NUCLEAR INFRASTRUCTURE IN THE FIELD OF NUCLEAR FUEL CYCLE FOR THE NEWCOMER-COUNTRY: MAIN PRINCIPLES AND STEP-BY-STEP ALGORITHM OF DEVELOPMENT

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Abstract

Nuclear infrastructure development is vital for the effective implementation of the nuclear energy programme (including the construction and maintenance of nuclear power plants) because it helps to minimize the potential risks that may arise during the planning, construction and operation of nuclear facilities. The report addresses key issues in the development of national policies, strategies, legislation, regulation, technology, management and personnel. It presents the main factors influencing the choice of strategy in the field of nuclear fuel cycle, predicts the key directions of its long-term development and provides recommendations for the newcomer-country. The focus of the report is devoted to the back-end of the nuclear fuel cycle, the scenarios of its development and criteria for the final selection of either option. Spent nuclear fuel treatment and the possibility of returning fissile materials back to the nuclear fuel cycle determine today the whole picture of the nuclear fuel cycle.

1. INTRODUCTION

The most important task of States embarking on the implementation of a nuclear energy program (NEP) for the first time is to ensure reliable fuel supply for the facilities provided for in the program, whether nuclear power plants (NPP) or research reactors.

Another challenge, no less important, will be the choice of a strategy for the management of spent nuclear fuel (SNF). Both of these tasks are united by the concept of the nuclear fuel cycle (NFC), development which is the subject of this report.

During the implementation of programs for the peaceful use of nuclear energy and the development of NEP the main task for the newcomer-country is to develop a national policy, strategy and regulatory framework in the field of NFC, which describes the main stages of development of NEP, time frame and responsible persons.

The combination of these documents and national efforts must meet national and international requirements in the fields of nuclear, radiation and physical safety, non-proliferation, economics, public health and environmental protection and take into account the views of all national and international stakeholders in the development of the nuclear sector of the country.

The national policy in the field of NFC means the definition of the main principles of NFC construction resulting from the main objectives of the use of nuclear energy, among which the main priorities are the protection of human health and the environment, both inside the country and abroad, the production of electricity and other energy resources, while ensuring stable and economically expedient operation of the national NEP.

The main participants of the national policy in the field of NFC are: operating organization – Operator, supervisory authority – Regulator and the Government, which monitors and coordinates the interaction of these and other national structures.

The legal framework means the set of laws, legislations, specialized rules, as well as security handbooks, which in a complex regulate all areas of activity related to the use of nuclear energy.

2. THE FORMATION OF NATIONAL POLICY AND STRATEGY CONCERNING THE NFC

The primary responsibility of the State embarking on the implementation of the NEP is to creation of a reliable legislative framework in the field of management and regulation, as well as mechanisms that cover all participants of the NEP and stakeholders at all stages of the formation of the NEP.

In the NFC part, this thesis is reflected, for example, in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which defines that **"formulation a policy in the field of the nuclear fuel cycle remains the prerogative of the state"**.

National policy and strategy of NFC development must be determined taking into account national priorities, peculiarities of the country and national plans for peaceful use of nuclear energy, including the development of NEP.

The initiator of the development of national policy and strategy of NFC in the country is recommended to be the NEP Implementation Organization (NEPIO), which is, at the initial stage, organization for the use of nuclear energy in the country and the implementation of the NEP authorized by the State.

NEPIO can legally delegate its powers of managing the use of nuclear energy and the implementation of NEP to the agency created in the country- the National Atomic Energy Agency (NAEA), which, together with the national regulatory authority (NRA) and other interested ministries, agencies and organizations of the country develops State policy in the field of the NFC and submits it for consideration to the Government with its subsequent codification at the legislative level as part of the Basic Law on the peaceful use of nuclear energy and/or as part of a separate law on the safe handling of RW and SNF.

The national policy in the field of NFC must formulate the basic principles of NFC construction, which arise from the main objectives of the use of nuclear energy, among which the main priorities are the protection of human health and the environment, both inside and outside the country, the production of electricity and other energy resources, while ensuring stable and economically expedient operation of the national NEP.

The main principle of the formation of national policy in the field of the NFC is to implement safe and responsible SNF management, which include not to impose excessive burden on future generations.

For the formation of the national strategy for the NFC development, that is acceptable and meets the national requirements, NEPIO must initiate the comprehensive researches of the various options for implementing NEP in relation to a particular country at a very early stage of the preparation of political decisions about the NFC development in the country taking into account its political situation, geographical position, social and economic patterns, technological level and safety culture.

In the course of these researches, the models for different situations of NFC need to be developed taking into account the requirements and recommendations of IAEA and international practical experience in the field of use of atomic energy.

The simulation must meet the national requirements in the fields of economics, nuclear and radiation safety, protection of the population and the environment, non-proliferation and physical protection. Based on the researches, the final version must be selected and the feasibility study for the creation of the national NFC must be prepared.

The feasibility study must describe the scale of NEP development, the types of NPPs involved in NEP and fuel types for the NPPs, the scheme of SNF handling, timing and economic evaluation, as well as national capacities to participate in one or another stage of the NFC. The feasibility study is the basis for the development of the NFC strategy, which must include a step-by-step plan for the establishment the objects of NFC infrastructure in the country.

In the formation of national policy and strategy for NFC, it is necessary to consider the NFC in its entirety, not only the issues of fuel supply for NPPs and separately – the handling with SNF. This is important both from the point of view of postulating the basic principles, and from the point of view of creating separate redistribution of the national NFC.

For example, national policy may include the recycling of SNF that entails the need to recycle fissile materials-uranium and plutonium; the best way to recycle today is to return them to the NFC with the production of new fuel for NPPs. In this way, the back-end and the front-end of NFC becomes inextricably linked.

The decision on positioning of spent nuclear fuel is fundamentally important. SNF may be considered either as non-recyclable waste and sent to deep geological repository or as a valuable material to be recycled for the recovery of useful products, including recovered uranium and plutonium.

The NFC development strategies that are generally accepted in the world practice:

— open nuclear fuel cycle (ONFC) strategy, with long-term storage and subsequent direct (without recycling) disposal of SNF;

— closed nuclear fuel cycle (CNFC) strategy, with recycling of SNF, involvement in the nuclear fuel cycle of its products and disposal of only radioactive waste (RW), the use of which in the future is impossible;
— delayed decision, with accumulation of SNF.

Depending on the type of reactors and the type of nuclear fuel, the nuclear fuel cycles may differ in detail, but their general concept remains.

3. FACTORS AFFECTING THE CHOICE OF NFC TYPE

Without the worked out decision in terms of handling with SNF and RW, the NPPs construction in the newcomer-countries will be significantly hampered.

When forming State policy, strategies and related programs in the implementation of one or another situation for the NFC development in the country, the government, the NAEA, the NRA and other involved ministries, agencies and organizations in the country can do it on the basis of careful planning for the NEP development (modelling), and also from the point of view of public acceptability of nuclear energy and taking into account other factors.

Many factors affect the choice of the country between ONFC and CNFC. The main factors include economic, technological, personnel, environmental, social and non-proliferation (political) factors, including nuclear security.

Economic factor. On the basis of the economic characteristics of CNFC and ONFC, as shown by several researches [1], it can be argued that there is no fundamental difference in their ultimate cost in the long term today: first is burdened with costly radiochemical production and complicated fabrication; the second is burdened with the increased costs of temporary technological storage and SNF encapsulation (putting the SNF in special containers for final disposal), deep disposal, and risks that are difficult to predict in the long term. As a result, ONFC is more attractive at the NFC front-end development, while CNFC is more economically expedient in the long term.

Scale factor. The choice of SNF handling strategy and therefore the NFC type is also greatly influenced by the capacity of national nuclear energy. When there are the relatively high power of nuclear energy (10 GW and higher) and the big amount of formed SNF, the probability of finding the place (places) for SNF disposal is significantly hampered, as well as the implementation of the project(projects) of construction and filling of storages and disposal objects. In this case, the choice of the CNFC is expedient not only from the economic point of view, but from the point of view of safety and easy handling with SNF and RW.

Technological factor. CNFC is much more knowledge-intensive compared to ONFC. The CNFC creation requires availability of highly developed scientific-technical complex, as well as relevant industrial power.

Personnel factor. When choosing between ONFC and CNFC, special attention should be paid not only to the availability of appropriate technologies, but also to specialists in the field of SNF and RW handling, the preparation of which may take much longer time than the construction and commissioning of the appropriate infrastructure.

ONFC requires specialists in the field of nuclear and radiation safety, as well as specialists in the field of transportation, storage, disposal and physical protection of SNF. In addition to this, CNFC requires a wider range of highly qualified specialists as research profile for creating technologies of RW handling and as engineering and technical profile for the commercialization and improvement.This is due to the need for SNF reprocessing and further RW handling, changing their shape, properties and characteristics for subsequent storage and disposal.

Environmental factor. Under no circumstances, handling with SNF and RW must not have a negative impact on human and the environment in accordance with national and international standards and requirements. In the case of ONFC, the construction of the storages and SNF disposal objects imposes serious requirements on place and conditions of location of object sites: for SNF disposal it is necessary to choose a seismically-stable deep hard rock masses.

Additional conditions are appropriate hydrogeology, distance from densely populated and industrialized areas and etc. It is obvious that not all countries have sites that meet these conditions. In the CNFC, ensuring environmental safety is much easier to achieve because the final product is RW, the

characteristics and shape of which can be selected in the way that to maximize the safety of storage and final isolation of waste.

Social factor. The attitude of the population to nuclear energy can have a significant impact on the pace and situations of development of nuclear energy and NFC up to the stop of NEP development. From the point of view of social support, CNFC may be more attractive, as it demonstrates in real time practical actions with hazardous material, leading him to safe condition.

Whereas, ONFC actually stretches the bringing of the spent fuel in safe condition for hundreds of thousands of years. In any case, the negative attitude of the population may require a number of comprehensive activities to increase education and awareness of the population in matters of safety and technology of nuclear energy.

Non-proliferation (political) factors. The choice of the NFC type can be influenced by the political partnership of the newcomer-country with one or another supplier of nuclear technology. For example, a number of countries choose the ONFC, because this type of NFC is declared by these countries as optimal from the point of view of non-proliferation of nuclear technologies (in this case, the delayed decision is actually implemented). While other countries are implementing the CNFC, either independently or in partnership with other countries with the relevant technologies.

The choice of the NFC type between countries-suppliers of nuclear fuel and countries-recipients in both cases is usually fixed at the level of intergovernmental agreements. In case of any choice, the implementation of nuclear projects in newcomer-country is possible only with a stable and long-term domestic and foreign policy of the State and consistent implementation of obligations in the field of nuclear safety and non-proliferation, as the NFC creation requires the implementation of long-term programs that must not be subjected to political fluctuations in the country.

Installed capacity utilization factor. The type of reactors and the value of installed capacity utilization factor1 can influence on the choice of the NFC type. For example, the increase of the depth of fuel burn-up increases the installed capacity utilization factor, but the amount of plutonium and fragmentation elements increases in the fuel, which complicates its further reprocessing, increases the necessary time of SNF aging, tightens the requirements for temporary storage of SNF, and also reduces the amount and quality of the material obtained in the reprocessing of SNF, which could be used in the further fabrication of new fuel.

Infrastructure factor. Another factor influencing on the choice between ONFC and CNFC is the need of creation of appropriate infrastructure. If this structure is similar for both variants in the part of NFC front-end, the differences are significant in the part of NFC back-end.

They are determined mainly by the fact that the industrial infrastructure ensuring the SNF safe handling and reprocessing of requires significant investments, resources and the country's high technological level and is implemented in countries with appropriate technologies.

ONFC and CNFC have their own serious differences and disadvantages, but if the disadvantages of the CNFC are temporary and eliminable, so the disadvantages of ONFC can be called systemic and getting rid of them is difficult.

There is a possibility to avoid considerable difficulties in the choice of CNFC, if the operations for the SNF and RW handling is delegated by the newcomer-country to another country that already has experience and all the necessary set of technologies for making this kind of operation.

In this case, only the creation of deep geological repository for the final RW isolation is necessary in the newcomer-country, which greatly facilitates the task. This option is also more cost-effective, as it avoids the cost of research, development of SNF and RW handling technologies, as well as creation of expensive infrastructure and training of qualified personnel.

This type of partnership allows the newcomer-country to take full advantage of CNFC without the substantial costs required for the independent CNFC development (the above mentioned training, technology and infrastructure costs).

In this connection, there is a gradual universalization of national strategies in the field of NFC: on the one hand, many States declare the development of projects for the search and construction of objects of final SNF

[1] The installed capacity utilization factor reflects the ratio of the average power to the installed capacity of the NPP for a certain period of time (usually for a quarter, a year or the full service life from the moment of power start-up).

and/or RW isolation; on the other hand, carefully study and evaluate the possibilities that can give SNF reprocessing, including in other countries.

4. ECONOMICS OF THE NFC

The economics of the NFC, as the resource provision of the NEP development program, is the most fundamental for the newcomer-country.

Economic rates and parameters of the NFC can vary significantly depending on a wide range of parameters: the selected situations for the NFC development, strategy implementation, technology, parameters of the factory, infrastructure readiness and others. Generally, the economic costs of NFC can be divided into capital and fuel costs (Fig. 1).

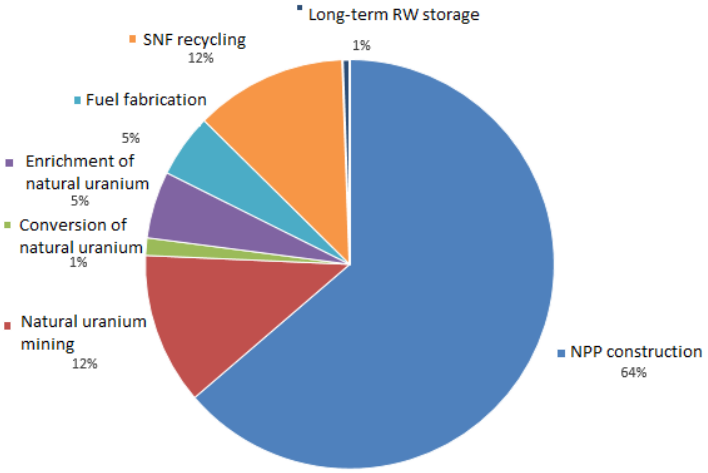

FIG. 1. Share of NFC and LCOE in total capital and fuel costs for VVER-1200 unit for 85 years of operation, %.

The capital costs of NPPs construction for the whole period of exploitation are about 64%, while fuel costs, including production, conversion, enrichment and fabrication, are about 23%. Transaction costs of the NFC back-end, including SNF reprocessing and long-term RW storage are approximately 13%.

Depending on the country, the developed strategy, technologies and equipment, the final cost can vary significantly.

The data for ONFC to create object of final disposal of the SNF is taken of the forecast (currently not established any such disposal), whereas data for CNFC operate on economic indicators of real operating plants (in the world today there are at least six reprocessing plants). At the same time, it should be noted that there are currently no disposal sites for HLW.

Given the considerable uncertainty in the valuation of the initial cost parameters, such a small difference can be considered insignificant. In any case, it is negligible in terms of total costs for the implementation of the NFC and the production of electricity at nuclear power plants.

From the point of view of the nuclear fuel cycle's economy, the most important factor is that the world has a competitive global market for nuclear fuel cycle services. The services offered in this market can cover the needs of a newcomer country with any set of baselines, consistently ensuring the safety and long-term reliability of SNF management. The customer has to choose the most convenient (currently) option.

At the same time, despite the existence of competition in various areas of NFC, global companies that can provide services in all areas, the world market has a limited number. The advantage of global players is the integration and maximum compatibility of services at all stages. This positively affects the cost of complex turnkey projects, and also significantly reduces the risks associated with the mutual integration of the various stages of the nuclear fuel cycle and the responsibility of suppliers.

As far as the redistribution of the NFC back-end is concerned, one should keep in mind the availability of the following solutions, products or services on the market:

— Assistance in registration and support when approving the necessary permits in the supervisory and regulatory bodies (transport and technological schemes, certificates, assessment and justification of safety, etc.).);
— Transportation of empty containers to the nuclear power plant site;

— Loading of snf and preparation of the container for transportation;
— Transportation of snf containers to a reprocessing plant;
— Temporary technological snf storage (if necessary);
— Reprocessing of snf and partitioningof hlw to reduce activity to ilw (if necessary);
— Services for rw management, including sorting, processing, packaging and temporary storage (when selecting cnfc);
— Fabrication of fresh fuel from recovered reusable materials (repu, remix, mox, if necessary);
— Transportation of fresh fuel from regenerated materials to the customer (if necessary);
— Transportation of rw to the customer;
— Services for the establishment of storage and final isolation of snf and/or radiation waste in the customer's territory (depending on the type of nfc).

The ability to get these services on the market and their availability at a price allows the novice country to implement any type of NFC of its choice.

The nuclear damage risk insurance program for third parties is based on insurance contributions from operating organizations, possibly with the support of the state insurance Fund and with the involvement of reinsurance instruments in international insurance pools specializing in nuclear risk insurance.

5. LEGISLATIVE AND REGULATORY FRAMEWORK

As already mentioned above, the NFC actually describes the path of nuclear materials movement, that is, fresh nuclear fuel and SNF, as well as RW as components of SNF after its reprocessing.

The basic international conventions regulating the activities on SNF and RW management are:

— The Convention on Early Notification of a Nuclear Accident;
— The Convention on Assistance in the Event of a Nuclear or Radiological Emergency;
— The Convention on the Physical Protection of Nuclear Material and the Amendment thereto;
— The Convention on Environmental Impact Assessment in Transboundary Area;
— The Convention on Nuclear Safety;
— The Vienna Convention on Civil Liability for Nuclear Damage;
— The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management;
— The International Convention for the Suppression of Acts of Nuclear Terrorism.

In accordance with the Joint Convention on the Safety of SNF and RW Management, each state has ethical obligations to future generations regarding the volumes of accumulation of RW and SNF.

The state's obligations with regard to the nuclear materials that make up the NFC are mandatory in the international agreements of the newcomer-country with the state-supplier of nuclear technology and nuclear materials, and with the IAEA on the application of IAEA Safeguards to ensure that the use of nuclear facilities and nuclear materials in the newcomer country is carried out exclusively in accordance with the provisions of the Treaty on the Non-Proliferation of Nuclear Weapons.

Among such obligations, in particular, should be mentioned obligations in the field of liability for the nuclear damage on the NFC facilities, etc.

It is also important that the creation of a legislative and regulatory framework is an integrated task, the implementation of which must take into account a wide range of knowledge from the principles of international nuclear law to the technical characteristics of nuclear fuel and equipment for working with it.

In this regard, it is advisable for the newcomer country to resort to the help of experienced consultants and authoritative international organizations in the creation of nuclear infrastructure.

The NAEA should initiate the creation of a legislative and regulatory framework in cooperation with other national authorities, primarily the NRA, environmental authorities, national security authorities, health authorities and organizations responsible for the transport of dangerous goods.

The said structures should audit the existing national legislation in this area and prepare joint proposals for accession to the fundamental International Conventions and amendments to existing legislative acts or drafts of the following new acts:

— National Law on the Use of Atomic Energy;
— National Law on the Safe Management of SNF and RW;
— Government decisions regarding the safe transport of nuclear materials;
— Government decisions on the establishment of a national system for the accounting and control of nuclear materials;
— Government decisions on the national system for the physical protection of nuclear materials and facilities;
— Government decisions on the establishment of a national system for export / import control of nuclear materials and radioactive substances.
— Legislatively, the following shall be fixed:
— The state's right to the nuclear materials mined or imported into the country;
— SNF obligations;
— Empowerment of certain organizations in the field of nuclear materials control;
— Creation / maintenance of the operational capacity of the NFC infrastructure.

On the basis of the set of these laws and the decisions of the government of the country, the National Agency for the Use of Nuclear Energy, together with the NRA, develops normative and technical documents regulating the technical, legal, organizational, administrative and financial issues of interaction of all participants in the process of handling fresh nuclear fuel, SNF and RW at all stages of their life cycle.

Regulation of safety in the management of SNF and RW is also carried out based on safety manuals and guidance documents of the state safety regulatory authorities (NRA), documents developed by the state atomic energy management authorities (NAEA)

Next it come the level of national norms and rules. These include the rules of radiation safety in the handling of nuclear materials, the national rules for accounting and control, the procedure for certification and licensing when handling nuclear materials the rules for the tariffing of certain redistributions of the NFC, the law on the SNF handling fund, etc.

Supplements to international conventions and bilateral intergovernmental agreements are define the frames of commercial contracts, assigning roles and responsibilities to Contracting Countries - which is necessary, given the degree of responsibility of the Parties to the Agreements in the field of non-proliferation, physical protection, cross-border transportation, etc.

6. REQUIRED STAFF COMPETENCIES

The development of nuclear energy in the country requires the availability of qualified and competent personnel in various areas of the nuclear fuel cycle. A large number of specialists in engineering, technical and scientific research are required who carry out design, construction, operation, expertise and inspection of NPP or research reactors, as well as the overall scientific and technological development of the nuclear fuel cycle in the country.

The knowledge and skills that are necessary for the acquisition, construction, licensing, operation, maintenance of NFC facilities and compliance with relevant regulatory documents cover most of the scientific and engineering disciplines. First, these are specific knowledge of nuclear physics and nuclear materials needed to manage the nuclear fuel cycle.

Along with technical knowledge, safety culture skills and personal responsibility for the work performed are mandatory. The training of such specialists requires a long and deep training in specialized training and research centers, as well as practices at already operating nuclear power facilities.

In addition, training and further training of specialists in the field of economics, law, management and other fields of humanitarian profile is required, since the specific nature of the NFC requires such knowledge and approaches.

The listed competencies are required, first, for the development of a rational NFC Development Strategy taking into account the factors listed above, as well as creating a balanced legislative and regulatory framework that meets international requirements and norms and does not contradict national legislation.

Assessment of the number of personnel with the required level of education and competencies should be carried out at the earliest stages of considering the possibility of developing a nuclear fuel cycle in the country. This is necessary in order to be able to prepare a sufficient number of qualified specialists by the time a decision is made on the development of nuclear energy and the implementation of technical decisions taken to implement them.

Based on the results of such an assessment, those areas in which there is a shortage of staff of the required level of knowledge and experience are identified. When assessing the number of required staff, it is also necessary to consider the recruitment of new employees to replace retired or job changers.

The number of trained specialists should be sufficient for the staffing of both the Operator and the Regulator. It is assumed that for the start-up country at the NFC development in the NAEA and the NRA, the number of personnel responsible for the development of the NFC in the country should be from 3 to 10 people. The number of personnel at the enterprises of different stages of the NFC depends on the scale of the enterprise and the level of development of the nuclear industry in the country as a whole.

Even ordinary workers at NFC facilities usually require several years of specialized training in nuclear and radiation safety, physical protection, and also to study the structural and operational characteristics of selected technologies. The most preferable option is the passage of specialized training and obtaining a fundamental education from the developers and suppliers of nuclear systems and their components.

To ensure the stable development of nuclear energy, the state is recommended to develop its own system of training and personnel training, using the experience of foreign partners.

Despite the fact that such a development of the training system requires additional investments, the availability of personnel trained in the national interest and taking into account all the specific features of a specific country's NFC in the long run increases not only the level of the security, but also positively affects to economic indicators.

Specific staffing requirements for the implementation of the national NFC, both in the type of ONFC and in the type of CNFC in the newcomer country include:

— The staffed organizations providing fresh nuclear fuel and SNF handling (storage and transportation), RW management (storage, conditioning, transportation) and disposal of SNF and RW;
— The staffed regulatory authority with a specific qualification for supervision of NFC facilities at all stages of their life cycle (site selection, design, construction, operation, etc.);
— The staffed organization of technical support of the Regulator, which has qualified scientific and engineering specialists in all aspects (nuclear and radiation physics, chemistry, fire-explosion-safety and others) of the national NFC;
— The staffed national commission for export control of nuclear materials and its secretariat;
— Planning the development of staff and succession mechanisms to maintain competence in all areas of the NEP;
— The national program for improving the education level in nuclear physics and nuclear technology.

Specialists involved in the planning of works for the NFC should have the following knowledge:

— In the field of nuclear reactor physics (for understanding the options for the nuclear fuel cycle and nuclear technologies offered by the nuclear suppliers);
— In the field of technical and economic characteristics of individual elements of the nfc;
— The market of national and international sources of providing services for various redistributions of nfc;
— National natural and staff resources, applicable for the development of the nfc;
— Options for national fuel cycle strategy;
— Requirements to the staff required to implement the chosen strategy of the nfc.

The key competencies, at the NFC development of the newcomer-country are:

— Development of technical and economic models of the fuel cycle, taking into account the requirements for fuel supply and the availability of a resource base for the newcomer-country;
— Establishment of relations between the producer, developer and supplier of fresh nuclear fuel;
— Planning of sustainable development and functioning of nuclear energy, guarantees and reliability in providing the NPP with fresh nuclear fuel;
— Development of legislative and regulatory framework for the supply of fresh nuclear fuel;
— Organization of transportation of fresh nuclear fuel and SNF;
— SNF and RW management onsite.

7. NFC OF THE NEWCOMER-COUNTRY

Summing up what was said in the previous chapters, we can distinguish the following most important points that directly influence the formation of the NFC of the newcomer country:

- NFC of light water reactors has a developed structure and consists of several important stages. One of the most important stages is uranium enrichment and reprocessing of spent fuel, using dual-use technologies; the development of these stages for many reasons, including economic ones, is inappropriate in the newcomer country.
- The products of all redistribution of the NFC without exception are available in the international commercial market. Therefore, the newcomer country may well do without the development of its own NFC (on its territory).
- For determination of the policy in the field of selection of the NFC, NAEA should conduct an analysis of the various options of ONFC and CNFC for the planned reactor technologies and the capabilities of NFC suppliers, on the basis of which the national Government should approve the national NFC policy, adopt a decision at the choice of the front-end and back-end of NFC and proceed to the formation of the regulatory and legal framework.
- The newcomer country, which has its own reserves of natural uranium, must determine the economic feasibility of its extraction and involvement in the NFC, for what needs together with the supplier of nuclear technology, must carry out the necessary technical and economic research.

A typical scheme of the life cycle of the newcomer country NPP is shown in Fig. 2.

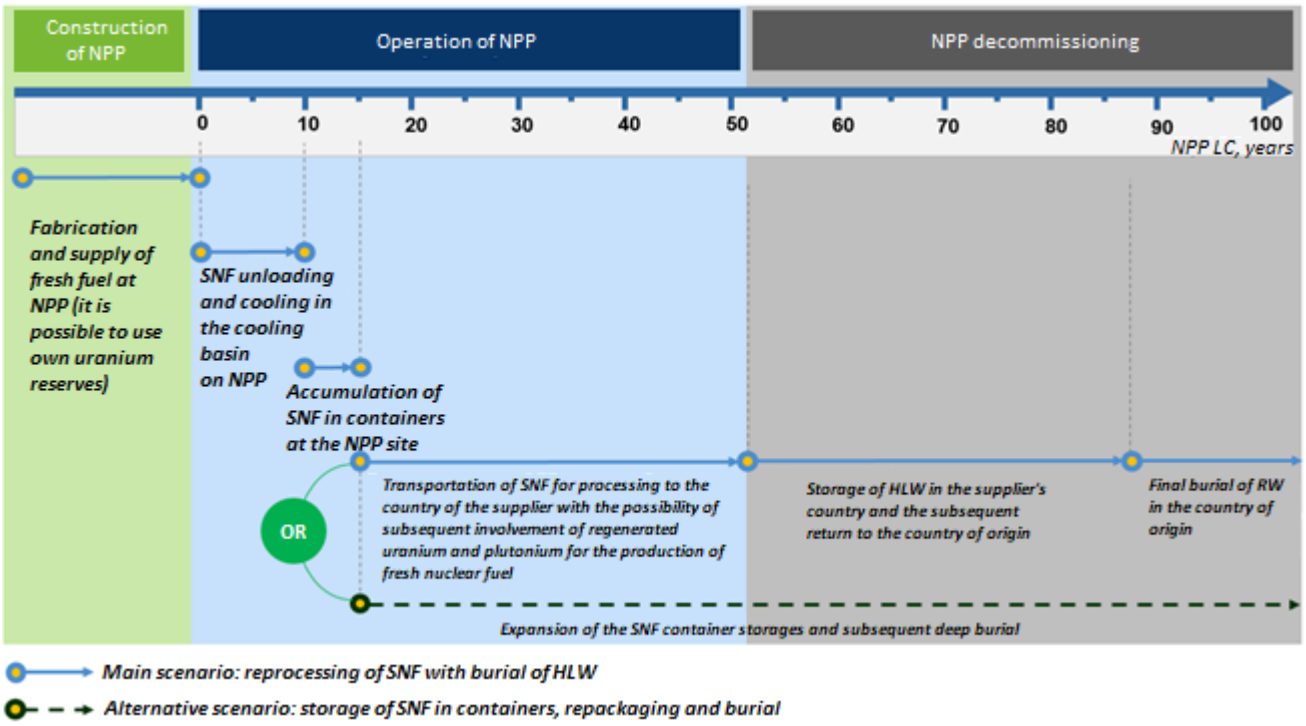

FIG. 2. Typical scheme of the life cycle of the newcomer country NPP.

8. COOPERATION WITH THE COUNTRY SUPPLYING NUCLEAR TECHNOLOGY

At the earliest stage of the development of the NEP, it is recommended to establish close cooperation with a potential country or different suppliers providing nuclear technology within the framework of the concluded intergovernmental agreement on cooperation in the peaceful uses of atomic energy.

This will allow planning the development of the NFC in advance from the moment of planning (modeling) the NFC options in support of the development of the NEP to the practical implementation of the selected NFC concept and ensuring the training of national personnel, the technological and legislative basis for the management and regulation of the NEP.

At the same time, assistance can also be provided in the formation of the appropriate infrastructure of the newcomer, including the development of national legislation, training of personnel, the formation of a plan for scientific, research, experimental and design work, and the construction of specific infrastructure facilities.

For the development of a NFC, a newcomer country will need to create such redistributions of NFC as fresh nuclear fuel reception and storage at NPP and temporary storage of SNF and RW.

The complete fuel supply in the basic version of the NFC implies the delivery of fuel assemblies to the NPP or research reactor that meet the requirements of the operator of a NPP or research reactor for operational characteristics. In this case, the newcomer country does not need to create any of its own technical facilities for the NFC (except for the corresponding access roads).

With regard to the NFC, the need for its own technical means is determined by the strategy of the newcomer country in relation of the type of NFC. If a country chooses a CNFC, then the supplier can take care of all SNF. In this case, the newcomer country will not need to create anything additional at the first stage of the development of the NEP: all the necessary means for packing, temporary storage and dispatch of SNF are included in the NPP or research reactor.

If the country chooses an ONFC, it is necessary, together with the beginning of the construction of the NPP, start creating the final SNF disposal facility, because world experience shows that the solution of this problem can take several decades. At the same time, it is advisable to start the creation of a temporary storage facility for SNF in the variant of either a near-station or centralized (outside the NPP or research reactor) storage facility.

Temporary storage will also be required in case of a deferred decision; in this case, it is recommended to create a storage of SNF dual-purpose containers, in order that in the event a decision is made to switch to a CNFC, it is easier to organize the export of SNF for reprocessing.

The organization providing the functioning of the NFC in the basic version is (apart from national regulatory and supervisory organizations controlling the development of the nuclear power plant as a whole), is the operator of the NPP.

9. CONCLUSION

The creation of the NEP includes a set of activities, one of which is the development of NFC. The importance of this element is determined, first, by the need to guarantee reliable fuel supply of the NPF being created. In addition, the development of the NFC involves determining the status and the way of SNF management, which is extremely important for creating social support for the development of the NEP and determining the most important characteristics of NFC.

The implementation of the NEP requires responsible and progressive development at all levels of government. Given the long-term nature of nuclear power, over the course of its operation, there is a change in more than one generation of government, and one of the basic requirements is the developed and successive state policy and strategy in the use of atomic energy. Another need is the development of new and/or revision of existing legislative and regulatory acts that regulate all aspects related to the development of the NFC, in accordance with existing international practices. For newcomer countries, tackling such tasks from scratch is a significant challenge, but with an experienced partner and support from international organizations, these countries can develop policies, strategies and legislation that meet modern international standards and the world's leading practices, proven by time.

When developing the policy and strategy of the NEP, one of the most difficult issue is the choice of the NFC type. On what type will be selected - open or closed - depends on infrastructure and economic performance of the entire NEP. An ONFC or a deferred solution requires less initial costs, but in the long term they are more expensive in terms of SNF and RW management than a CNFC. In addition, when choosing in favor of an ONFC or a CNFC, factors of scale, environmental safety, technological, infrastructure, personnel and so on should be taken into account.

The modern international market of NFC services allows newcomers to create an NFC with the maximum use of foreign production facilities. Up to the point that NPF can only receive nuclear fuel from the supplier and immediately after irradiation in the reactor send it for reprocessing, receiving in replacement only radioactive waste, conditioned for further safe disposal.

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