Roses in the so-called building 18 that represented about 10,000 m^2 of laboratories and associated utilities. These programs are now under development at Marcoule in a new facility called « ATALANTE » not yet totally completed (Saudray D. et al. 1996) that will include:

- high and medium activity laboratories for flexible, small scale process integration,
- safety and $\alpha\ \beta\ \gamma$ radioprotection for 20 kg of irradiated fuel at most (several pins of LWR UOX or MOX fuel),
- flow rates in chemical contactors up to 1 l/h, with possible small diameter pulsed columns, mixer settlers, centrifuge contactors experimentation. Run duration will be of a few tens of hours,
- capability of nearby HA chemical analysis, α glove boxes for MA analysis equipment, liquid waste storage and treatment, solid products transformation.

This facility replaces the former one in Fontenay-aux-Roses that is now in the cleaning stage before dismantling.

FUEL CYCLE FACILITIES: WASTE MANAGEMENT

This is a major field for R&D in many countries, with new approaches since 1990. The emphasis in France is put on waste characterisation, new conditioning for long-term surface or sub-surface storage and specific R&D programs related to geological disposal, allowing the French Parliament to state his position in 2006 on the implementation of a deep underground disposal. This R&D program is carried out jointly by CEA and ANDRA.

The programs related to waste characterisation, conditioning and long term behaviour assessment are developed in a specific facility called CHICADE (Rozain JP. et al. 1996)

The R&D programs related to deep geological disposal concern the knowledge of long term behaviour of glasses, cements, bitumens, waste packaging, and also of the engineered barriers. They include the understanding of retention-migration radionuclides processes in various conditions. Part of these programs are developed in existing or planned underground laboratories: about 16 of them are already in use in different countries.

Deep underground laboratories are planned in France, located in selected geological layer formations in order to qualify the corresponding geological environment as a potential deep underground disposal.

Three geological sites have been selected, two in clay (GARD and MEUSE, HAUTE-MARNE) and one in granite (VIENNE). The laboratories would be at a depth of respectively 700 m, 400 m and 500 m. Licensing procedures have just been completed on all three sites. The realisations are scheduled to last between 3 to 4 years starting in 1998.

CONCLUSION

Because it relies strongly on nuclear electricity and believes that fission power should not be a mere parenthesis in mankind's history of energy use, France is implementing a ***comprehensive*** program of building and upgrading R&D facilities, to support nuclear developments in the next century.

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