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Potential vulnerabilities of nuclear fuel cycle facilities to the year 2000 (Y2K) issue and measures to address them

May 1999

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POTENTIAL VULNERABILITIES OF NUCLEAR FUEL CYCLE FACILITIES TO THE YEAR 2000 (Y2K) ISSUE AND MEASURES TO ADDRESS THEM
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FOREWORD

In resolution GC(42)/RES/11 on "Measures to Address the Year 2000 (Y2K) Issue", adopted on 25 September 1998, the General Conference of the International Atomic Energy Agency (IAEA) — inter alia — urged Member States “to share information with the Secretariat regarding diagnostic and corrective actions being planned or implemented by operating and regulatory organizations at ... fuel cycle facilities ... to make those facilities Year 2000 ready”, encouraged the Secretariat, “within existing resources, to act as a clearinghouse and central point of contact for Member States to exchange information regarding diagnostic and remedial actions being taken at ... fuel cycle facilities ... to make these facilities Year 2000 ready”, urged the Secretariat “to handle the information provided by Member States carefully” and requested the Director General to report to it at its next (1999) regular session on the implementation of that resolution.

The exchange of information and experience among Member States is an essential component of the IAEA’s action plan for addressing the Y2K problem. The objective is to enable Member States to identify any gaps in their own conversion programmes, benefit from the experience of others in developing remedial actions and establish the basis for further action to solve remaining problems.

During 24–26 March 1999, the IAEA convened a Specialists Meeting on the Potential Vulnerabilities of Nuclear Fuel Cycle Facilities to the Year 2000 (Y2K) Issue and Measures to Address Them. Governments were invited to designate participants who are experts in Y2K issues, particularly where these related to digital equipment at nuclear fuel cycle facilities. Experts from Belgium, Canada, France, Germany, Japan and the United Kingdom attended the meeting and prepared a draft of this report which addresses means of dealing with the Y2K problem in nuclear fuel cycle facilities.

The IAEA wishes to thank the experts who took part in the preparation of this report for their valuable contribution. The IAEA is also grateful to the Member States and individual organizations for their generous support in providing experts to assist in this work. The IAEA officer responsible for this publication is R. Shani of the Division of Nuclear Fuel Cycle and Waste Technology.

DISCLAIMER

It is the responsibility of each Member State to ensure that all its equipment is Y2K compliant or ready. In these circumstances, it is for each Member State to evaluate the information received from the IAEA and make its own independent judgement as to the value and applicability of that information with respect to Y2K compliance or Y2K readiness in that Member State. Accordingly, the IAEA cannot accept any responsibility or liability with respect to the use by a Member State of any information received from the IAEA relating to the Y2K issue.

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1. INTRODUCTION

Computer-based systems are widely used in nuclear fuel cycle facilities, for example, during operations and data processing and storage. Y2K induced events are events that arise from a date related problem that is experienced by a software system, a software application, or a digital device at a key rollover date when the system, application or device does not perform its intended function. 31 December 1999 to 01 January 2000 and 28 February 2000 to 29 February 2000, are examples of key rollover dates. The problem may arise because of incorrect representation of date by using two-digit year field or not identifying year 2000 as a leap year. Y2K problems can affect operation of mainframes, desktops, local area networks or digital control system including embedded systems.

The problem may impact nuclear fuel cycle facilities in a number of ways because embedded systems are used in routine operation and control systems. A general-purpose definition of embedded systems is that they are devices used to control, monitor or assist the operation of equipment, machinery or plant. “Embedded” reflects the fact that they are an integral part of the system. All embedded systems are or include computers or microprocessors. We can find such systems in all nuclear fuel cycle facilities, dealing with hazardous or radioactive materials, from milling to conversion and enrichment, from fuel fabrication to reprocessing and spent fuel storage.

There are further date problems associated with the application of computer-based systems. It may happen that the year 2000 is not correctly identified as a leap year with the risk of failure on 29 February 2000, or 31 December 2000, which is the 366th day of that year. Another critical date is even earlier, for example, 09 September 1999 (9/9/99). This date is important for systems handling the year with two digits because 99 (or 9999) was used as an end-of-file marker or "STOP" code. Date related problems can affect the proper functioning of computer-based systems and may lead to errors or malfunctioning in operations and the management of records and files. Such errors or malfunctioning may result in safety problems which have to be avoided.

The severity and extent of the date problem in computer-based systems, simply referred to as "year 2000" or "Y2K" problem, for nuclear fuel cycle facilities and activities should be evaluated and, as necessary, measures should be taken in order to ensure safe operations at all times.

The IAEA was requested by a resolution of the General Conference in September 1998 [1] to deal with the Y2K problem and act as a focal point of contact for Member States to exchange information regarding diagnostic and remediation actions being taken at nuclear power plants, fuel cycle and/or medical facilities which use radioactive materials to make these facilities year 2000 ready. The IAEA, amongst other activities, has developed a set of reports [2, 3, 4], including the present report, which addresses the potential vulnerabilities of nuclear fuel cycle facilities to the Y2K issue.

In the nuclear fuel cycle the types of facilities and activities can be very diverse. They may range from the refining of uranium ore to the reprocessing of spent fuel discharged from nuclear power plants. The need for and the use of computers in various nuclear fuel cycle facilities and activities is also very diverse. It may range from fully computerized processes to the total lack of computer applications, in particular in simple nuclear fuel cycle processes or steps.

In view of this situation and the fact that the time for remediation of eventually existing Y2K problems is very short, this report on the potential vulnerabilities of nuclear fuel cycle facilities to the year 2000 (Y2K) issue and measures to address them, may help to establish readiness for the Y2K problem in time.

2. TYPES OF NUCLEAR FUEL CYCLE FACILITIES

The nuclear fuel cycle may be broadly defined as the set of processes and operations needed to manufacture nuclear fuels, to irradiate them in nuclear reactors and to treat and store them, temporarily or permanently, after irradiation. Several nuclear fuel cycles may be considered depending on the type of reactor and the type of fuel used and whether or not the irradiated fuel will be reprocessed. A generalized nuclear fuel cycle which encompasses all the major options is shown schematically in Fig. 1 and described below.

Uranium mining and ore processing. Uranium is mined by conventional methods (either open pit or underground). Uranium ores usually contain 0.1 to 0.2% U_3O_8 (1 to 2 kg/t) although higher grades have been found in several cases. The ores are processed to produce concentrates with a content of 70% U_3O_8 or higher. Several processes, such as acid leaching, alkaline leaching, heap leaching and in situ leaching, are available for this purpose. Uranium is also recovered industrially from wet process phosphoric acid and copper ores and may, in principle, be recovered from other non-conventional resources such as coal ashes and sea water.

Uranium refining and conversion. Commercial grade uranium concentrates are dissolved in nitric acid, purified by solvent extraction and precipitated as a nuclear grade material, usually ammonium diuranate. This is calcined to uranium trioxide and then reduced to uranium dioxide, which is used to fabricate fuel for heavy water reactors. Light water reactors, however, use enriched uranium as fuel and the enrichment processes currently in use require uranium hexafluoride as feed material. Uranium hexafluoride is produced from the dioxide in two main steps: uranium dioxide is converted to uranium tetrafluoride by hydrofluorination and the tetrafluoride is then converted to hexafluoride by fluorination with elemental fluorine. Gas cooled reactors use enriched metallic uranium as fuel and this is produced by reduction of the tetrafluoride with calcium or magnesium.

Uranium enrichment. Natural uranium consists of three isotopes: ^{238}U (99.28% by mass), ^{235}U (0.711% by mass) and ^{234}U (0.0054% by mass). Uranium-235 is fissionable by thermal neutrons and is the only naturally occurring uranium isotope which can be used as nuclear fuel. Heavy water reactors can use natural uranium as fuel (i.e. uranium with the naturally occurring isotopic distribution) but light water reactors require uranium enriched to about 3.5% ^{235}U (low enriched uranium). Two enrichment processes are currently in industrial use: gaseous diffusion and centrifugation. Both processes require uranium hexafluoride as feed material. New enrichment processes, such as atomic vapour laser isotopic separation (AVLIS), are being developed but have not yet reached the stage of industrial application.

Reconversion. Enriched uranium hexafluoride is reconverted to ceramic grade uranium dioxide which is then used to manufacture fuel for light water reactors.

Fuel fabrication. Ceramic grade uranium dioxide powder (either natural or enriched) is cold pressed into pellets. These 'green' pellets are then sintered at high temperature (between 1400 and 2000°C) under vacuum or in a controlled atmosphere. The sintered pellets are rectified to precise dimensions, washed, dried and clad in metal (Zircaloy, stainless steel or aluminium) tubing to form fuel pins. The pins are filled with helium under pressure, sealed and arranged into fuel assemblies ready to be introduced into the reactors.

Irradiation. The finished fuel is inserted in nuclear reactors and irradiated, i.e. nuclear fission reactions are allowed to take place, thereby releasing energy which is used to generate electricity. The amount of energy that can be obtained from a given amount of uranium depends on the type of reactor used, the degree of burnup achieved and other variables. One metric tonne of unenriched uranium dioxide can produce approximately 30 million kilowatt-hours of electricity.

At reactor spent fuel storage. A 1000 MW(e) reactor will discharge every year about 30 metric tonnes of spent fuel, depending on the burnup. When spent fuel is removed from the reactor it is highly radioactive and generates a considerable amount of heat, of the order of 10 kW/t of heavy metal. The fuel must be stored in water pools at the reactor site for a minimum cooling down period of 150 days or more, depending on the degree of burnup. Water serves as shielding and as a cooling medium to dissipate the heat released by the fuel elements. After this cooling down period the fuel may be sent to an away from reactor storage facility for interim storage (for several decades or longer), to a reprocessing facility or to other facilities for conditioning and long term storage (up to several centuries).

Away from reactor (AFR) spent fuel storage. Some facilities for the interim storage of spent fuel are currently in operation and the capacity of existing reprocessing plants is very limited. At the same time, the available capacity of at reactor storage pools is being rapidly used up. Under these conditions it has become imperative to design and build facilities for away from reactor storage of spent fuel for periods of several decades or more.

Disposal of spent fuel. After being properly conditioned, spent fuel can be disposed in deep geological formations for an indefinite period (of up to several centuries). As indicated above, no facilities for disposal of spent fuel are currently in operation although several are under study. The first large scale facilities are expected to become operational in the years 2000 to 2020.

Spent fuel reprocessing. Spent fuel contains about 1% of 'unburned' ^{235}U, more than 90% of the ^{238}U originally present in the fresh fuel, between 0.5 and 1% of ^{239}Pu and ^{240}Pu, small amounts of ^{237}Np and other higher actinides and fission products. The unused uranium and the plutonium can be recovered by reprocessing the spent fuel, i.e. by chemically separating its various components. The recovered plutonium can be used to produce mixed oxide fuels for light water reactors or fuel for fast breeder reactors. The recovered uranium can be converted to uranium hexafluoride, enriched and reused as fuel for light water reactors.

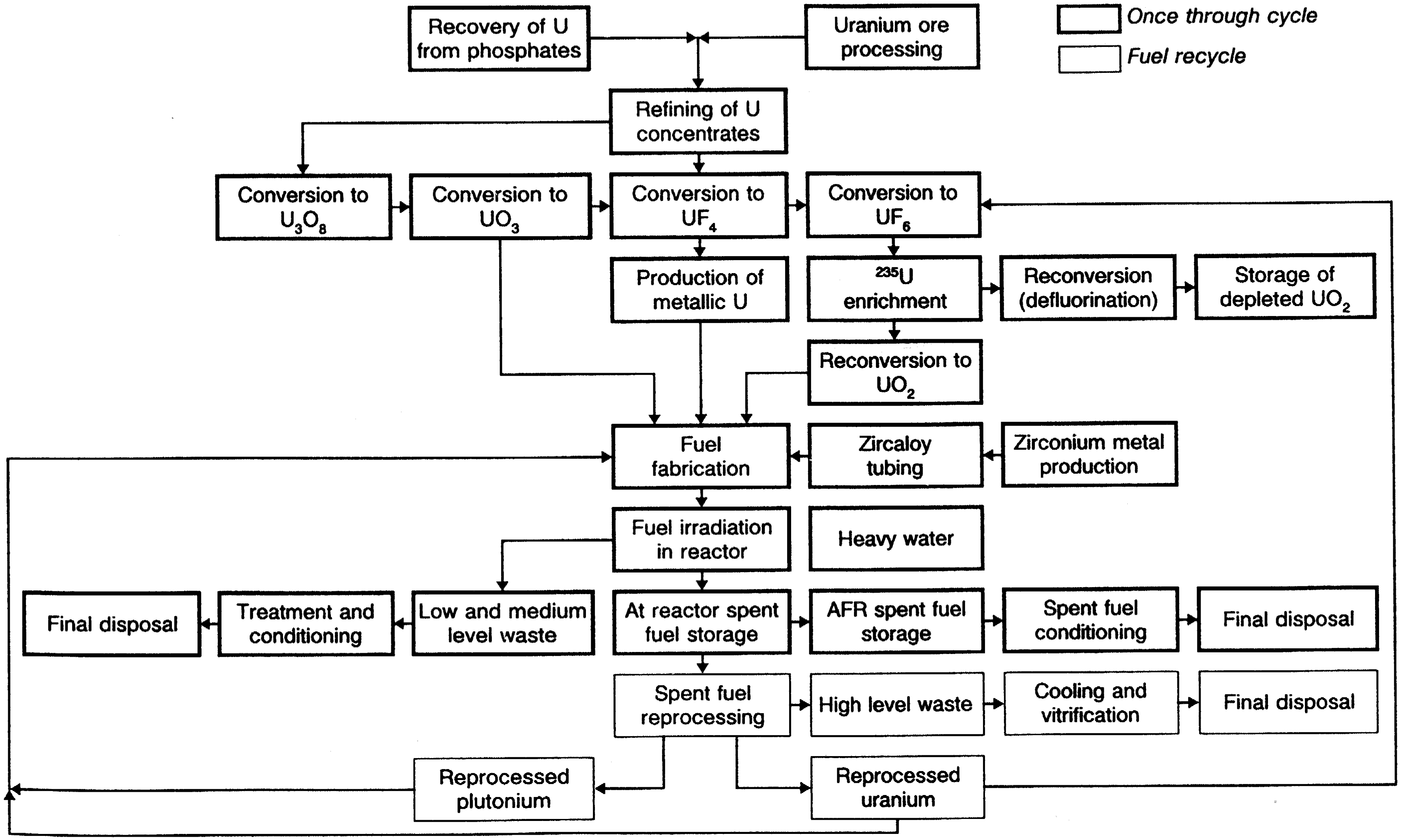

FIG. 1. *Generalized nuclear fuel cycle.*

3. GENERAL CONSIDERATIONS

3.1. Basic steps in the nuclear fuel cycle

In this section a brief description of the typical processes used in the refining, conversion, enrichment, fuel fabrication and reprocessing stages is given. A general overview of the process material streams and routes in the front end facilities of the nuclear fuel cycle is shown in Fig. 2.

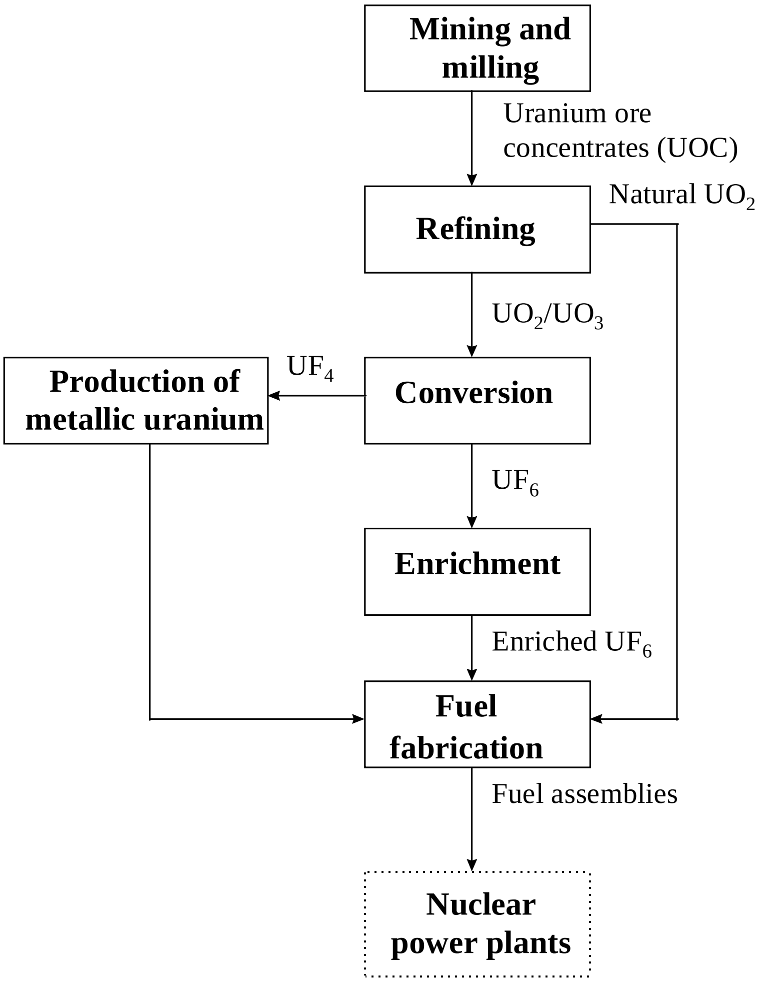

FIG. 2. Simplified scheme of the front end of the nuclear fuel cycle.

3.1.1. Refining

Refining for the purpose of this report is defined as the processing of uranium ore concentrates (UOC) to produce uranium trioxide (UO_3) or uranium dioxide (UO_2). This process may be carried out on a single site or as part of an integrated process involving different sites.

A general sequence of different processes resulted in UO_3 and UO_2 production is presented in Fig. 3 and briefly described below.

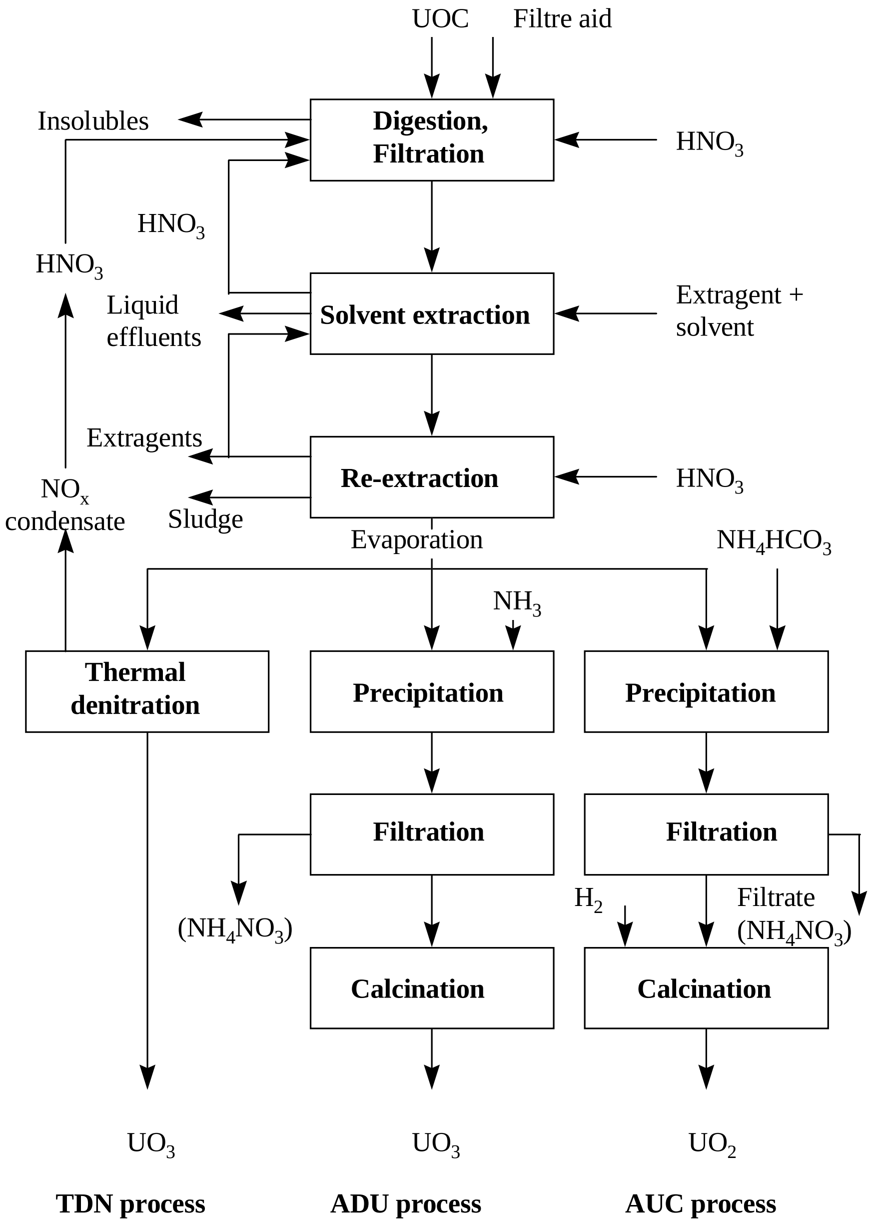

FIG. 3. Refining processes to produce UO_3 / UO_2.

3.1.1.1. Purification

All refining processes have a common initial purification stage. Uranium ore concentrate is dissolved in nitric acid and then purified from a broad spectrum of impurities with a purification factors from 100 to 1000 by solvent extraction using, for example tributyl phosphate (TBP). Then the purified product is re-extracted from the organic phase to the aqueous phase forming so called uranyl nitrate liquor (UNL).

3.1.1.2. UO_3 and UO_2 production

Three basic processes are usually used to produce UO_3 and UO_2 from the purified UNL.

Thermal denitration (TDN) process

After the concentration of uranyl nitrate liquor, thermal dehydration and denitration are conducted in one single step. Uranium trioxide obtained is a fine powder with low reactivity.

Ammonium diuranate (ADU) process

After the concentration of uranyl nitrate liquor, ammonium diuranate (ADU) is obtained by the precipitation of the uranium from the UNL using ammonia. ADU is separated from the liquid phase by filtration and then dried and calcinated to UO_3 at 250–350°C.

Ammonium uranyl carbonate (AUC) process

UNL is treated with ammonia bicarbonate to form ammonium uranyl carbonate (AUC) as a solid precipitate. This is separated from the solution, dried with methanol and then calcinated with hydrogen directly to UO_2.

3.1.2. Conversion

Conversion, for the purpose of this report, is defined as the processing of UO_3 or UO_2 to produce uranium hexafluoride (UF_6)[1] . UF_6 is the only uranium compound that is suitable for performing enrichment because of its thermal stability and relatively high volatility. All current enrichment processes are based on the use of uranium hexafluoride. The flowchart of UF_6 production is presented in Fig. 4. This process has the following stages: reduction (if necessary), hydrofluorination and fluorination.

3.1.2.1. Reduction stage

The UO_3 is reduced to UO_2 by reaction with hydrogen or cracked ammonia in different kinds of reactors equipped with either moving bed, fluidized bed or rotary kiln. Reduction is carried out using hydrogen in a counter-current process.

3.1.2.2. Hydrofluorination stage

Two different technologies are used for converting UO_2 to UF_4: wet process and dry process. In the wet process, UO_2 is converted to UF_4 by reaction with aqueous hydrofluoric acid. UF_4 is then precipitated from the solution. The only material arising from the wet process is some calcium fluoride from neutralization of unreacted HF by lime $Ca(OH)_2$.

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[1] Although, uranium tetrafluoride can also be used, e.g. for production of metallic uranium.

In the dry process UO_2 reacts with gaseous HF. Any excess HF is recovered in the form of dilute hydrofluoride (DHF). This DHF has a very low uranium content and is reused in the chemical industry. Thus no significant waste is generated by dry process.

3.1.2.3. Fluorination stage

UF_4 reacts with fluorine to form UF_6 either in a flame reactor or a fluidized bed reactor which uses calcium fluoride as an inert bed. The tail gases from the flame reactor process contain residual UF_6, F_2 and HF. These substances are recovered by treating the gases with potassium hydroxide (KOH). The spent KOH is regenerated by reaction with lime. The fluorides are precipitated as CaF_2 which is stored as non-radioactive waste. Gaseous products from both processes are recycled within the plant.

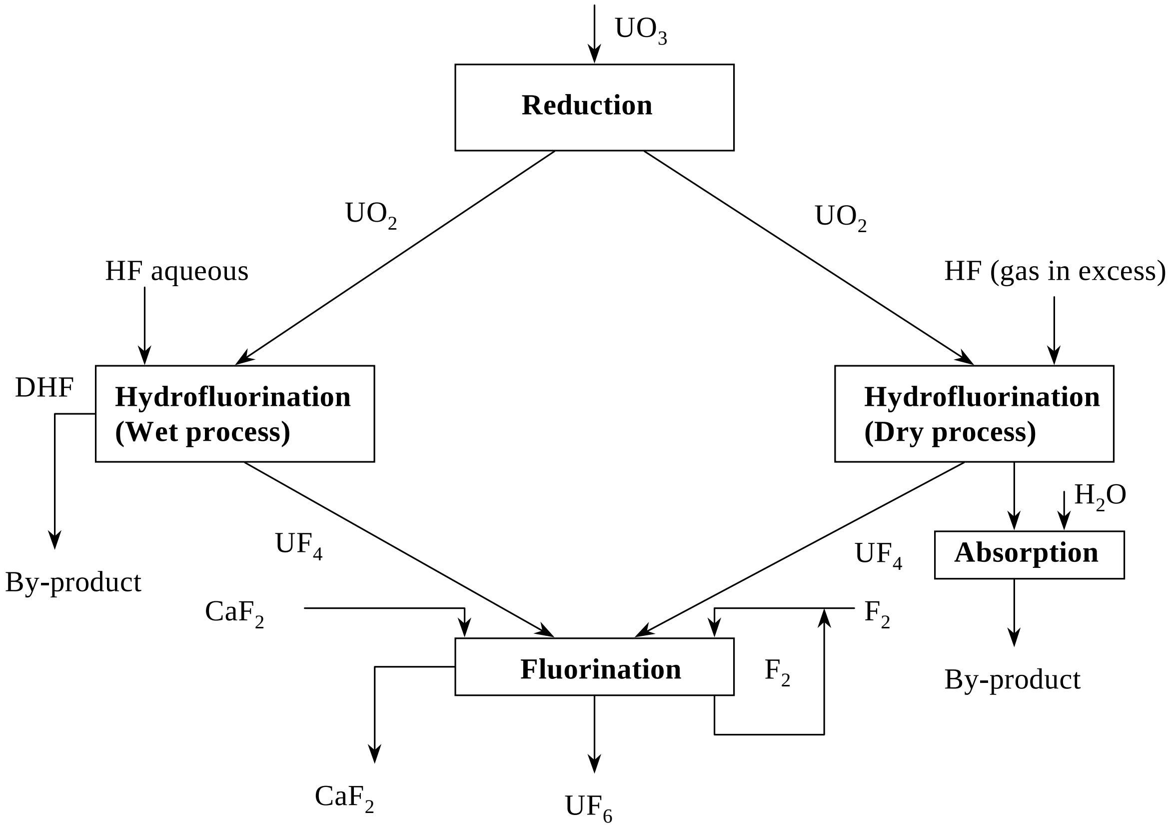

FIG.4. Conversion of UO_3 to UF_6.

3.1.3. Enrichment

Enrichment involves increasing the proportion of ^{235}U, from the natural level of 0.7% to an average level of 3–5%, in UF_6. This can be done mainly by two different industrial methods: gaseous diffusion and centrifugation (Fig. 5).

Gaseous diffusion enrichment is based on different diffusion rate of gaseous $^{235}UF_6$ and $^{238}UF_6$ through membranes. The lighter $^{235}UF_6$ diffuses slightly quicker than the $^{238}UF_6$. Repetition of the operation in cascade diffusion columns leads to increasing degrees of the enrichment to the required level. Owing to the high number of steps needed to reach the desired degree of enrichment the plant tends to be very large, and the compression and circulation of the gases is very power intensive.

In the centrifuge process enrichment is achieved by differential centrifugation. The lighter ^{235}U is separated from the heavier ^{238}U when injected as UF_6 into a high speed centrifuge. Cascade arrangement of centrifuges leads to a progressively enriched fraction. Centrifugation is more efficient than the diffusion process, thus the plant is smaller for the same output and the energy consumption is significantly lower.

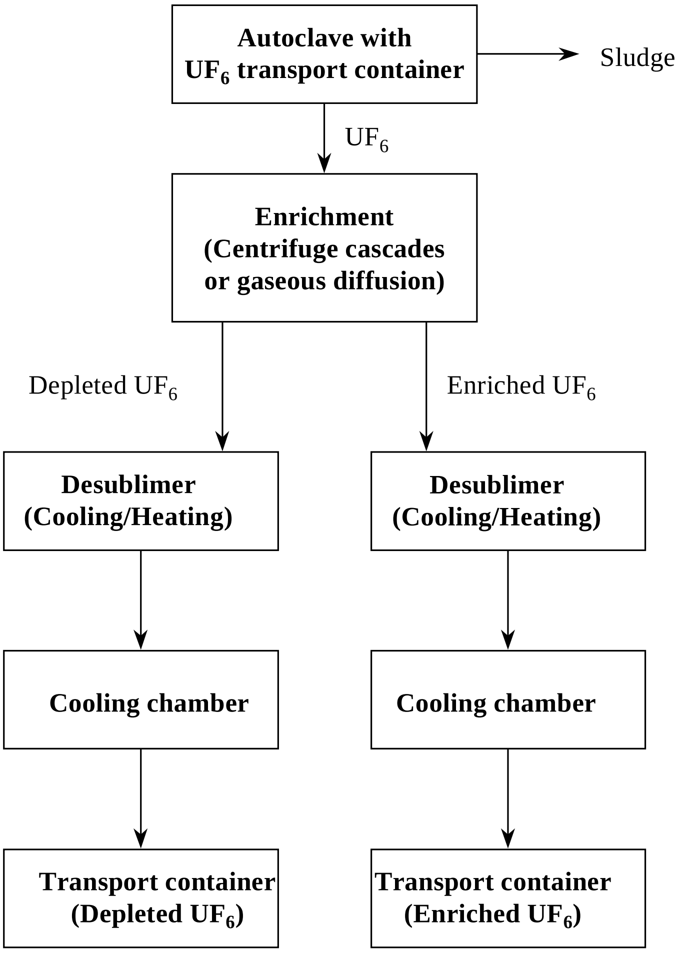

FIG. 5. Flowsheet of the enrichment processes.

3.1.4. *Fuel fabrication*

For fuel fabrication, two products, uranium dioxide and metallic uranium are used as starting materials. Only natural uranium is used for production of metallic uranium fuel. When uranium dioxide is used for fuel fabrication it can be both natural or enriched.

3.1.4.1. Uranium dioxide production

There are three basic processes for the production of UO_2 powder for fuel fabrication: ammonium uranyl carbonate (AUC) process, ammonium diuranate (ADU) process and integrated dry route (IDR) process. These processes are schematically shown in Fig. 6.

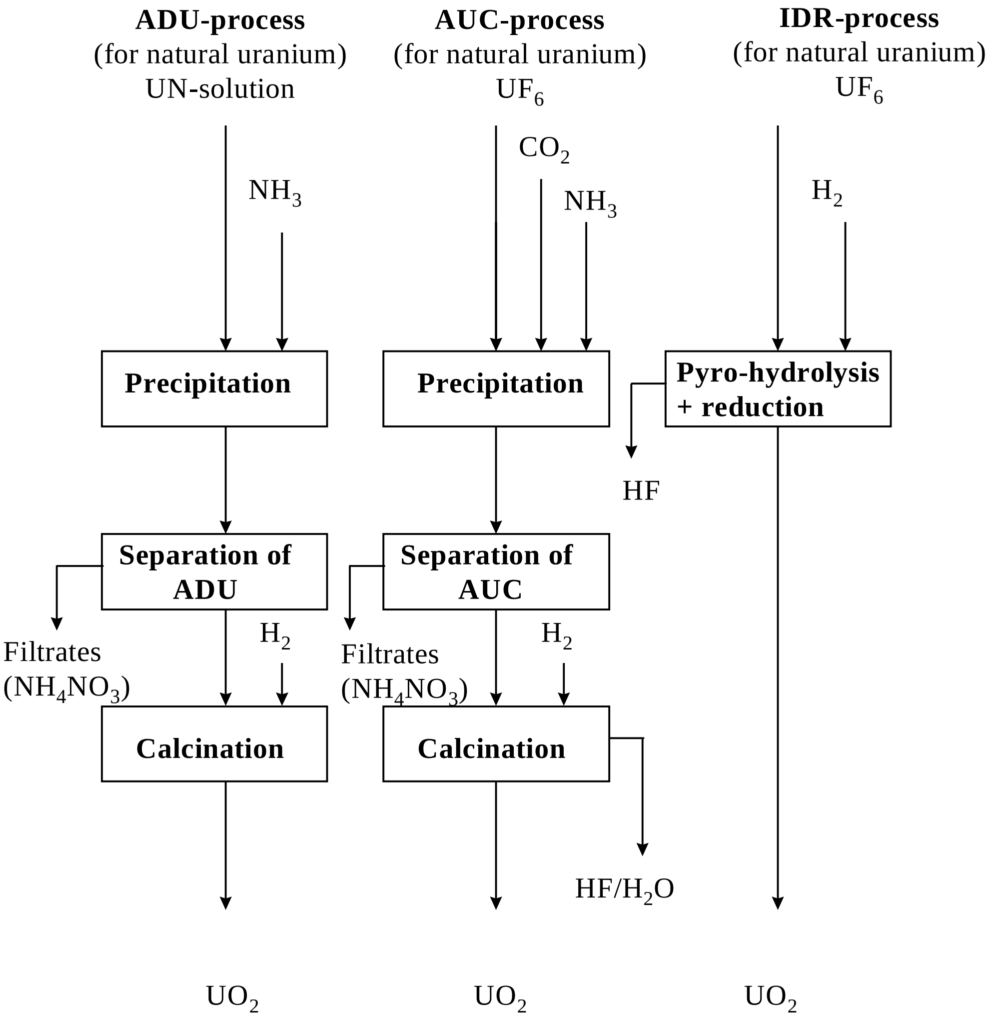

FIG. 6. Processes to produce UO_2.

The AUC process may be used to produce natural or enriched UO_2. The starting material to produce natural uranium may be uranium ore concentrate, or uranyl nitrate liquor. For enriched UO_2 the starting material is UF_6.

The ADU process is primarily used to prepare natural UO_2 powder used for CANDU type reactors. The starting material for the ADU process is uranyl nitrate liquor. This may be prepared directly from the refining process or by the dissolution of UO_3 or other uranic compounds.

The IDR process is used to produce enriched UO_2, via a single stage starting with enriched UF_6.

3.1.4.2. Uranium dioxide fuel fabrication

Most of the power reactors use uranium dioxide fuel in form of pellets sealed inside a metal cladding. Both natural and enriched uranium are used. The major reactor systems are light water reactors (LWRs) which utilize enriched UO_2 as fuel, and zirconium alloys as cladding material.

While there are variations in both the cladding material and the enrichment of the fuel, the main manufacturing process from the UO_2 powder to the finished fuel is basically the same. Therefore, only one process description is provided which identifies the major stages involved.

The UO_2 powder is first blended to provide an homogenized powder batch. U_3O_8 or other additives may be added if necessary. In specific cases, for fuel containing a neutron poison (e.g. gadolinium) the gadolinium/UO_2 mixture is prepared at this stage. All operations involving neutron poisons are carried out separately in a special facility. The blended powder is pre-compacted and granulated (some facilities do not use these steps).

The granulated powder is compacted in a press into a cylindrical form ("green pellet"). The green pellets are sintered in a high temperature furnace in a hydrogen (reduction) atmosphere.

After the sintering the pellets are grounded and loaded into zirconium alloy tubes. The tubes are filled with helium and then welded. The last production step is the assembling of the fuel elements to fuel assemblies. The whole fabrication process is shown in Fig. 7.

3.1.4.3. Metallic uranium fuel fabrication

Natural metallic uranium is used as a fuel in a certain cases, for example, in Magnox reactors (United Kingdom). The term “Magnox fuel” refers to the cladding material that is an alloy, on magnesium base. The starting material for this fuel is natural UF_4, and the production route is shown in Fig. 8.

The fuel canning stage follows the production of the metallic uranium rods. These rods are first machined to turn grooves along the length of the rod. The rod is then inserted into a Magnox can, the can is filled with helium and an end cap welded in place.

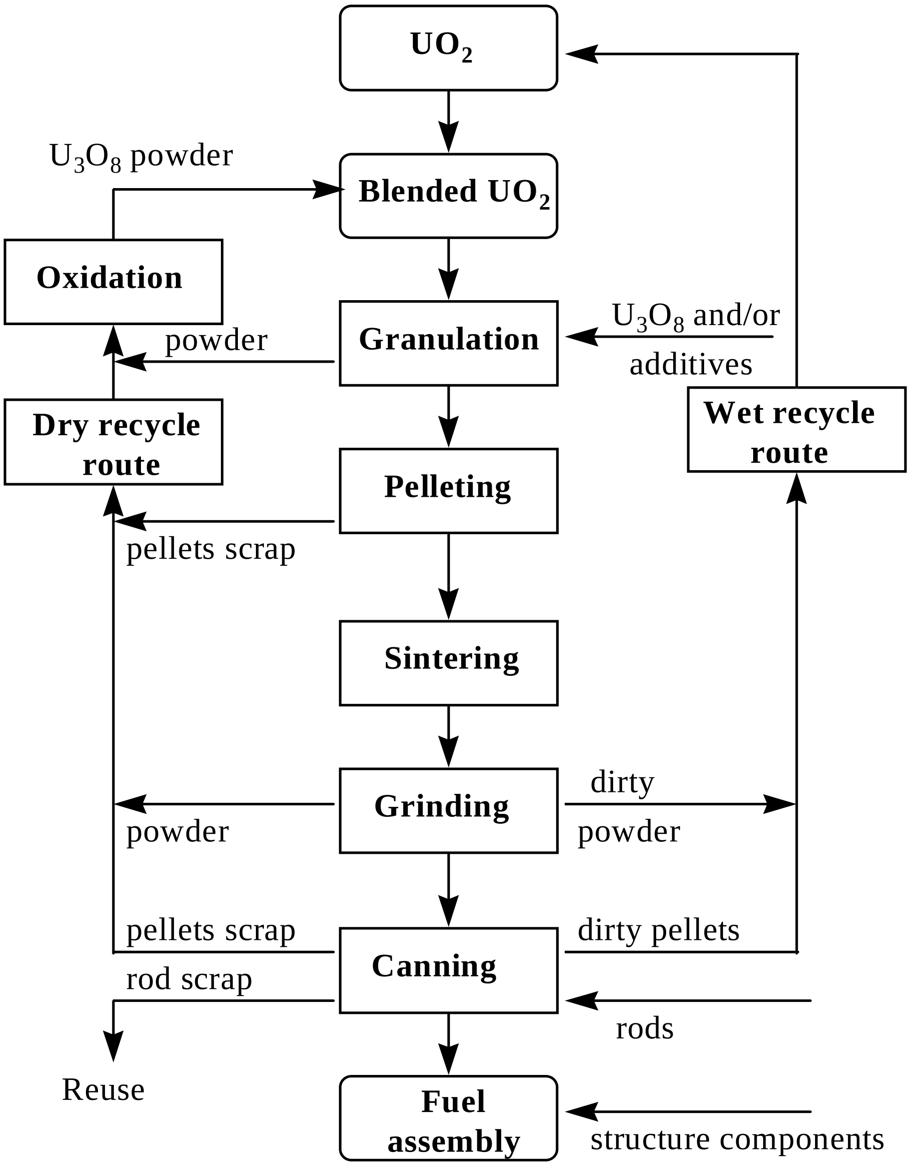

FIG. 7. UO_2 *fuel fabrication process.*

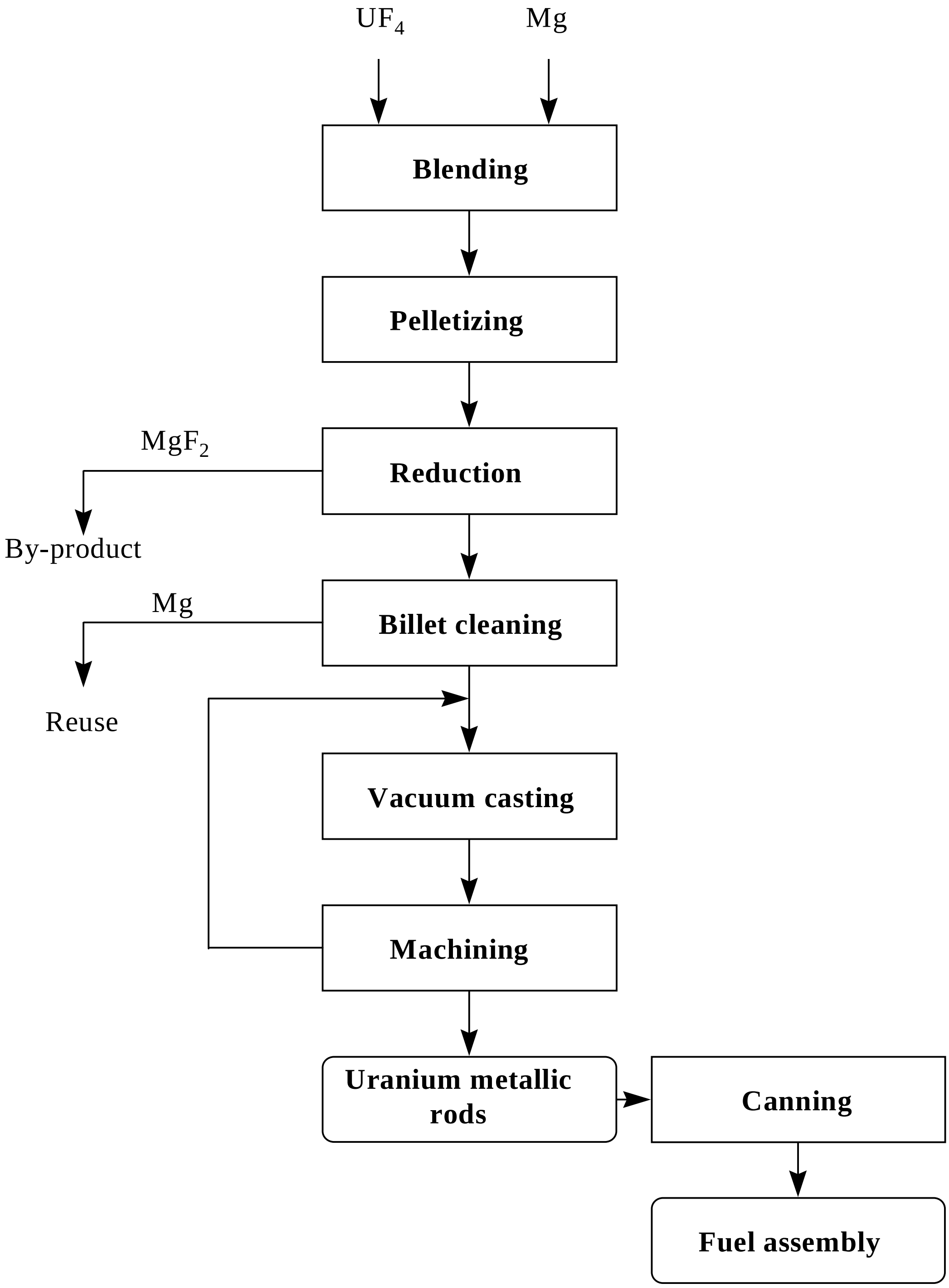

FIG. 8. Metal uranium fuel fabrication process.

3.1.5. Reprocessing

Initially, spent fuel from a reactor is transported to the reception and buffer storage ponds of a reprocessing plant. After a delay depending on its burnup level, the spent fuel elements are then passed into the head-end plant where they are first mechanically chopped into short lengths by a shearing process and then leached in nitric acid. The uranium and plutonium are extracted in the form of uranyl nitrate and plutonium nitrate solutions in up to three solvent extraction cycles. In the first cycle the feed stream of uranium and plutonium is co-decontaminated, to remove the highly active fission products, and then separated into separate uranium and plutonium streams. In the second (and possibly third) cycle, the separated uranium and plutonium streams are further purified and concentrated.

The plutonium nitrate is then converted into oxide. The uranyl nitrate is shipped to a fabrication plant or converted into uranium hexafluoride (UF_6) in a conversion plant. Some facilities may have a conversion capability built into the reprocessing plant to change the form of the uranium to UO_2 or UF_6. Plutonium oxide from the conversion plant is mixed with uranium oxide to form mixed oxide (MOX), which is then fabricated into fuel elements. The UF_6 is transported to an enrichment plant for enrichment to a desired concentration of ^{235}U. The plutonium oxide may also be placed in store until required. A simplified flow diagram is shown in Fig. 9.

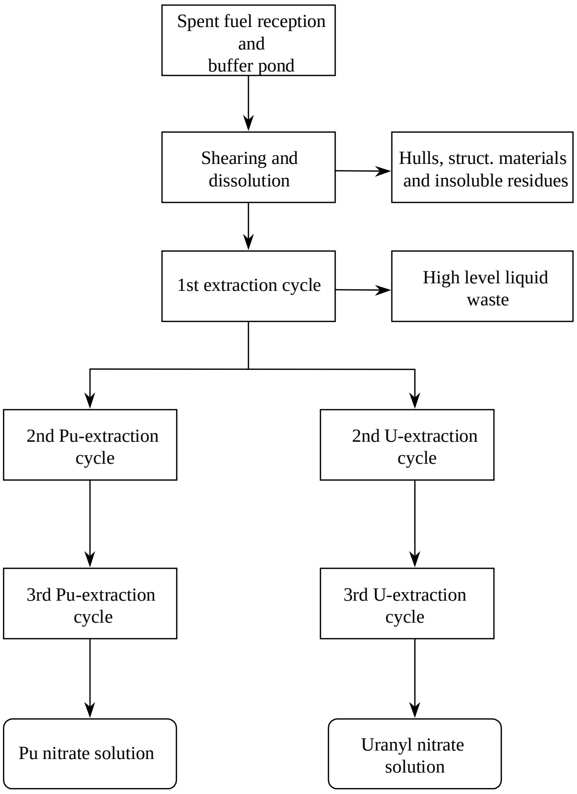

FIG. 9. Simplified spent fuel reprocessing.

3.2. Potential vulnerabilities of nuclear fuel cycle facilities

Potential vulnerabilities of nuclear fuel cycle facilities in relation to the Y2K problem could be divided into two aspects, i.e., internal vulnerabilities of each facilities' computer systems and the vulnerabilities which will be caused by external elements.

3.2.1. Internal vulnerabilities

Internal vulnerabilities of each nuclear fuel cycle facility could be further categorized into two types. One directly relates to the safety of the facility; the other is not related to the safety of the facility, but has a serious effect or damage on the activities of the facility (i.e. milling, conversion, enrichment, uranium fuel fabrication, mixed oxide (MOX) fuel fabrication, spent fuel storage, etc.).

3.2.1.1. Safety-related vulnerabilities

The computer systems which have safety-related vulnerabilities in relation to the Y2K problem consists of two systems; control systems and monitoring systems. The control systems include operation control systems and protection systems. The monitoring systems could include environmental monitoring systems, fire alarm systems, and others.

Each of these includes a computer system, however, not all of these computer-related systems are vulnerable to the Y2K problem. The most critical point of these computer systems is whether or not they use the absolute time data processing. If a computer system does not use the absolute time data processing, the system is not vulnerable to the Y2K problem. However, problems may occur with computer systems which are connected through the communication network.

From this point of view, the computer systems which have safety-related vulnerabilities in relation to the Y2K problem, should be investigated to determine whether or not they use the absolute time data processing.

When investigating the computer systems, it is very important to check not only the application software, but also the operating system (OS) as well as any embedded systems (e.g. those containing micro-controllers) used.

3.2.1.2. Other vulnerabilities

Lower priority should be given to computer systems whose vulnerabilities are not related to safety, e.g. inventory management systems, budget and personnel management systems.

3.2.2. External vulnerabilities

There are many cases of vulnerability caused by external elements. For example, loss of the external electrical power supply due to the shut down of the grid, telecommunications network errors, stoppage of the water, material and special gases supply.

There should be suitable remediation to each external vulnerability:

- as for the loss of the electrical power supply, and only in those facilities where this vulnerability will have an impact on safety or on environmental protection, this facility should have or prepare the independent electric generator; in other words, emergency electrical power supply;
- as for communication network errors, a test is recommended including all systems which are connected by network; and
- as for the stoppage of external water, material or special gases supply, and only in those facilities where this vulnerability will have an impact on safety or on environmental protection, this facility should ensure that maximum stocks are maintained prior to the vulnerable dates and that appropriate contingency arrangements are in place to cover an appropriate time for supply loss.

Regarding external vulnerabilities, each nuclear fuel cycle facility should be prepared in accordance with case by case methods such as mentioned above.

4. APPROACH TO THE YEAR 2000 PROBLEM

This report, based on the strategy for Y2K readiness set out in Ref. [2], specifically addresses the various types of nuclear fuel cycle facilities and activities. The Y2K strategy emphasises the essential elements, explains their importance and provides guidance for accomplishing the programme. The programme consists of four principal phases:

- initial assessment;
- detailed assessment;
- remediation; and
- contingency planning.

Figure 10 shows the relationship between the principal phases and the stage to be carried out.

The regulatory authorities should ensure that their licensees (operators) are aware of the Y2K issues and are responding effectively to them. Regulators also need to monitor the implementation of the Y2K programme by the operator.

The programme manager at a facility is responsible for the management of the Y2K programme and is responsible to the facility management, which is responsible for the safety and operability of the facility. The programme manager accomplishes the objective of the programme by implementing the steps identified in Ref. [2], Section 2.

4.1. Initial assessment

The purpose of this initial assessment is to establish an inventory of items that are required to be reviewed, determine the importance of each item to the facility and schedule those items that require further analysis during detailed assessment. Initial assessment is the first step toward accomplishing the Y2K readiness of each item.

Initial assessment, as described in this report, employs a method that takes a potentially large population of items and reduces it to the minimum appropriate population. The traceabillity of important devices is to be maintained.

It is proposed that for nuclear fuel cycle facilities the first step in the initial assessment phase is to establish a “Preliminary Inventory”, based on the guidance set out in Section 3.2.1 of Ref. [2]. This preliminary inventory establishes, by careful examination of the equipment in the process, whether there are any items that are date sensitive. At the end of this initial review it should be clear which facilities do or do not have date dependent systems in them.

If in this initial review it can be established that the nuclear fuel cycle facility does not involve the use of computer-based equipment or that any such equipment is not date sensitive, then it can be declared as Y2K Ready. Further guidance is given in Chapter 6 on the sensitivity of nuclear fuel cycle processes to the Y2K problem.

The review of the preliminary inventory should identify each of the processes at the facility and identify their potential hazards. It should identify the process functions and the main plant parameters associated with the control and protection of the process. The broad consequences of process control and protection system failure should be identified, based on existing plant safety analyses.

Once this step has been completed each potentially vulnerable item should be recorded on the Initial Assessment Inventory. This inventory will contain a mixture of operational and safety items that must be categorized and prioritized (prior to the next phase of the compliance process).

An example of a categorization and prioritizing process can be viewed on the following impact matrix.

	Critical	Necessary	Desirable
Safety	**1**	**2**	**3**
Environmental	**2**	**3**	**4**
Operational	**4**	**4**	**5**

— “Safety” means failures could affect people on or off site;
— “Environmental” means failures could affect people off-site or the environment; and
— “Operational” means failures could affect operations and products.

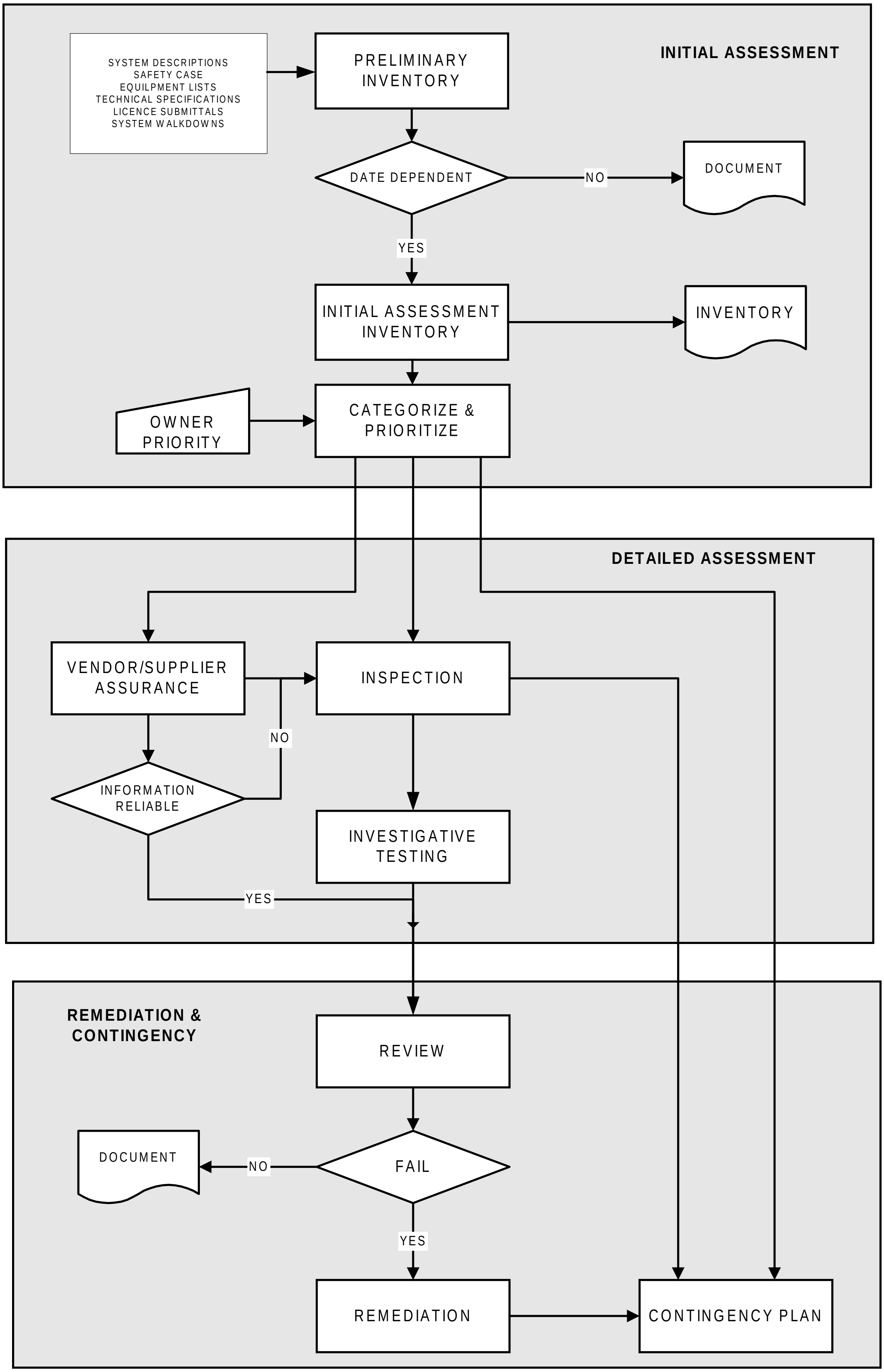

FIG. 10. Recommended strategy for Y2K readiness.

Preliminary Inventory Analysis provides an objective means of excluding items from the inventory. At the end of this phase it should be clear what date dependent systems are involved in nuclear fuel cycle processes and what their relevance is to safety. The initial assessment helps to ensure that subsequent phases focus only on items of importance to the programme.

4.2. Detailed assessment

The purpose of detailed assessment is to obtain or generate sufficient information about an item to determine its expected behaviour on critical dates. Detailed assessment results (see Ref. [2], Section 4 for details) are used to make decisions regarding remediation and/or contingency planning.

There are two main steps to completing the detailed assessment. Firstly, information should be sought from the vendor on the item with regard to its date sensitivity. The vendor's willingness and qualification to support the facility's Y2K programme should be evaluated, the aim being to determine whether the vendor will participate in the evaluation and provide certification of an item's performance. A vendor's unwillingness or inability to support the Y2K programme may be obstructive to the way in which investigation tests or remediation can be carried out.

The second step in the detailed assessment is an evaluation of the item's sensitivity to the critical dates. In the situation where the vendor has provided information, a verification of the validity of the information, as it relates to the specific item, should be arranged by the operator of a facility or activity. Where this is carried out by the vendor, it should be checked by the operator.

Due to the immovable end date and the confidence of some of the vendor/supplier evaluation, the phases of vendor/supplier evaluation and detailed assessment should be carried out in parallel.

Where the facility management is not able to obtain information from the vendor or involve the vendor in conducting the evaluation, the facility management should carry out a formal evaluation and arrange for this to be checked.

Two methods of evaluation are identified in this report, based on the detailed information provided in Ref. [2] Section 4.2. “Inspection” and “Investigative Testing” are acceptable means to determine the acceptability of the item (see Ref. [2], Sections 4.2.1 and 4.2.2 for details).

Where a system is critical to safety and the supplier/vendor has given a statement of compliance then this item should go through investigation tests. Live testing should only be used if all other types of investigative testing have failed to verify the system.

4.3. Remediation

The purpose of remediation is to address the failure modes identified in the detailed assessment. During remediation the programme manager should track the timeliness of delivery of purchased material and the progress of conversions, replacements, deletions, retirements and vendor efforts. Remediation efforts that are not timely require the programme manager’s attention.

From the schedule of remediation forms, priorities should be set by considering:

- classification of an item;
- competing project schedules;
- availability of qualified personnel; and
- the number of items of a given type.

4.3.1. Remediation strategy

Once an item has been determined to be susceptible to Y2K failures or that there is a likelihood of failure, a remediation strategy should be selected. Strategies include:

- retire/remove the item from service without providing a replacement;
- replace/remove the item from service and provide an alternate means of fulfilling the function performed by the item;
- modify/alter the existing item to remove the noted Y2K problem; or
- work around the problem which provides a means of satisfying the functional requirements without correcting the Y2K fault.

The remediation strategy chosen should take account of the time available from when a strategy is selected to the critical date that will cause the item to have a problem, as there may be insufficient time to install and validate modifications or replacements.

4.3.2. Perform remediation

Once a remediation strategy has been chosen, the next step is to perform the remediation.

Where "retire" has been chosen, the facility should treat the retirement of an item as a modification to the plant and follow its usual modification procedures to establish that it is safe to retire the item.

Where "replace" has been chosen, it removes the item from service and replaces it with another. Two aspects should be addressed; firstly the facility should treat replacement of one item with another as a modification to the plant and follow its usual modification procedure to establish that the replacement is safe. The second aspect is that the replacement should be completely reviewed for Y2K readiness and be Y2K ready or compliant.

Where "modification" is chosen, the usual modification procedures for the facility should be followed to establish that the proposed modification is safe.

Where "work-around" is chosen the facility management should recognize that Y2K compliance or readiness is not achieved. Work-around is not a preferred remediation strategy but it is pragmatic reality. The facility should analyze any work-arounds to ensure they are achievable and safe. Consideration should include failure modes, interaction effects and consequences of failure upon staff resources.

Work-arounds include rolling dates back, for example, 01 January 2000 could be set to 01 January 1972 as 1972 begins on a Saturday and was a leap year, as is 2000. Shutting down the facility over the critical date periods also constitutes a work-around. For nuclear fuel cycle facilities this may be a viable approach, particularly if the work production process does not normally operate continuously.

A facility that proposes this course of action should be able to demonstrate in advance of the critical date that the restart of the process after the critical date is safe by providing specific date related tests on the item during the restart.

Whichever remediation strategy is chosen, a validation activity should be carried out by the facility to establish that the remediation is successful. Further details on remediation are provided in Section 5 of Ref. [2].

4.4. Contingency planning

Contingency planning is an integral activity to the Y2K programme. Contingency planning is a process that may begin at any time subsequent to the initial assessment and may continue throughout the programme. The primary goal is the preparation of individual contingency plans which have to be combined into a single integrated contingency plan. Contingency plans are developed to deal with specific hazards associated with internal or external sources.

The following are recommended steps for developing contingency plans:

— risk identification — determines risks to the facility from Y2K induced events;
— risk analysis — reviews the identified risks, determines potential failure modes and consequences, and documents pertinent information;
— risk management — uses information from risk analysis to determine mitigation strategies. It should consider Y2K induced risks and their interdependences; and
— validation — reviews the results of risk management and provides confidence that the contingency plan will effectively mitigate the risk.

The integrated contingency plan provides facility management with a comprehensive perspective of the risks associated with Y2K induced failures. The programme manager should ensure that a facility specific integrated contingency plan is developed. The integrated contingency plan allows the facility management to posture the facility in such a way as to deal with events most comprehensively. Further details on contingency planning are provided in Sections 6.1–6.3 of Ref. [2].

5. COMMON ISSUES

This section discusses common systems that may be present in all nuclear fuel cycle processes and are important to safety and may have date functionality. As there are many different types of systems in use this is a general list and does not discuss any specifics. Systems that should be considered include (but are not limited to):

- computer systems and their software applications, programmes, operating systems and device drivers that use dates;
- data and databases — where dates are stored along with other information, spreadsheets are also included in this category;
- communications networks — transmitted information may be date-stamped. Care is required to ensure that the date format is compatible between systems. Different system date ‘windows’ are of particular concern;
- human/machine interface — devices used for inputting and outputting dates. PLC’s may control a series of events or monitor user actions;
- safety support systems — may use controllers to support safety systems such as defined sequence of interlocks;
- control and monitoring — these may be embedded systems, computer systems and software that is using dates to stamp events or calculate trends. This includes all types of environmental monitoring systems. SCADA systems are particularly vulnerable;
- maintenance support systems — used to track and determine which devices require maintenance;
- fire alarm systems — may contain dates to log and record event history;
- building access/security systems — many are now controlled by computer systems which may communicate date and connect to embedded systems;
- criticality detection and alarm systems — may use dates for monitoring and tracing events;
- emergency control centres — use date dependent equipment to monitor and communicate in an emergency situation;
- embedded systems — devices that may have date dependent microprocessors embedded within them for the purposes of control or monitoring, such as ‘smart transmitters’ for measuring levels and pressures;
- ventilation and air cleaning — may have embedded devices used for control and monitoring of systems. PLC’s may be used for in-cell filter changes;
- cooling water monitoring — may use embedded devices for control and monitoring purposes;
- internal services — failure of internal monitoring and control systems may stop supply of electricity, water and other services; and
- external services — dependency on external suppliers may affect operations.

6. ASSESSMENT OF NUCLEAR FUEL CYCLE PROCESSES

6.1. Enrichment

In order to produce fuel with a ^{235}U concentration higher than in natural uranium it has to be enriched, therefore UF_6 is transported in cylinders to enrichment plants. For feeding the process the solid UF_6 in the cylinders is heated up to about 90°C in order to reach the gas phase of UF_6. The process step is done in autoclaves under pressure and temperature control. The UF_6 gas is lead to separation cascades which work at very low pressure.

For separation, two different processes are in use:

— centrifuges; and
— gaseous diffusion.

After this separation process the enriched product as well as the depleted tails are solidified in UF_6 by cooling. The filling procedure is controlled by a weighing device to keep the UF_6 weight in the cylinder within specified limits.

In order to achieve the exact enrichment grade of special product UF_6 is revaporized, blended and solidified followed by homogenization in another process station. The product and tails cylinders are taken to storage.

All process steps in which UF_6 is heated up and brought into liquid or gas phase are under pressure and temperature control and the equipment should be tested for potential malfunction in order to avoid UF_6 releases.

Also, the pumps, or cold traps and the under pressure control should be checked for safe operational reasons.

The weighing devices for the control of UF_6 cylinder filling are very safety relevant and should be checked, if there are electronic processing components included. These devices are also in combination with material accounting which is essential for correct operation.

6.2. Uranium fuel fabrication

The operators of a fuel fabrication facility have an interest in accurately accounting for material in all of the storage and process areas of the facility. Some facilities may have a completely independent accounting unit and a separate production control unit. Other facilities may give both responsibilities to a “production and material control” unit which has responsibility for maintaining accurate inventories of all raw, in process, finished materials, and wastes; as well as for production scheduling and procurement.

In addition, many different types of measurements are required because of the many different forms of materials in a fabrication facility. The general types of measurements required include bulk measurements of weight, volume or flow rate; chemical assays; and isotopic or nuclear assays. Some nuclear fuel manufacturers are using advanced accounting and control systems which utilize computer systems to process measurement information and to provide process control information. Such systems might integrate on-line measurements of weights or enrichment with related project identification inputs.

These systems can centralize information for record keeping purposes providing direct control of the production line. An example of this type of application is a system that will physically prevent material of the wrong enrichment from being entered in to the product stream. Such systems, which involve using of computers, where date stamp is in use, are vulnerable to the Y2K problem.

Uranium fuel fabrication requires in most cases the manipulation of large quantities of uranium. In some cases these processes are steered by computers. Failure of these computers could cause problems in the production process. While it is recognized that these disturbances can have serious consequences on the availability and quality of the final product, special attention should be given to failure of systems important to the safety of workers and the environment.

Typical areas of concern for uranium fuel fabrication facilities are discussed below:

6.2.1. Chemical processes

Fuel fabrication requires a number of chemical processes to convert the uranium to the desired final product (in most cases this process is a conversion from UF_6 to UO_2, but other products are in use such as metallic U). The process involves a lot of equipment for flow control, pressure control, measurement of concentration and temperature control. Malfunctioning of this equipment could cause hazards due to mixing wrong flows, wrong concentrations of chemical products, excessive pressure or overheating. Potential consequences are explosions due to the formation of explosive products or excessive pressure.

A lot of the equipment involved uses micro processors (transmitters, controllers). The plant should be checked carefully for the presence of such equipment and its behaviour for the Y2K. For older plants recent modifications must be checked.

6.2.2. Criticality control

Criticality is an important topic for plants dealing with highly enriched uranium, but even plants treating only low enriched uranium could be affected, for example due to flooding.

Care must be taken for flow control process. Malfunctioning of this could cause high concentrations or high quantities of uranium. The facilities usually keep a detailed inventory of uranium present in the different locations. This databases must be checked. Errors could cause the presence of excessive quantities of uranium in certain areas, with criticality accidents as a consequence.

6.2.3. Criticality monitoring system

Most fuel fabrication facilities have specially designed radiation monitoring equipment for fast detection of criticality. This equipment must have a very high reliability. An alarm on the criticality detection system causes a fast evacuation procedure with many serious consequences. The system should be checked not to give false alarms.

6.2.4. Ventilation systems

Fuel fabrication plants are equipped with ventilation systems in order to avoid the build up of hazardous gases from the production process (explosive or toxic gases) and to reduce the presence of radon in the buildings. Failure of the ventilation systems could cause excessive concentration of these gases with a possibility for explosions within a short time. Evacuation of radon can only be a problem in case of unavailability during longer periods.

6.3. Mixed oxide (MOX) fuel fabrication

The difference between a fuel fabrication plant for mixed oxide fuel and a plant for uranium based fuel is the presence of large quantities of plutonium. All issues indicated in section 6.2 on uranium fuel fabrication remain valid for mixed oxide fuel fabrication. The high radiation toxicity of plutonium and the higher probability for criticality requires additional measures. Physical protection must have special attention in case of large quantities of plutonium in lose form.

In the following paragraphs, some of these additional topics due to the presence of plutonium are described:

6.3.1. Air contamination

Air contamination by plutonium must be avoided in all cases. Production processes which are computer controlled must be checked very carefully. In case of failure of the controlling system, the installation must return to a safe state.

6.3.2. Measurement of air concentration

The equipment measuring the concentration of plutonium in the air must function correctly. Special care should be taken when monitoring systems are used which calculate an average concentration for a certain period of time since these systems make use of dates.

6.3.3. Physical protection system

Although it can be expected that most plants will be shut down on the critical dates, the physical protection systems must remain operational. Special care should be taken if time controlled locking systems are used.

6.4. Away-from-reactor spent fuel storage

Irradiated fuel elements can be stored off site of the reactor for long periods of time. There are two types of interim storage in use, dry storage and wet storage.

6.4.1. Dry storage

The spent fuel elements are loaded in heavy thick-walled containers which are closed with a double tightening system. The containers are brought to store where they are connected with a leakage control system in order to assure the long term safety of the container tightening. Short time disturbances in the leakage control has no effect on the system and the safe enclosure with double tightening. So no specific problems for millennium rollover can be seen, since no active function of control is necessary for safety or operational reasons.

6.4.2. Wet storage

The spent fuel elements are stored in water pools positioned in storage racks. The water in the pools has the function of cooling the elements and to transport the decay heat away and of shielding the radiation. For criticality reasons the water is borated. Therefore water level and temperature have to be controlled by a feeding and a coolant system. The building with the storage pool is a control area with ventilation and activity monitoring.

Since all possible disturbances on water level and temperatures will occur very slowly only small interest has to be given to these systems with respect to the millennium rollover.

The handling of transport containers and the unloading and positioning of fuel elements is done by cranes or by manipulating machines so the handling control systems should be checked before use after rollover.

The database for accounting fuels and positioning the elements is essential for correct operation. The data should be secured properly and all related computer programmes should be checked.

6.5. Reprocessing

The reprocessing process starts with the reception on the reprocessing site of the casks containing spent fuel assemblies coming from reactors, and unloading of this spent fuel for the interim storage under water in pools.

When radioactivity has sufficiently decreased, the assemblies are moved to a remotely controlled shearing device. As the integrity of the cladding is broken, the gaseous fission products in the spaces not filled by the fuel pellets are allowed to escape. Since these gases are radioactive, they must be contained and treated before the non-radioactive and less radioactive gases are allowed to be vented to the atmosphere.

The chopped pieces of fuel rods will usually fall (through a chute) into a dissolver tank filled with a nitric acid solution for separation of uranium, plutonium and fission products. The solution of fuel and other materials is removed from the dissolver and transferred to an accountability tank.

This is a tank which is carefully calibrated to provide accurate measurements of the volume of the solution entering the process stream. The solution is also mixed and sampled at this point to allow accurate determination of the composition of the solution. This operation is very important for materials accountancy in reprocessing facilities. Great care is required in accountancy activities to ensure that the quantities of materials being recycled are accurately determined.

In further steps, uranium and plutonium are purified, concentrated and converted to an appropriate form allowing intermediate storage before recycling. Fission products are concentrated and stored in tanks before vitrification in glass containers which are stored in on-site facilities before long-term storage.

We assume here that the production will be stopped at year rollover and that all related installations will be out of service (e.g.: no unloading, shearing device and dissolver stopped, extraction, purification and concentration stopped, no production of liquid or solid waste.

This option of stopping production does not prevent from taking extra care when restarting the installation after the rollover. The installation should be restarted step by step, and all necessary time could be (and should be) taken at the restart in order to ensure that all safety conditions are met.

Whenever production could not be stopped, additional risks would appear in the following areas:

- safety/criticality all along the process;
- handling faults, especially in the fuel storage areas;
- radionuclide emission; and
- process control errors due to incorrect data.

It is strongly recommended that all facilities that could stop from a technical point of view actually stop at the year rollover. Additionally, non strictly necessary operations should be avoided, namely modifications or non-urgent fixes.

In any case, an appropriate organization must be set up in order to detect and manage any incident connected to the year rollover. This organization should, of course, have been verified previously. This concerns, in particular, the mode of operation of installations, provisions for special surveillance, training of staff and the availability of additional means.

The following paragraphs focus on safety functions that have to be assessed in any case, since they need to be present, whether the installation is running or not.

6.5.1. Cooling

High priority should be given to those micro processor based systems which could lead to failure of the following cooling functions.

- pool water cooling systems;
- fission products and insoluble residues tanks cooling;
- plutonium interim storage cooling;
- glass containers storage cooling; and
- hulls storage cooling.

6.5.2. Containment

The following functions need to remain operative:

- process ventilation, in order to avoid contamination;
- off-gas treatment, if a failure could cause radionuclide releases into the environment; and
- related electronics and micro processor based devices.

6.5.3. Air dilution of hydrogen produced by radiolysis

In order to avoid any explosion due to hydrogen produced by radiolysis in radioactive solutions such as fission products, this function should imperatively remain operative.

6.5.4. Radiation monitoring

Two types of radiation monitoring are necessary, even if production is stopped:

- inside monitoring so as to detect any containment failure and any dissemination of radioactive materials in the facility; and
- outside monitoring (chimneys) so as to detect any abnormal release of radioactive materials outside the facility through a permanent acquisition of corresponding data.

6.5.5. Fire detection, alarm and extinction systems

Fire detection systems have to be checked, specifically for those related to storage of flammable solvents used in the process.

6.5.6. Power supply

For all those systems mentioned above, power supply must be ensured even in the case of failure of the national grid by appropriate redundant and backed-up operating sets.

Consequently, related microprocessor-based devices and equipment have to be carefully checked.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

(a) A systematic approach commensurate with the hazards involved is essential in order to ensure that Y2K compliance testing is carried out and that necessary remedial measures are taken in order to ensure the safety of nuclear fuel cycle facilities.

(b) The systems for which the Y2K issue poses potential safety problems at nuclear fuel cycle facilities include:

- systems involving “open” radionuclides and active components, where an off-gas treatment failure could cause radionuclide releases into the environment;

- systems involving computerized process control, where a control failure could lead to unsafe situation, such as:

    - incorrect dosages resulting in criticality situation;
    - failure to retrieve and store spent fuel assemblies;
    - damage to fuel assemblies which may lead to critical situation; and
    - overflow of radioactive material in containers; and

- data processing systems, where — for example — an unnoticed incorrect calculation may have direct safety implications if clearance or discharge operations depend on computerized decay calculations, done by specific computer codes or spreadsheets.

(c) More specifically:

- in the uranium enrichment facilities, priority should be given to all process steps in which UF_6 is heated up and brought into liquid or gas phase, as failure of the pressure and temperature control may lead to UF_6 release;

- in all fuel fabrication facilities, many different types of measurements are required because of the many different forms of materials in a fabrication facility. Some nuclear fuel manufacturers are using advanced accounting and control systems which utilize computer systems to process measurement information and to provide process control information. Such systems might integrate on-line measurements of weights or enrichment with related project identification inputs. Those systems should be carefully checked to assure Y2K compliance;

- in the uranium fuel fabrication facilities, assuming that the production is stopped, priority should be given to those computer-based systems controlling the chemical processes in order to avoid formation of hazardous products;

- in the MOX fuel fabrication facilities, priority should be given to those computer-based systems controlling plutonium-contained processes to avoid criticality and dispersion of plutonium; and

- in the reprocessing facilities, priority should be given to the remotely controlled sheering device and dissolver, and those computer-based systems which drive cooling systems, ventilation and off-gas treatment systems and air-dilution of hydrogen. Attention should also be given to radiation monitoring systems, fire detection systems and power supply.

7.2. Recommendations

National authorities throughout the world and competent international organizations should be aware of the identified potential for radiation exposures caused by Y2K problems at nuclear fuel cycle facilities.

Authorities worldwide should be encouraged to ensure that registrants and licensees of nuclear fuel cycle facilities carry out systematic actions to identify the nuclear fuel cycle facilities and activities that may be affected by Y2K problems and take appropriate remedial measures.

National authorities and registrants and licensees of nuclear fuel cycle facilities should be encouraged to exchange, in a timely manner, the information acquired and experience gained through such systematic actions.

As temporary shutdown of operations would not have a dramatic impact, licensees of nuclear fuel cycle facilities are recommended to take the following points into consideration:

- nuclear fuel cycle facilities should stop production, if technically possible, before the year 2000 rollover date. Other critical dates may demand similar actions, depending on the Y2K readiness of the facility. During shutdown, safety functions will however be operational;

- nuclear fuel cycle facilities should restart operations in a controlled procedure, and all necessary checks should be made at the restart, in order to ensure that all safety conditions are met; and

- care is required for investigative testing of in-service equipment, as this may introduce faults and cause unexpected hazardous events.

Additionally, to ensure the success of the year 2000 programme, it is recommended to consider the following practice:

- implication of top management in the project is a must;

- each facility keeps the final responsibility of Y2K compliance;

- a risk management approach drives one global project for information systems and other aspects;

- last term of 1999 is left for fine tuning of organization and procedures; and

- communication and human resource management must not be forgotten.

International organizations should support the exchange of information and experience, by making use of a dedicated Y2K Experience Internet Site.

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