Nuclear Fuel Cycle Activities in Iran

Mohammad Saeidi

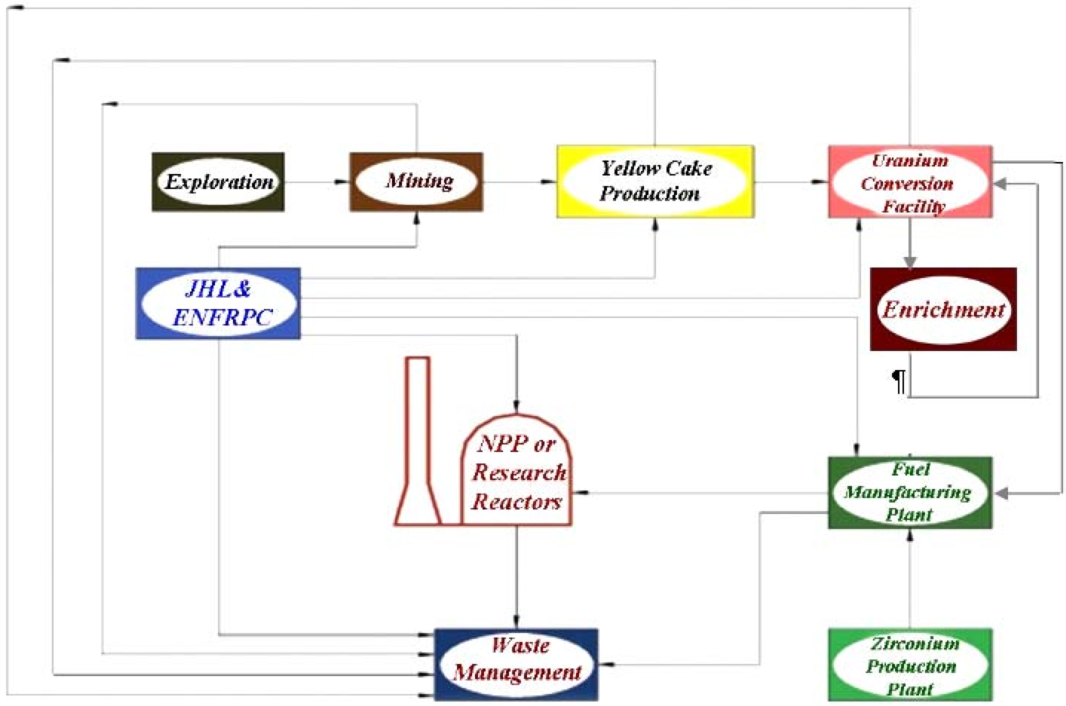
Nuclear fuel cycle activities in Iran for the generation of electricity have been carried out in all of the components except reprocessing. A summary description for each activity (Uranium Exploration, Mining, Milling, Conversion, Enrichment, Fuel Fabrication and Waste Management) is presented here, but the uranium conversion facilities are further emphasized.

Due to the rapid socio-economic development of the country during the past three decades, the strategy for using fossil resources has been affected by two restrictive elements. On the one hand, rising living standards and improvement of economic indicators have prompted increases in energy demand in the domestic and industrial sectors and, on the other hand, Iran's national economy depends on oil revenues. Hence, development of a long-term program to reverse the trend of unrestrained use of fossil resources is needed.

At present, three-quarters or more of the installed power generation capacity in Iran is natural gas-fired, with the remainder either hydroelectric or oil-fired. The nuclear power programs will help free up oil and natural gas resources for export, thus generating additional hard-currency revenues.

The nuclear program of the Islamic Republic of Iran for the production of electricity from nuclear reactors determines the importance of supplying nuclear fuel for the reactors. Activities on the completion of the 1000 MWe nuclear fuel cycle is at an advanced stage and it is expected that the nuclear fuel cycle could be scaled up from 1000 MWe to 7000 MWe up to 2020 and 20 000 MWe up to 2030. *Figure 1* shows activities in the nuclear fuel cycle in Iran.

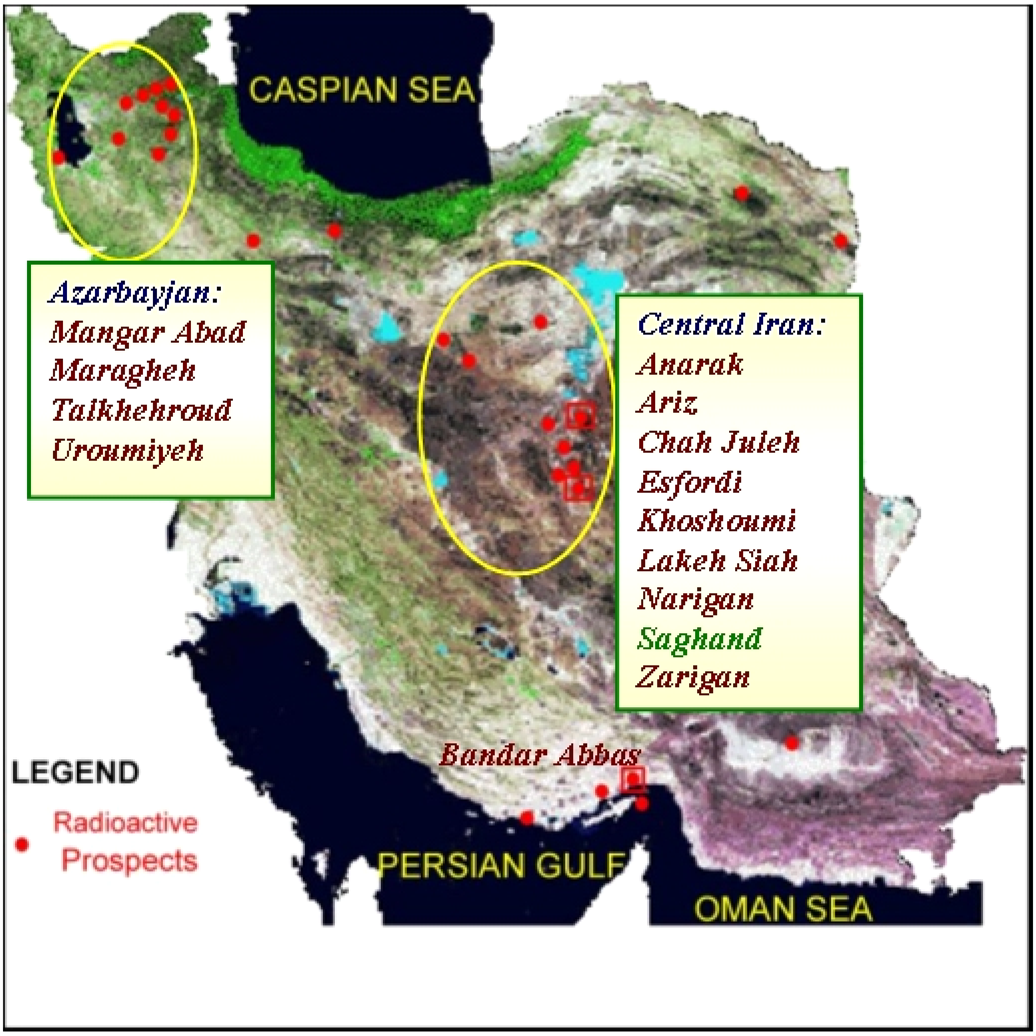
Figure 1 - Nuclear Fuel Cycle in Iran



Uranium Exploration, Mining and Milling

Uranium Exploration: High-tech methods for uranium prospecting in the country have been used by AEOI (Atomic Energy Organization of Iran) since 1974. The reserves discovered so far are estimated to be around 3000 tonnes of uranium. At present, exploration in different phases is being carried out, mainly in the central part of the country (Saghand, Narigan, Khoshoumi, Zarigan, Chah Juleh, Esfordi, Lakeh Siah and Ariz), and work is continuing on the identification of other favourable basins for uranium mineralization. *Figure 2* shows radioactive prospects in Iran.

Figure 2 - Radioactive Prospects in Iran



Saghand Mine: Work in Saghand is being conducted at two mines. The first (an open pit called Mine No.1) has 10% uranium reserves, while the second (called Mine No.2, reached by two shafts) has 90% reserves. The depth of the two shafts is about 357m and they are connected to each other by different routes underground. The total estimated reserves are about 1.58 million tonnes of uranium ore, with an average grade of 553 g/tonne.

More than 78% of the total activities have been undertaken so far and this work progress is in accordance with the formal time schedule. AEOI will be able to extract uranium ore in the first half of 2006 from the mine.

Yellow Cake Production Plant: In the Yellow Cake Production Plant (YCP), 120 000 tonnes of ore (from Saghand mine) with an average concentration of 553 ppm of uranium will be processed annually by acid leaching and resin in pulp method for production of 65 tonnes U_3O_8 annually.

In BUP (Bandar Abbas Uranium Production Plant), uranium will be extracted from ores by two methods: agitation and heap leaching. The plant is under construction now.

Uranium Conversion Facility (UCF)

The UCF, as one of the main components of the nuclear fuel cycle, has been designed and built 15 kilometres south–east of Esfahan. It is used in producing fuel materials for different types of power and research reactors: natural UO_2 powder, enriched UO_2 powder (average 4%) and natural U-metal crude ingots.

The contract for the establishment of the UCF was signed on 9 January 1991 between AEOI and CNNC (China National Nuclear Corporation) for construction of the complex at ENFRPC (Esfahan Nuclear Fuel Research & Production Centre). Although some of the basic work and a few of the detailed design documents were carried out by Chinese experts, later on the design, construction and commissioning were undertaken completely by Iranian experts.

Technology and Engineering of UCF

The facilities in the complex include the main process lines, nuclear auxiliary facilities, offsite auxiliary facilities and common facilities.

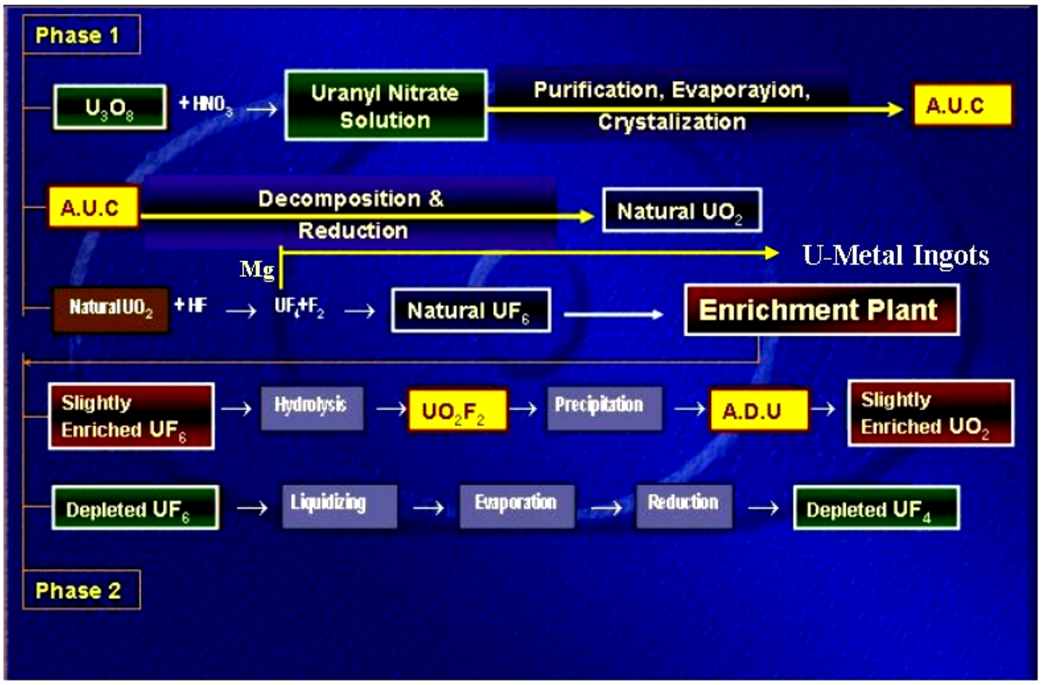
Main Process Lines

The main process lines consist of the following units:

1. Production of natural UF_6.
2. Production of natural UO_2.
3. Production of natural U- metal crude ingots.
4. Production of enriched UO_2.
5. Production of depleted UF_4.
6. Effluent treatment.

Production of F_2 is a complicated chemical process and is produced by electrolyzing of HF and KHF_2. *Figure 3* shows the UCF process flow sheet.

Figure 3 - UCF Process Flow Sheet



Despite the various routes and products of the complex, an attempt has been made to unite the common segments of the routes in order to make the plant as compact as possible. Since the process development activities may require modification in the plant, a flexible design has been considered for possible future expansion. Criticality considerations for any segment of different routes have been made according to the enrichment requirements of the related final products.

The starting material for operation of the complex is natural U_3O_8 in phase I and enriched UF_6 in phase II. The complex is capable of being fed by commercial U_3O_8 (uranium content > 75%). UF_6, as a feed material of the plant, will have average 4% enrichment. Effluents from all units will be collected and treated in a waste treatment unit. Uranium and any valuable products are recovered and harmless fluids and solids are released to the environment.

The complex has been designed with a high standard of safety against toxic and hazardous materials, fire, reactive gases explosion, radioactive exposure and environmental pollution.

Construction and Installation

Iranian companies carried out the construction and installation of the UCF. They supplied the main equipment, auxiliary equipment and installation materials, with technical support from AEOI experts.

Commissioning

In first experience, the UCF was operated tentatively and tested for a duration of 76 days (13 March to 27 May 2004) for the conversion of almost 1240 kg U_3O_8 98% to natural UF_6. The process lines that were tested consist of the following units:

Unit 101K – Conversion of U_3O_8 to AUC

The purpose of the process in Building 101K is the purification of uranium and the preparation of ammonium uranyl carbonate (AUC) for further conversion to natural UF_4 in Building 101B. The design capacity for the U_3O_8 purification section is to produce 220 tonnes uranium or 482.52 tonnes of dry AUC as an intermediate product.

The uranium purification process is used to treat natural U_3O_8 for producing AUC by a series of wet processes. The main process consists of four steps, i.e. 1) dissolution; 2) extraction; 3) evaporation; and 4) AUC precipitation.

In the dissolution process, $UO_2(NO_3)_2$ solution is produced by reaction of U_3O_8 with nitric acid below boiling point temperature in a mixing reactor. The chemical reactions of dilute and concentrated nitric acid with U_3O_8 are as follows:

$$3U_3O_8 + 20HNO_3^{diluted} \rightarrow 9UO_2(NO_3)_2 + 2NO\uparrow + 10H_2O$$

$$U_3O_8 + 8HNO_3^{concentrated} \rightarrow 3UO_2(NO_3)_2 + 2NO_2\uparrow + 4H_2O$$

Nitric acid oxidizes uranium from lower oxidation states to the hexavalent uranyl ion in solution, with the production of a mixture of nitrogen oxide and nitrogen dioxide. In dilute acid the reaction produces mainly NO, in concentrated acid the product is mainly NO_2. Since both of these conditions are met in batch digestion, the composition of the fumes may vary during the course of the digestion.

The gas produced is evacuated from the reactor and the insoluble materials are also removed by vacuum filters. A stream including uranium and acid-soluble impurities enters into a holding tank in $UO_2(NO_3)_2$ solution. The purification area contains four pulse columns (extraction, scrubbing, stripping and solvent recovery columns).

$UO_2(NO_3)_2$ solution is fed to the top of the extraction column whilst the solvent (TBP & kerosene) enters at the bottom of the column. In this case the $UO_2(NO_3)_2$ solution with soluble impurities from the dissolution procedure is mixed with organic extractant to transfer $UO_2(NO_3)_2$ from aqueous phase into organic phase, leaving most impurities in the aqueous phase. The rich extracted stream from the top of the extraction column enters the bottom of the scrub column and raffinate leaving the bottom of the extraction column is sent to an auxiliary system in Building 101A for uranium and HNO_3 recovery.

In the scrub column, the organic phase is washed with acidified water and the organic stream is then transferred to the stripping column.

In the stripping column, the organic phase stream enters the bottom of the strip column and acidified water is fed to the top of the column. The aqueous product from the bottom of the column is a pure solution of uranyl nitrate, which is sent to a storage tank. Stripped solvent from the top of the stripping column is transferred to the next pulse column in order to recover the organic solvent.

Purified $UO_2(NO_3)_2$ solution is concentrated by evaporation in two–stage evaporators in the evaporation section and is then fed to the next section for reaction by $(NH_4)_2CO_3$ solution in a mixing reactor. AUC is collected in vacuum filters and finally is packaged for transfer to Building 101B for conversion to natural UF_4.

Unit 101B – Conversion of AUC to UF_4

The section 101B is a production building, supplying intermediate product-UF_4 with an annual output of 285.8 tonnes for both UF_6 production (with a yield of 200 tonnes uranium as UF_6 per year) and natural U-metal production line (with a yield of 10 tonnes uranium annually). UF_4 production consists of two procedures:

1. Decomposition and Reduction of AUC.
2. Hydrofluorination of UO_2.

The decomposition and reduction of AUC is a complicated process and its reaction mechanism can be described in many ways. The project process was designed and based on the following chemical reaction:

$$(NH_4)_4[UO_2(Co_3)_3] \rightarrow UO_2 + 2NH_3 + 2CO_2 + H_2 + N_2 + CO + 4H_2O$$

A rotary reactor is used in order to carry out the decomposition and reduction of AUC. The AUC containers are fed into the feeder of the rotary reactor, and then added quantitively into the reactor through the feeding hole at one end of the reactor by the screw conveyer that is a part of the reactor. The temperature and pressure in the reactor are controlled within a suitable range to carry out the decomposition and reduction of AUC. UO_2 is dropped into the material seal hopper through the discharging hole at the other end of the reactor, and then sent to the hydrofluorination procedure for producing UF_4.

However, the rotary reactor runs stably, the production margin is wide, the composition and reduction processes can be completed in the same reactor, and the reducible gas generated in the decomposition process can be fully used without adding any other reducing agent.

The hydrofluorination of UO_2 is a reversible reaction:

$$UO_2 + 4HF \Leftrightarrow UF_4 + 2H_2O$$

In order to make the above-mentioned reaction favourable for the generation of UF_4, a two-stage horizontal stirred-bed was selected. UO_2 and anhydrous hydrogen fluoride are made to run counter currently to each other to form certain gradient both in temperature and in concentration which is beneficial to the regeneration of UF_4.

For this reactor, which consists of two horizontal stirred-beds, the operation is stable, the temperature and concentration gradients are easy to control, the requirement of reaction kinetics can be met, and qualified intermediate product UF_4 is obtained.

In this section the decomposed and reduced UO_2 is transferred to the feeder of the hydrofluorination procedure where it is stored temporarily, and it is quantitatively added into the low temperature end in the first hydrofluorination reactor. Under the action of the agitator blades in the reactor, solid material is forced to move to the high temperature area and reacts with gaseous hydrogen fluoride, having reacted in the second hydrofluorination reactor. Large amounts of UO_2 are converted into UF_4 at the first reactor. The mixture of UO_2 and UF_4 is forced from the high temperature area of the first reactor into the low temperature area of the second reactor. When the solid material is transferred into the high temperature area of the second reactor, it will react with AHF, preheated to complete the hydrofluorination of UO_2. The qualified UF_4 thus obtained is discharged into the hopper for temporary storage. Under the prerequisite of a given material seal height, UF_4 can be discharged into the container by the screw conveyer and transported either to the fluorination section in Building 101C for producing UF_6 or to Building 104 for producing natural U-metal.

Unit 101C – Conversion of UF_4 to UF_6

The design was based on the requirements in UCF. Its annual production capacity was designed to be 200 tonnes uranium of UF_6.

The UF_6 production includes three sections, i.e. fluorination of UF_4, condensation of UF_6 and treatment of tail gas. In the fluorination section, UF_4 powder reacts with gaseous F_2 to produce UF_6. Its reaction formula is as follows:

$$UF_4 + F_2 \rightarrow UF_6 + 263.5kj / mol$$

The process flow for the fluorination procedure consists of the following systems:

- N_2 supply system.
- F_2 compression and heating system.
- Fluorination system in the vertical fluorination reactor.
- Vacuum suction system.

In the fluorination section, reaction of UF_4 with gaseous F_2 is a chemical reaction, while in the condensation section the procedure is a physical process.

In the condensation section, UF_6 gas contained in furnace gas is condensed into solid state of UF_6 in a condenser, and procedures, such as replacement of F_2 by N_2, release of HF, heating, liquification and sampling for analysis are performed. Finally, product UF_6 is stored in the 48X cylinders and transported to the next procedure. Condensation process flow consists of the following systems:

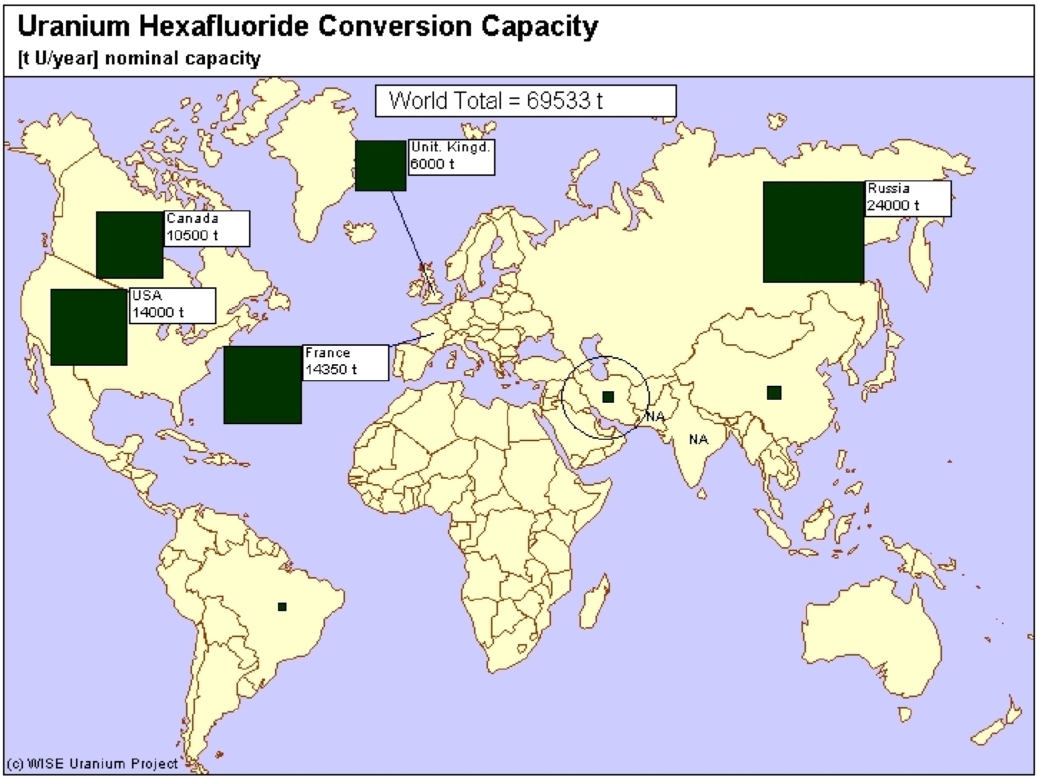
- Condensation system.
- Liquefaction and charring system.
- Freezing system.
- Vacuum system.
- Softened water-circulating system.
- Liquid UF_6 sampling system.

In the tail gas treatment section, the purpose is to treat the tail gas from the condensation procedure, that is, to recover uranium and decrease contents of harmful substances, such as F_2, HF, U and so on.

Uranium conversion plays an important role in the nuclear industry. There have been attempts to achieve nuclear fuel production by many countries, but only a few countries (Brazil, Canada, China, France, Russia, United Kingdom, and United States) and now Iran are capable of producing this material. Although there have been technical problems and international pressure, the design was completed by Iranian experts and the Iranian companies carried out construction and installation of UCF. They supplied the main equipment, auxiliary equipment, installation materials with the technical support of AEOI experts. Finally, UCF operated tentatively and was tested for the duration of 76 day successfully. *Figure 4* shows uranium hexafluoride conversion capacity in world.

Figure 4 - Uranium Hexafluoride Conversion Capacity in World

(Ref: Wise Uranium Project)



Fuel Enrichment Plant (FEP): The Fuel Enrichment Plant is located in central Iran, 250 km South of Tehran and near a small town called Natanz. UF_6 produced in UCF will be shipped to the plant for enrichment up to 4% average. This would require the presence of 54 000 centrifuge machines.

The product and tails again will be sent back to UCF for production of slightly enriched UO_2 powder and depleted UF_4.

Zirconium Production Plant (ZPP): The primary objective in the ZPP is producing 50 tonnes of zirconium sponge per year, 10 tonnes of tube and 2 tonnes of strip and bar from zirconium alloys annually as the main product and 100 tonnes of magnesium and 5 tonnes of hafnium as by-product annually. In addition to the above-mentioned products, the production line of this plant would be capable of producing further industrial products. Briefly, these products and capabilities are:

Production of pure magnesium, zirconium alloys, titanium and its alloys, the ability to cast ferrous and non-ferrous metals, the formation of stainless steel, ferrous and non-ferrous metals.

Fuel Manufacturing Plant (FMP): The annual production capacity of FMP is about 30 tonnes fuel for a 1000 MWe nuclear power plant and 10 tonnes fuel for research reactors.

The activities on the design and construction of buildings and equipment are underway and it is predicted that commissioning will be in 2008.

Nuclear Reactors: In order to determine the optimal shares of different types of power plants in supplying electrical energy need within the next 25 year, Iran conducted a survey following the WASP model, a widely known model for optimizing energy supply. Based on the results of this survey, a scenario was chosen (namely the production of 19 000 MW nuclear electricity in addition to the 1000 MW Bushehr power plant) as the backbone of the plans for the development of nuclear power plants.

What is noteworthy at this point is the decision and determination to diversify the range of nuclear power plants and at the same time to focus on those types of plants that can be designed and built on the basis of the nuclear knowledge that has been developed in the country.

In its long-term program, utilizing other types of power plants is being considered, including Heavy Water Reactors (HWR), in addition to the LWR that is now in Bushehr. The use of HWR, which is more amenable to indigenous development, will enable the country to use natural uranium for producing nuclear fuel.

The Tehran Research Reactor (TRR), a pool type reactor with a maximum thermal capacity of 5 MW, is under operation but is very old, so AEOI is constructing a Heavy Water Reactor (HWR) for the research and production of essential radioisotopes.

Waste Management: Waste management includes all administrative and operational activities in handling, treatment, conditioning, transportation, storage and disposal of radioactive waste.

The objective of waste management is to protect human beings and their environment now and in the future without imposing undue burdens on future generations.

The Waste Management Department of AEOI is responsible for the management of radioactive waste. At the present time, in addition to the management of current institutional waste, WMD is trying to develop the required infrastructure for safe management of wastes for future generation from the operation of NPPs and the nuclear fuel production program through technical cooperation projects with IAEA.

Design Activities for Development of Nuclear Fuel Cycle: By decisions of the government it has been decided to produce 7000 MWe nuclear energy by the year 2020. Nuclear power plants will be constructed to produce this amount of energy in various parts of the country and it is necessary to provide their fuels.

For the fulfillment of this requirement, as a first step, design activities have been started by the nuclear fuel production division under the Nuclear Fuel Cycle Development project (NFCD) in three subprojects: Yellow Cake Production (or Purchased) Project, Uranium Conversion Project, and Fuel Fabrication Project.