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EVALUATION OF THE PROBLEMS ASSOCIATED WITH ENEL'S IRRADIATED FUEL MANAGEMENT

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ABSTRACT

The present difficulties in the reprocessing field, which will continue for a period of time not easily definable, impose on the nuclear utilities the research of adequate solutions to solve the problem associated with storage of the fuels discharged by the nuclear power stations in operation. In this context, the paper examines the technical aspects of the various possible alternatives and on the basis of the Italian nuclear program, possible storage strategies are discussed in the assumption of the development of an adequate oxide-fuel reprocessing capacity. The problems related to storage in pools at the station or away from reactor are described in the light of the recent experience made in Italy with the adaptation of an old pool reactor out of service, that is, the Avogadro reactor in Saluggia, to store the fuels of the stations now in operation.

Finally some economic aspects are considered in order to ascertain their impact on the cost of energy produced.

1. Foreword

Because of several difficulties that are mainly of a technical, economic and also political nature, the industry of the chemical reprocessing of the irradiated fuel discharged from light-water reactor stations is going throught a crisis all over the world, even though with different intensity and different aspects from one country to another. The technical difficulties concern on one hand the development of certain stages of the chemical reprocessing technology and on the other the simultaneous evolution, still under way, of the legislation on health physics and environmental protection. These difficulties could not but reflect on the reprocessing costs, which have become very high and unstable. The difficulties are accompanied by the difficulties arising from desire for non-proliferation on nuclear weapons. and particularly from the potential risk of uncontrolled diffusion of plutonium for industrial uses. In this connection we are all aware of the American policy announced by President Carter in April 1977 and stressed by the Non-Proliferation Act in March 1978. Today, the USA are exerting great pressure in order to extend to other countries their decision of postponing irradiated fuel reprocessing in order to delay the transition to the so-called "plutonium economy" as much as possible.

In this situation of a lack of adequate reprocessing capacity it is evidently necessary to store the irradiated fuel for an period of time to dayunknown. Storage in the spent fuel pool, however, should be considered only a temporary necessity and should not be taken as a provision for non proliferation because in this case, in our opinion, the opposite effect would be reached. In fact, the build-up of large amounts of irradiated fuel would constitute a "plutonium mine" that would grow with time and become more accessible. In fact, as Marshall states [1], the plutonium contained in irradiated fuel assemblies may be inaccessible initially because of its high radioactivity, but it become less so as time goes by because the radioactivity decays and the reprocessing operations become relatively simpler.

To reduce the risk of proliferation it is thus necessary to burn the plutonium in reactors; in this case the build-up of plutonium grows proportionately only with the installed capacity and not with its integral, and besides it is totally inacessible because it is in the reactors. As a result, plutonium recycle is a policy that would solve not only the problem of a better exploitation of the energy content of uranium but also, in the long run, the problem of nuclear weapon proliferation.

Therefore, from the standpoint of containing nuclear proliferation, the benefits of foregoing reprocessing appear to be rather questionable. On the other hand, each country would have to make a decision on fuel reprocessing or not bearing in mind its own energy requirements and the cost of either decision. For instance, at present the USA depend on foreign supplies only for 18% of her energy requirements [2]. She has considerable reserves of coal and about one third of the world's ascertained reserves of uranium at less than 30 $/1b. With such huge energy resources, the USA can well defer commercial reprocessing and the advent of fast breeder reactors: the cost would only be a poor utilization of the uranium, which could be recovered later on anyhow.

The situation in Europe, and particulatly in Italy, is quite different. Italy depends on foreign resources for 83.5% of its energy requirements [3]. The only energy sources of some magnitude are natural gas deposits and the hydroelectric potential, both under intense exploitation today. The development of fast breeder reactors, which would entail the availability of reprocessing, would in the long run allow Italy to achieve full autonomy, at least in the generation of electricity. On the other hand by signing the Non-Proliferation Treaty, Italy has already foregone possession of nuclear weapons.

It is within the framework of this political vision that the Italian energy plan approved by the Parliament at the end of 1977 provided for a national reprocessing plant and it is in this light that the question of storage of ENEL's irradiated fuel should be viewed.

2. Storage

Lacking reprocessing services we must find a manner in which to take care of the irradiated fuel that is discharged each year from nuclear power stations. Power utilities must solve this problem in the very short term without waiting to see the conclusion of the reprocessing issue. The point for concerh is that the lack of any solution, albeit of a temporary nature, may lead to clogging of the station pools, through which the fuel must go anyhow, and thus interfere with normal plant operation.

The possible alternatives to reprocessing are diverse and differ in the final destination of the irradiated fuel:

- Short-term storage pending availability of reprocessing services
- Storage pending the definition of the technical and/or statutory procedures for reprocessing (stowaway cycle)
- Storage pending ultimate disposal of the irradiated fuel as a waste (throwaway' cycle).

Whatever the final destination, every alternative requires initial storage of the fuel in special pools for longer or shorter periods. Apart from the ends, storage has become an important stage of the fuel cycle with its own characteristics and problems On the contrary, up to a few years ago storage was considered a transient operation dictated exclusively by logistics.

Storage in the station pools (that is, adjacent to the reactors) in special racks that allow high density storage of irradiated fuel would allow a deferment of the decision on the destination of the fuel by a period that may vary between five and eight years, depending on the particular cases. An increase in the station pool storage capacity depends on many factors, especially for first-generation stations whose structures are not always adequate or easilyadaptable to the criteria adopted today for new power stations.

The storage of the fuel in pools that are away from the stations--whether centralized national or international storage facilities or old nuclear facilities adapted for this purpose--would avoid the need to operate the stations with the pools full of fuel and thus even the least loss of operational flexibility that is essential for proper station operation (possibility of discharging the whole core into the pool at any time; underwater jobs, for instance ro repair faulty fuel assemblies etc)

The construction of a centralized storage facility requires rather long times (on the order of four years) and entails considerable difficulties from the siting standpoint. because it would preferably have to be built at the site of an abuilding reprocessing plant if not actually at the site selected for an interregional fuel cycle center.

The adaption of the pools of old research reactors for storage purposes may usefully contribute to alleviate the problem in the short term, and thus allow more time to carry out other projects for the solution of the problem in the short and long terms

However, it should be pointed out that at the present state of the art, pool storage cannot be envisaged for more than 20 or 30 years [4]. In fact, there is no experience on the behaviour of fuel for longer periods, and it may be that even after twenty years it will be necessary to intervence on the storage conditions.

The ipothesis of the throw-away cycle leads to consider systems for incorporation of the whole fuel assembly, for instance in water-tight concrete casks and burial of the fuel so incorporated in deep geological formations. Incorporation would serve the purpose of avoiding the risk of contamination by the radioactive substances contained in the fuel assembly under the wash-out effect of water. There remains to question the logic of the throw-away approach which not only wastes most of the energy content of uranium, but also renders the whole fuel assembly with all its plutonium content a radioactive waste.

3. Storage of ENEL's Irradiated Fuel

In order to evaluate the consequences of the situation described above, in 1975 ENEL started a series of studies on the problems of both the existing and planned stations aiming at defining the most suitable means to solve the storage for its own irradiated fuel. The work has placed in evidence how the problem can be divided into two components, one for the medium term concerning the existing stations (160-MW BWR at Garigliano 270-MW PWR at Trino Vercellese and 860 MW BWR at Caorso) and one for the longer term concerning the stations provided for in the nuclear program.

3.1 Medium-term solutions

A few solutions have been suggested for the problem in the short term (that is, for the next 10 years or so) in order to avoid station shutdown because of the complete congestion of the pools. If no provisions are made, the Trino Vercellese station, where the situation is most critical, would have to be shut down in 1980 with the added disadvantage of not being able, from this year onward to discharge the whole core for inspections on the reactor internals.

The situation for the Garigliano station is just us gloomy: the reactor would have to be shut-down in 1982, but the possibility of discharging the whole core was already jeopardized in 1976.

On the contrary, the Caorso station would have to be shut-down in 1984 and the possibility of discharging the whole core in the station pond will end starting from 1981.

Therefore, a series of actions were started to ensure a sufficient storage capacity for the existing stations unitl 1987, so that any decision on the reprocessing of irradiated fuel could be postponed till later date.

The proposed solutions are the following.

a. Centralized storage facility

One of the short-term targets of the national energy program is the selection and qualification of a suitable site to accommodate the activity of the final portion of the fuel cycle (reprocessing, re-fabrication of the recovered fuel, treatment and disposal of the wastes); this entails the construction of a national storage facility which will act as the head pool of the future reprocessing plant.

b. Modification of the storage systems in the pools of existing stations (re-racking).

This modification requires the replacement of the present racks with others suitable for high density storage, and the procurement of proper licenses from the Safety Authorities.

c. Adaptation of an abandoned research reactor into a storage facility.

The pool of the ex-reactor AVOGADRO of the SORIN Company at the Saluggia Research Center is easy to adapt in a short time into a storage facility for the irradiated fuel assemblies of the Garigliano and Trino Vercellese power stations.

With regard to the first solution (a), the construction times are linked to the implementation of the national nuclear program and for this reason it is not possible to have even part of the centralized storage facility ready in good time for the operating requirements of the Trino Vercellese and Garigliano stations.

For the installation of the high-density storage racks in the Trino Vercellese and Garigliano station pools it would be necessary to verify the adequacy of the existing facilities from the following points of view:

(1) Seismic requisites. - The station pool must be capable of withstanding the effects of the design earthquake assumed today for modern stations.

(2) Structural requisites. - The pool structures are to be verified for the new loads.

(3) Auxiliaries capacity. - The capacity of the residual heat removal system, of the water treatment and clean-up system and of the ventilation system, must be adequately increased.

The solution of the problems associated with these three aspects is most uncertain for the Trino Vercellese and Garigliano stations owing to the great change in the related design criteria since 1960. There is also a potential risk that any requirements prescribed by the Safety Authorities for adaptation to the new design criteria for nuclear stations pools may have a negative impact on the whole stations. Instead, reracking of the Caorso station pool does not appear to present any particular difficulty. Fig. 1 shows the amount of irradiated fuel to be discharged in the various years for different hypotheses of increased station storage capacity.

As to the possibility of using abandoned research station for storage purposes, in Italy there is an old pool reactor, the AVOGADRO, which can be adapted for this purpose with minor modifications. The existing structures can be adapted to accommodate over 130 tonnes of irradiated fuel. A technical-economic analysis indicated the convenience of this solution to meet the required timing.

Section 4 illustrates the main technical aspects and problems that were encountered to fit up this facility. Figs 2 and 3 show the expected situation of the discharged fuel in the station and in the Avogadro pools, for the various years. The same figures indicate also when the possibility of discharging the whole core in the station pool is definitely jeopardised.

In view of the foregoing, it was decided that the solution should be proceed with the adaptation of the AVOGADRO reactor pool into a storage pool for the Trino Vercellese and Garigliano stations and at the same time to program for high density storage racks in the Caorso pool. The solution of finding an adequate accommodation for the fuel abroad has been discarded for the time being.

3.2 Long-term solutions

The question of long-term storage mainly concerns the fuel that will be discharged from the stations now provided for in the Italian nuclear program.

For this program the Italian Parliament has recently approved immediate action on the construction of eight nuclear power stations, with an option for other four stations to be commissioned later. In addition, the program also contemplates the possibility of experimenting heavy-water units with an order for two CANDU stations

The amont of irradiated fuel that will be discharged from all the aforesaid water reactors is on the order of 300 tonnes/year since the stations already in operation will also be discharging fuel by 1990 there would be almost 2000 tonnes irradiated fuel accumulated

Therefore the question of irradiated fuel storage in Italy pending the availability of adequate national or international reprocessing facilities must be considered very carefully in order to avoid negative repercussions on the implementation of the whole nuclear program

4 The AVOGADRO Storage Facilities in Saluggia

The research pool reactor AVOGADRO RS-1 of the SORIN Company operated from 1959 to 1971 at a maximum output of 7 MWth and then shut-down.

In order to exploit the storage facility as a spent fuel pool the following major problems had to be coped with:

1. Seismic analysis of the containment building and of the pool structures.
2. Dismantling of the equipment used for reactor operation (decommissioning).
3. Adaptation of the pool to the new storage condition.
4. Reinforcement of the more heavily loaded civil works.
5. Modification of the lifting means for cask handling.
6. Adaptation of the auxiliaries.
7. Rack design.

The seismic analysis has proved that all the main structures are capable of withstanding the stresses caused by the new "design earthquake"; in fact, the facility design criteria adopted data back to the second half of the fifties.

The facility decommissioning has sadisfactorily been completed in ten months by cutting under water the equipment fastened to the pool bottom with the help of a purposely skilled frogman team.

As regards the adaptation of the pool structures, it is necessary to chose the various penetrations with blind flanges, to prepare the bottom with plates for rack load distribution and to ascertain the tightness of the pool lining. Furthermore, some structural additions are to be performed mainly with a view to reinforce the slabs in the area where the transport means with the spent fuel casks arrive.

Depending on the type of cask to be used, an ad-hoc room has to be provided for the decontamination of the cask prior to its shipment.

The capacity of the polar crane in the building is not sufficient to lift the transport cask, whose weight is on the order of 50 t. Therefore, a new lifting system has been designed that, among other things, meets the requirement of avoiding the physical passage of the cask above the rack area.

Removal of the decay heat of the irradiated assemblies (up to a maximum of about 1 MW, when the pool is full) will be performed by means of the existing cooling system appropriately modified. Also the pool water clean-up system, the make-up water demineralization system and the reactor building air conditioning and ventilation system, can be utilized with minor changes.

In addition to the radiation protection provisions with which the storage facility is equipped, it will also benefit by the effective measures established within the nuclear site at Saluggia for protection of the population.

The fuel assembly storage racks are of the compact type (HDSFR) without interposition of neutron poisons other than the structural material. The design is based on a type of rack that was licensed for the Calvert Cliffs station in the USA, that is, free-standing racks. These racks are divided in modules, each module consisting essentially of a frame of stainless steel channels connected to one another so as to achieve a sufficiently stiff structural unit.

The modules simply rest on the pool bottom without any anchorages underneath or laterally. This arrangement has the merit of simplifying the manufacture and the installation of the racks. The only precaution necessary is that the racks must be placed at a greater distance than the maximum slide presumable in the event of an earthquake, so as to prevent the racks from knocking into one another.

The nuclear design is based on a K_{eff} of 0.95 for every conditions, i.e. both for normal and for incident conditions; as a result, the following lattice pitches have been chosen:

Modules for Trino Vercellese fuel: 12.75 inches

Modules for Garigliano fuel: 9.5 inches

The storage density with these pitches will be respectively 3.0 tonnes of uranium per sq.m. for Trino Vercellese and 3.5 tonnes of uranium per sq. m. for Garigliano.

5. Economic considerations

The storage of the spent fuel outside the reactor pool in view of its reprocessing has to be carefully considered from the economic standpoint in order to assess the charges versus time associated on the one hand with the cost of storage and reprocessing and on the other with the credit of the recovered fissile materials.

This report will deal with the effect of the delayed reprocessing of the fuel resulting in its temporary storage in a pool on the cost of kWh associated with the fuel itself (fig.4).

In view of the foregoing and in the assumption that under to-day's money conditions the future cost of reprocessing and the credit of the recovered fissile materials will be higher than the present ones, it may be stated that the incidence of the fuel on the cost of the produced kWh is:

a. increased by:
- the higher reprocessing cost;
- the total expenditures for storage in the centralised pool;
- the interests due to the higher credit of the fissile materials for the period starting from their loading into the reactor and ending with their recovery, except for the time they have been stored in the centralized pool;
- the interests associated with the difference between the credit of the recovered fissile materials and the reprocessing cost for the period they have been stored in the centralized pool;

b. reduced by:
- the higher credit of the recovered fissile materials;
- the interests due to the higher reprocessing cost for the period starting from the loading of the fuel into the reactor up to the end of its residence in the reactor pool;
- the interests associated with the total expenditures for storage in the centralized pool for the time of residence in the reactor pool and for the half time of residence in the reactor and in the centralized pool.

Therefore, from the foregoing it can be inferred that no variation would occur in the incidence of the kWh cost associated with the nuclear fuel if the items under a) are fully compensated by those under b).

In the assumption that, again under today's money conditions, the reprocessing cost and the credit of the recovered fissile materials undergo no variations in the future, the fuel cost as a result of the delayed reprocessing will be increased by the total expenditures for storage in the centralised fool and by the interests associated with the difference between the credit of the recovered fissile materials and the reprocessing cost for the period of storage in the centralised pool, and reduced by the interests due to the total expenditures for storage in the centralised pool for the period of storage in the reactor pool and for the half time of residence in the reactor and in the centralised pool.

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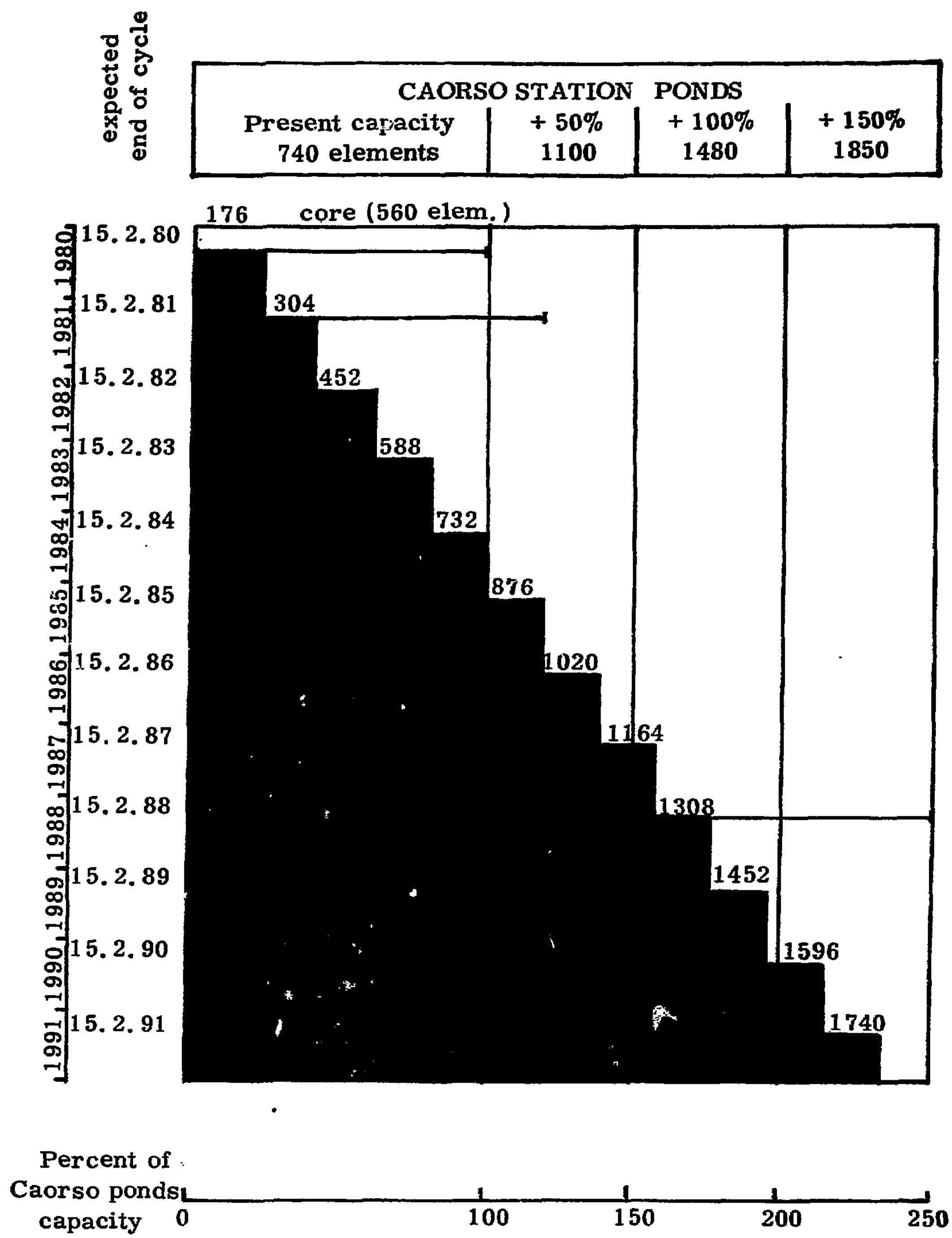

FIG. 1

Caorso station - Medium-term storage assessment

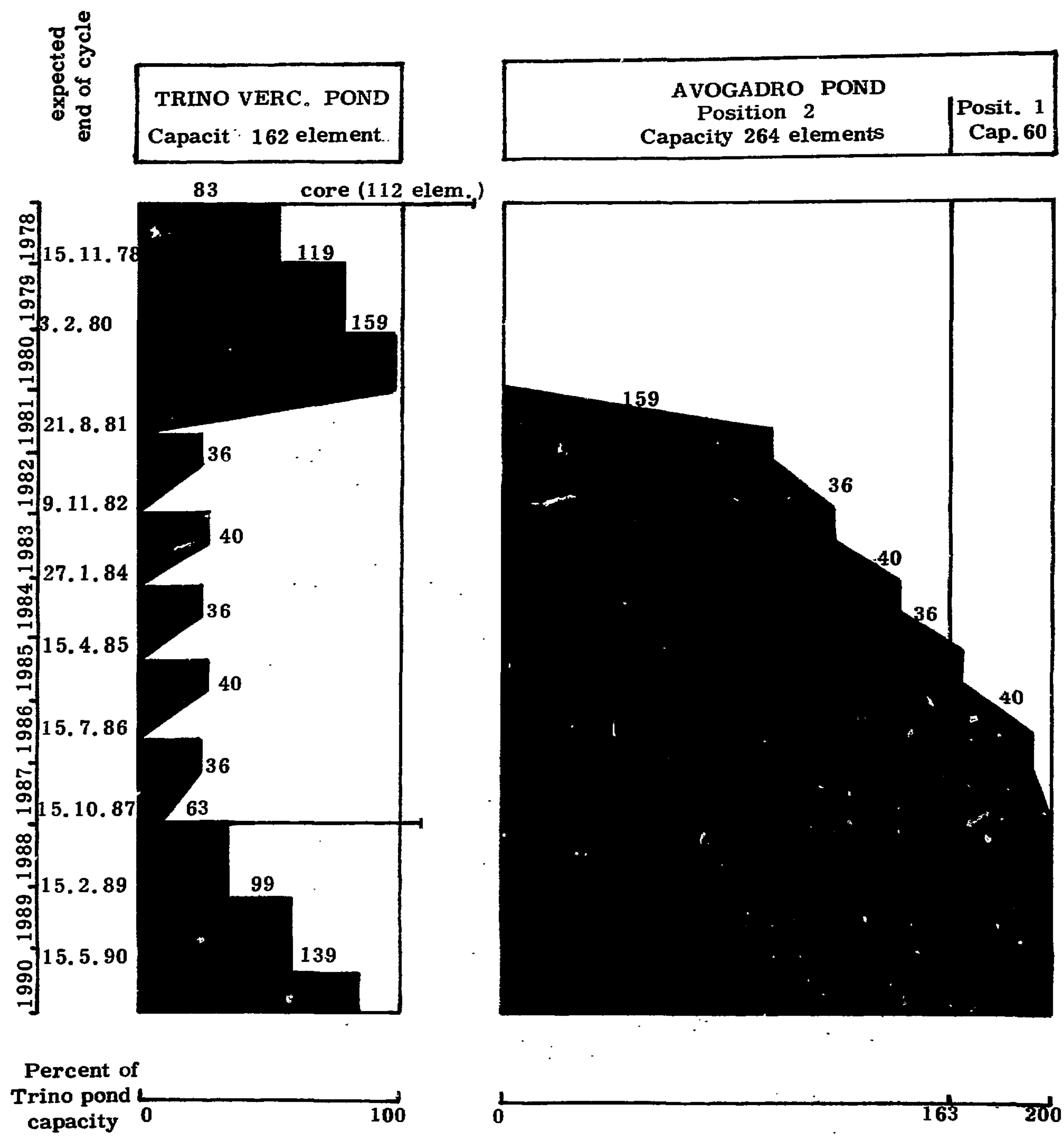

FIG. 2

Trino Vercellese station- Medium-term storage situation

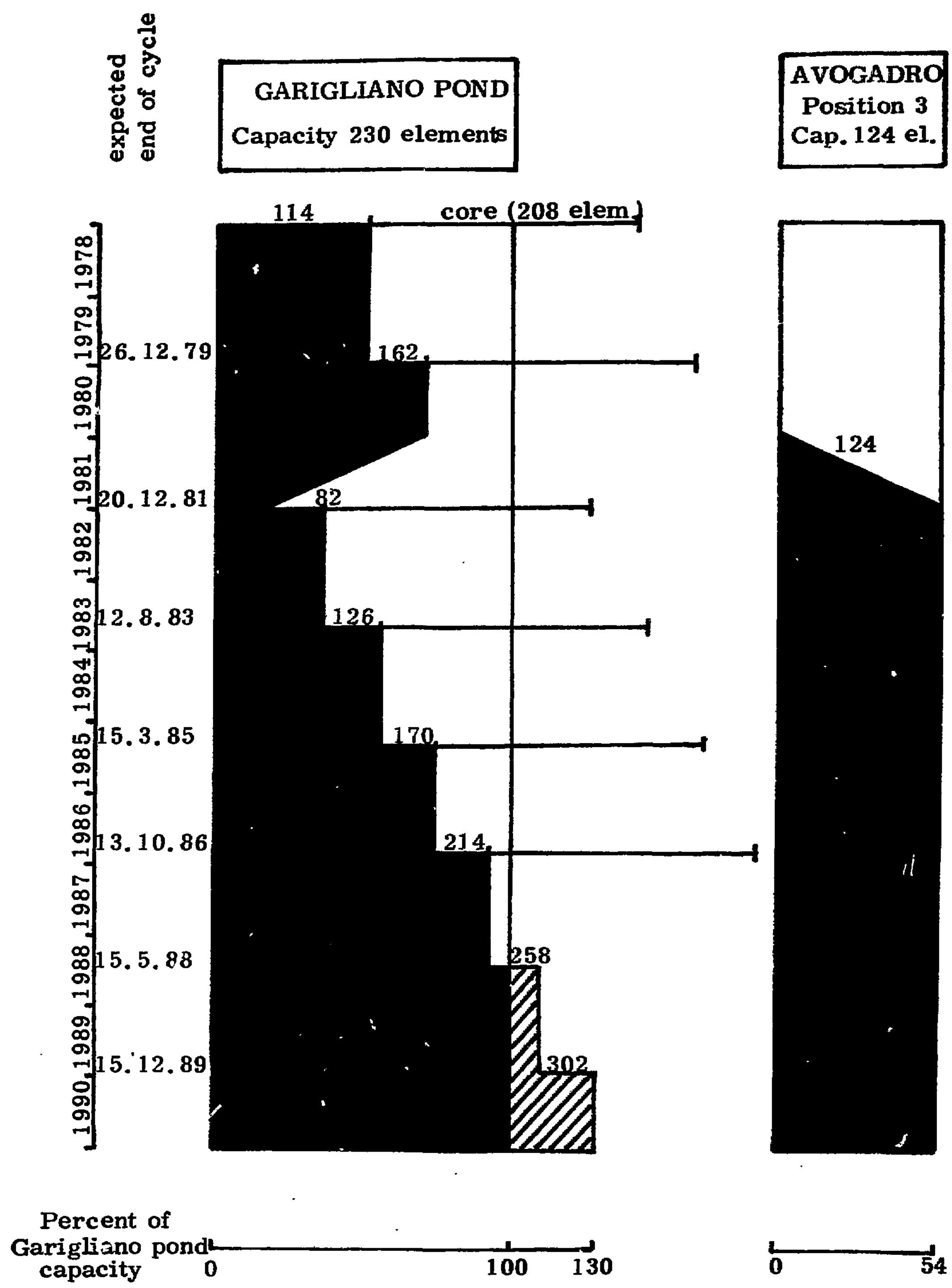

FIG. 3

Garigliano station - Medium-term storage situation

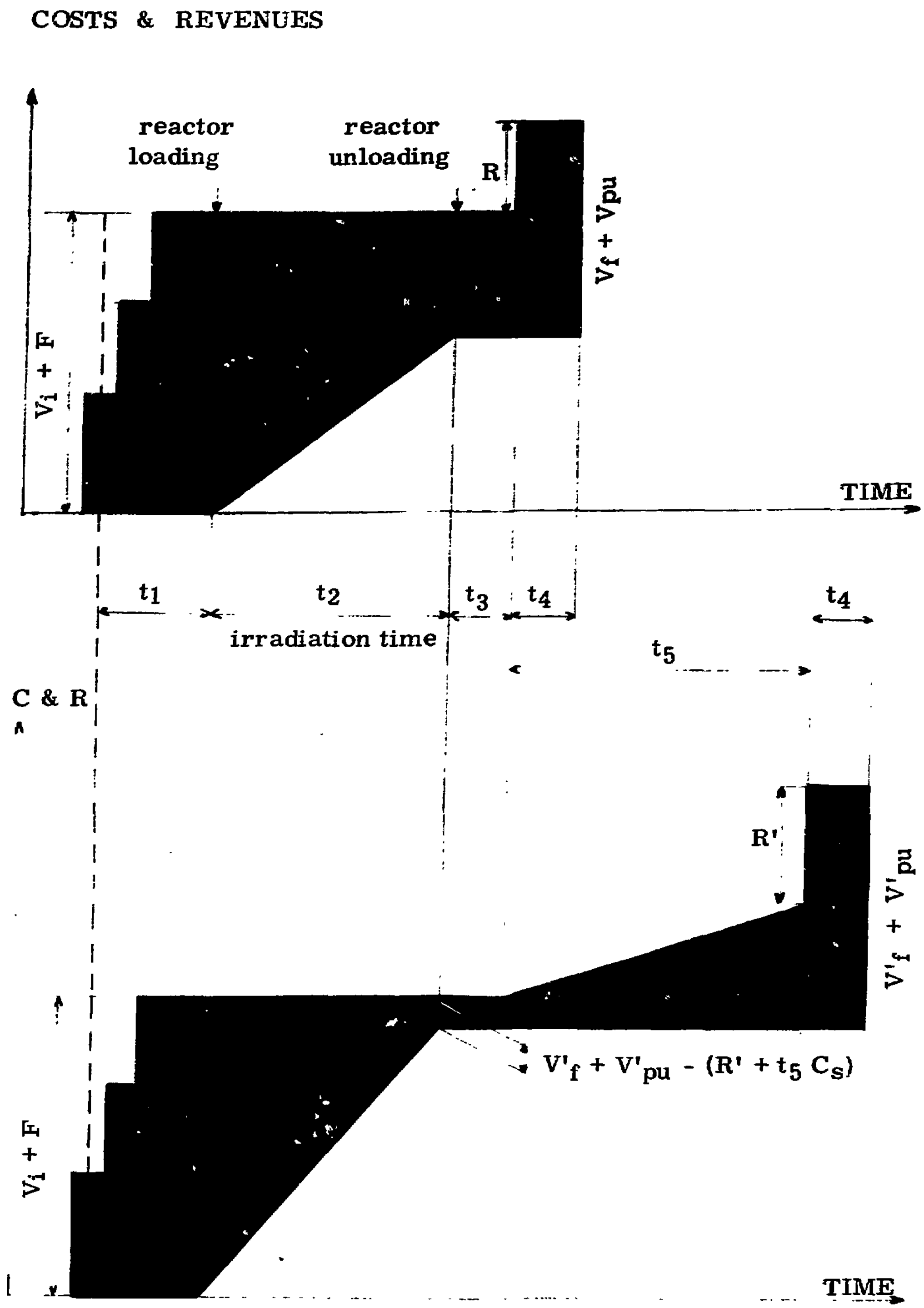

FIG. 4

Costs and revenues associated with a batch of fuel

Symbols in fig. 4

V_i = Initial value of uranium

F = Fabrication cost

C_5 = Yearly storage cost in the AFR pool

R = Plutonium value

V_f = Value of the recovered uranium

V_{pu} = Plutonium value

The mark refers to those quantities assumed to increase with time.