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THE AIDA-MOX 1 PROGRAM: RESULTS OF THE FRENCH-RUSSIAN STUDY ON PEACEFUL USE OF PLUTONIUM FROM DISMANTLED RUSSIAN NUCLEAR WEAPONS

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Abstract

The Intergovernmental Agreement signed on November 12, 1992, between the governments of France and the Russian Federation instituted cooperation between the two countries for the safe elimination of the excess Russian nuclear weapons. France has allocated 400 million francs to this program, covering transportation and dismantling of nuclear weapons, interim storage and subsequent commercial use of the nuclear materials from the dismantled weapons, nuclear materials accountancy and safeguards, and scientific research.

The concept of loading commercial Russian reactors with fuel fabricated from the plutonium recovered from dismantled nuclear weapons of the former Soviet Union is gaining widespread acceptance, and is at the heart of the French-Russian AIDA/MOX project.

AIDA/MOX 1, one of the five topics of the AIDA program, is intended to specify a complete industrial system to reach this ambitious objective, i.e. to use plutonium recovered from Russian nuclear weapons to fabricate MOX fuel in Russia for currently operating or planned commercial Russian nuclear power plants to produce electricity while diminishing the weapons-grade plutonium inventory.

Broadly speaking, the PWR-MOX and FR-MOX options for using excess dismantled weapons plutonium for peaceful commercial nuclear power generating purposes — like the CANDU-MOX and HTR-MOX options offer several advantages over the remaining options (interim storage, disposal in vitrified form, etc.) notably from a nonproliferation standpoint.
The joint French-Russian studies carried out under the AÏDA/MOX 1 program have led to the following conclusions:

1) Using 30% MOX fuel is feasible in certain WWER 1000 reactors, after implementation of design changes similar to those made in France from 1985 to 1990 when EDF began using 30% MOX fuel in its 900 MW PWRs. These modifications (mainly affecting the number and design of the control rods, the soluble boron concentration in the water of some systems, and radiological protection of the fresh MOX fuel assembly

transfer system) are currently the subject of preliminary studies by the Russian and the French parties, and will be covered in detail in the subsequent phase (1997-1998) proposed under the AIDA/MOX 2 program. This option would enable dispose of about 270 kg of W-Pu annually per WWER-1000 reactor.

2) Using 100% MOX fuel in the BN-600 fast reactor without breeding blankets is certainly the most promising option in a reasonable time frame (even though further studies are necessary to validate it) and should therefore be assigned medium-term priority. In the short term, the easily implemented BN-600 hybrid core solution should make it possible to use 240 kg of W-Pu per year. This solution complies with Russian safety requirements (negative void coefficient) by placing the MOX fuel around the periphery of the core (in the next-to-last ring) in limited quantities: less than 20% of the total number of fuel assemblies in the BN-600 core.

3) Studies on converting W-Pu into MOX fuel have led to the definition of a *reference process* for a future facility or plant to be built in Russia.

The *reference process* chosen by the French and Russian specialists comprises:

- acid dissolution of plutonium alloy in HNO_3 + HF
- purification by extraction of plutonium nitrate
- Pu oxalate precipitation and PuO_2 production
- MOX fabrication using the COCA and MIMAS processes.
- Additionally two process variants were considered, neither variant has been adopted to date for lack of sufficient industrial experience; further research and development work will be required in both cases.

1) The capacity of a MOX facility to be built in Russia was determined by the possibility of consuming MOX fuel in Russian BN-600 and WWER-1000 reactors. The AÏDA/MOX Coordinating Committee initially selected the following Russian reactors:

- BN-600 hybrid core option (⇒ 240 kg of W-Pu per year), as the first step toward the final objective of 100% MOX fuel in the BN-600 reactor core (1310 kg of W-Pu per year) and gradual removal of all the blankets,

- four WWER-1000 reactors at the Balakovo NPP (⇒ 4 x 270 kg of W-Pu per year), hence a total capacity of around 1300 kg of W-Pu for the TOMOX-1300 facility, i.e. approximately 30 metric tons of MOX per year.

2) Preliminary design work on the TOMOX-1300 facility implementing glove-box handling technology is underway in Russia with French participation by the CEA, COGEMA and SGN. The results will be available by mid-1997, together with a preliminary estimate of the total cost and itemized cost of the plant components; allowance will be made for the basic facilities already in place at Russian nuclear sites, including Chelyabinsk 65 and Krasnoyarsk 26.

3) A detailed proposal for the TOMOX-1300 plant will be required in 1997-1998 before construction begins in the Russian Federation. The detailed proposal is planned for the AIDA/MOX 2 program stipulated in the proposed Trilateral Agreement between France, Germany and the Russian Federation. The TOMOX 1300 project will be implemented in two separate entities: TOMOX and DEMOX.

1. INTRODUCTION

French aid in the safe dismantling of Russian nuclear weapons from 1992 to 1997 under the "AIDA" program was a natural outgrowth of the French Government's constant concern for active participation in both conventional and nuclear nonproliferation and disarmament. The AIDA program is the tangible application of the Intergovernmental Agreement signed on November 12, 1992, between the governments of France and the Russian Federation This agreement instituted cooperation between the two countries for the purpose of safely eliminating Russian nuclear weapons and using the resulting nuclear materials for commercial purposes. France has allocated 400 million francs to this program, covering transportation and dismantling of nuclear weapons, interim storage and subsequent commercial use of the nuclear materials from the dismantled weapons, nuclear materials accountancy and safeguards, and scientific research.

Within the scope of these agreements, the AIDA program covers the following points:

1) Supply of equipment:

- radiological protection and measuring equipment to ensure the safety and surveillance of weapons during transport, interim storage and dismantling;
- machine-tools (one vertical lathe and three cutting machines) for the nuclear warheads dismantling;
- overpacks to protect the Russian arms containers during transport from their current storage sites to the dismantling facilities.

2) Construction in Russia of a safe storage building for lithium and hydrogen-bearing materials from the thermonuclear weapons. The construction work should be completed by the end of 1997; the building will have sufficient capacity for over 3000 containers, and is designed to ensure the safety and security of the stored materials.

3) Performance of studies intended notably to demonstrate the feasibility of using weapons plutonium in commercial MOX fuel: these studies are known as the "AIDA/MOX 1" program.

The AIDA program is managed on the French side by an Interministerial Committee on Aid for Dismantling Nuclear Weapons, chaired by Admiral Francis Orsini, *charge de mission* in the Ministry of Defense; his Russian counterpart is the Minister of Nuclear Power, Mr. Victor Mikhailov. The CEA is the operator of the AIDA program, under the responsibility of M. de la Gravière. The co-chairmen of the Coordinating Committee are Xavier Ouin (Ministry of Industry) and Vice-Minister N.N. Yegorov (MINATOM).

Present Status of French-Russian Cooperation

Radiological protection and measuring equipment was delivered in January and September 1995 with subsequent training of the operating personnel. Machine tools were delivered in March 1996, with personnel training ensured by the CEA. The first high-integrity container overpacks were delivered in September 1996, and deliveries will continue throughout 1997. The deep foundations for the safe storage building were completed in 1996; turnkey delivery is scheduled for the second half of 1997.

The Final Report of the bilateral French-Russian survey of possible uses of weapons plutonium for commercial electric power generation (AIDA/MOX I program) will be internationally distributed in the first half of 1997. The Report provides the following recommendations:

- For the short term: the use of Russian weapons plutonium as MOX fuel in existing Russian BN 600 reactor and WWER 1000 units with the construction of a facility known as TOMOX 1300 in Russia for converting the plutonium into MOX fuel. The proposed MOX-fabrication capacity of 1300 kg of plutonium per year would be sufficient to supply the BN 600 reactor (about I metric ton of MOX fuel per year) and four WWER 1000 reactors (about 29 tons of MOX per year).
- For the medium and long-term: various scenarios involving the construction of new reactors (e.g. BN 800, WWER 640) loaded with 100% MOX fuel, designed to enhance the utilization rate of plutonium from dismantled Russian nuclear weapons for commercial electric power generating purposes.

2. FROM RUSSIAN WEAPONS TO MOX FUEL FOR RUSSIAN REACTORS

The concept of loading commercial Russian reactors with fuel fabricated from the plutonium recovered from dismantled nuclear weapons of the former Soviet Union is gaining widespread acceptance, and is at the heart of the French-Russian AIDA/MOX project.

A program of this scope implies the commitment of substantial technical and financial resources. Dismantling thousands of weapons and removing the fissionable materials that may be recycled (military grade plutonium and highly enriched uranium) and separating the thermonuclear materials (hydrogen isotopes) for storage are delicate and costly operations. French scientists and industrial firms have acquired considerable experience in the area of defense-related nuclear activities, in reprocessing spent commercial fuel and in the use of nuclear materials that may be recycled -- notably in the form of mixed uranium-plutonium oxide (MOX) fuel.

AIDA/MOX 1, one of the five topics of the AIDA program, is intended to specify a complete industrial system to reach this ambitious objective, i.e. to use plutonium recovered from Russian nuclear weapons to fabricate MOX fuel in Russia for currently operating or planned commercial Russian nuclear power plants to produce electricity while diminishing the weapons-grade plutonium inventory.

The CEA is the operator of the French-Russian Intergovernmental Agreement, and thus coordinates the French contributions to the AIDA/MOX 1 program by COGEMA, FRAMATOME and EDF. The Russian Ministry of Nuclear Power, MINATOM, has the same role with respect to the research organizations (RIAR, VNIINM, IPPE, Radium Institute, Kurchatov Institute) and project institutes (GSPI, GYDROPRESS, VNIPIET, etc.).

The initial results of these studies were presented jointly by the French and Russian parties at the GLOBAL '95 conference organized by the American Nuclear Society at Versailles in September 1995 [1,2,3,4]. The results obtained in 1996 were also jointly presented to the international scientific community during the "G7 + 1" Experts Meeting in Paris in October 1996 [5] and the American Nuclear Society's Winter Meeting in Washington DC in November 1996 [6,7,8,9]--in particular, the results of research on converting plutonium alloy from some warheads into nitrate and then into plutonium oxide for incorporation in MOX ceramic fuel: this technical exploit has not been achieved to date at industrial scale.

French work at Marcoule in the ATALANTE complex, at Cadarache in the Advanced Fuel Fabrication Research Laboratory (LEFCA) and at Bruyeres-le-Chatel led CEA scientists and their Russian partners to select four processes. Two of these are based on plutonium dissolution in hydrochloric or nitric acid, the third on direct oxidation and the fourth on pyrometallurgy. A reference process will eventually be selected for conversion of plutonium alloy, and for converting the plutonium nitrate to a mixture of uranium and plutonium oxides on the basis of current scientific results and on the industrial experience acquired.

The preliminary design work for a pilot facility known as TOMOX 1300 (Transformation of military Objects into MOX fuel) was contracted by the CEA to COGEMA and SGN in 1995. This project study implemented the direct oxidation process to produce plutonium oxide, followed by conventional mechanical milling of mixed oxide powder; it would allow the fabrication of about 30 metric tons of MOX fuel pellets annually, incorporated in fuel assemblies for Russian PWRs and FRs.

The TOMOX 1300 project study continued in 1996-1997 under CEA contracts with the Russian project institutes using the process in which plutonium alloy is dissolved by HNO_3 + HF, purified by extraction of plutonium nitrate, with subsequent oxalate precipitation and fabrication of

PuO_2. This study will yield a preliminary cost estimate for installing the process facilities on existing Russian nuclear sites.

Irrespective of the process and facility ultimately selected, the design is contingent on the total quantity of weapons-grade plutonium to be recycled, currently estimated at about 50 metric tons for the Russian Federation (the same quantity as announced by the United States in Paris at the G7+1 Experts Conference in October 1996). Will it be preferable to refurbish Russian facilities (e.g. the Complex 300 MOX fabrication plant at Chelyabinsk 65 or the RT2 plant at Krasnoyarsk 26), or to build one or more entirely new units? The AIDA/MOX 1 program calls for drafting a feasibility report on both options in 1997.

How much weapons-grade plutonium can be used as fuel by Russian power reactors each year? From a technical standpoint, the initial results of the studies conducted by the CEA, FRAMATOME, EDF and the Russian IPPE Institute at Obninsk suggest that a few hundred kilograms of plutonium could be used each year in MOX fuel, comprising 30% of the core load in a single WWER 1000 pressurized water reactor (seven WWER 1000s are now operating in Russia); this estimate remains to be demonstrated, together with an assessment of the required engineering modifications and their cost. The BN 600 fast reactor now operating at Byeloyarsk NPP with enriched UO_2 fuel could also use a few hundred kilograms of plutonium per year, assuming a limit of about 20% MOX in the core; the feasibility of this operation should be fully demonstrated by the end of 1998. If the BN 800 reactor is built, it could use up to 1700 kg of plutonium annually with a 100% MOX core. Four BN 800 reactors could consume fifty tons of Russian weapons plutonium in less than ten years. The future WWER 640 with a 100% MOX core should also contribute to meeting this objective. More realistically, and in the short term, operating the BN 600 at Byeloyarsk and the four WWER 1000s at Balakovo would allow the use of 1300 kg of weapons plutonium each year--i.e. the design capacity of the future TOMOX 1300 facility.

For the short and medium term, a broader international effort and financing are to be envisaged. Over the much longer term, the construction of facilities in Russia capable of using at least 5000 kg of weapons plutonium per year could be considered. Naturally, a project of this scope will depend on the conclusions of the international studies and especially on future Russian decisions concerning the construction of the first BN 800 fast reactor and additional WWER 1000 and WWER 640 light water reactors.

3. MAIN CONCLUSIONS OF THE AIDA/MOX 1 PROGRAM

The French-Russian studies conducted from 1993 to 1996 under the AIDA/MOX 1 program established the advantages and technical feasibility of the W-Pu MOX option in certain existing nuclear reactors within the Russian Federation.

Broadly speaking, the PWR-MOX and FR-MOX options for using excess dismantled weapons plutonium for peaceful commercial nuclear power generating purposes--like the CANDU-MOX and HTR-MOX options--offer several advantages over the remaining options (interim storage, disposal in vitrified form, etc.) notably from a non-proliferation standpoint:

1) high radioactivity of the final product, a spent MOX fuel assembly, making any addition of radioactivity unnecessary;

2) fission of a significant fraction of the initial weapons plutonium: in the PWR-MOX scenario, some 30% of the W-Pu is converted into fission products after irradiation on the order of 40 $GWd\ t^{-1}$;

3) plutonium accountancy: the W-Pu is processed in an industrial cycle in facilities under permanent surveillance by the international organizations responsible for non-proliferation safeguards (IAEA),

4) isotopic denaturing of the residual plutonium (around 70%): the 239Pu fraction diminishes and that of the even numbered isotopes (^{238}Pu, ^{240}Pu and ^{242}Pu) increases.

5) conservation of natural resources: 50 metric tons of weapons-grade plutonium are capable of producing some 350 TWh of electric power;

6) no additional nuclear waste (e.g. vitrified plutonium): the spent MOX fuel assembly replaces a spent UOX fuel assembly.

Compared with the other MOX options, the PWR-MOX and FR-MOX options also offer the following major advantages:

1) the LWR-MOX and FR-MOX options are the only ones implementing proven technology: over 400 metric tons of PWR and BWR-MOX fuel have already been fabricated in Europe, and 19 European reactors have been using MOX for a number of years; over 100 metric tons of FR-MOX fuel have been fabricated to date in Europe;

2) the PWR-MOX and FR-MOX options are the only ones compatible with existing Russian reactors capable of using large quantities of W-Pu and known to be economically viable.

Concerning the implementation of this option by the Russian Federation, the joint French-Russian studies carried out under the AIDA/MOX 1 program have led to the following conclusions:

1) Using 30% MOX fuel is feasible in certain WWER 1000 reactors, after implementation of design changes similar to those made in France from 1985 to 1990 when EDF began using 30% MOX fuel in its 900 MW PWRs. These modifications (mainly affecting the number and design of the control rods, the soluble boron concentration in the water of some systems, and radiological protection of the fresh MOX fuel assembly transfer system) are currently the subject of preliminary studies by the Russian and the French parties, and will be covered in detail in the subsequent phase (1997-1998) proposed under the AIDA/MOX 2 program. This option would enable dispositioning of about 270 kg of W-Pu annually per WWER 1000 reactor (Figure 1).

2) Using 100% MOX fuel in the BN 600 fast reactor without breeding blankets is certainly the most promising option in a reasonable time frame (even though further studies are necessary to validate it) and should therefore be assigned medium-term priority. In the short term, the easily implemented BN 600 hybrid core solution should make it possible to use 240 kg of W-Pu per year. This solution complies with Russian safety requirements (negative void coefficient) by placing the MOX fuel around the periphery of the core (in the next-to-last ring) in limited quantities: less than 20% of the total number of fuel assemblies in the BN 600 core (Figure 2).

3) Studies on converting W-Pu into MOX fuel have led to the definition of a *reference process* and two possible variants for a future facility or plant to be built in Russia.

The *reference process* chosen by the French and Russian specialists (Figure 3) comprises:

- acid dissolution of plutonium alloy in HNO_3 + HF
- purification by extraction of plutonium nitrate
- Pu oxalate precipitation and PuO_2 production
- MOX fabrication using the COCA and MIMAS processes.

The first process variant is the following:

- acid dissolution of plutonium alloy in HNO_3 + HF
- purification by extraction of plutonium nitrate
- coprecipitation of $(U,Pu)O_2$ with ammonia
- MOX fabrication by powder blending.

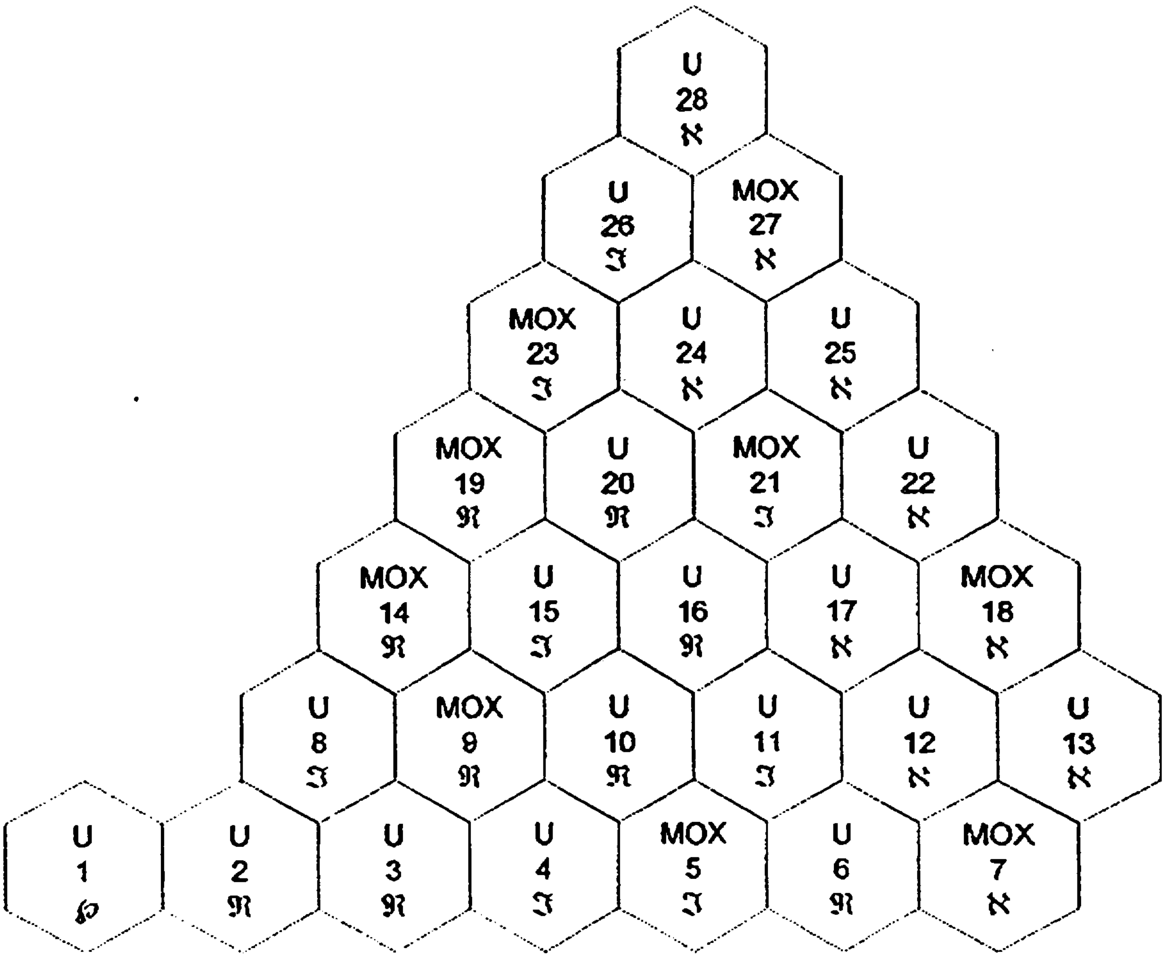

FIG. 1. Subassembly layout in MOX-fueled reactor (1/6 of WWER 1000 core)

U : UO_2 subassembly
MOX : MOX subassembly
11 : Subassembly position
ℜ : 3rd-year subassembly

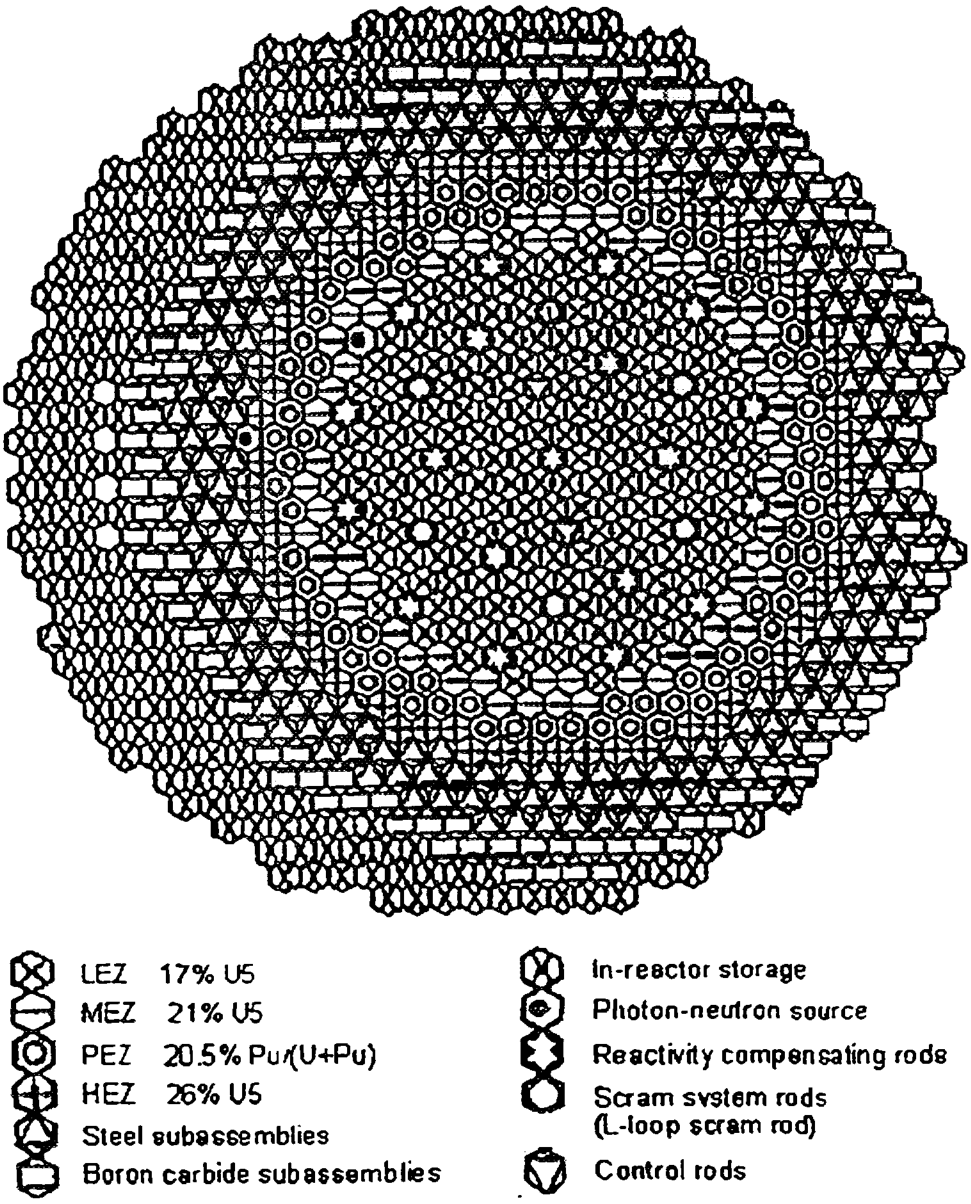

FIG. 2. Layout of the BN-600 reactor hybrid core with steel reflector

The *second process* variant (Figure 4) comprises:

- calcining of plutonium alloy into plutonium oxide
- acid dissolution of plutonium oxide in HNO_3 + Ag(II)
- purification by extraction of plutonium nitrate
- Pu oxalate precipitation and PuO_2 production
- MOX fabrication using the COCA and MIMAS processes.

Neither variant has been adopted to date for lack of sufficient industrial experience; further research and development work will be required in both cases.

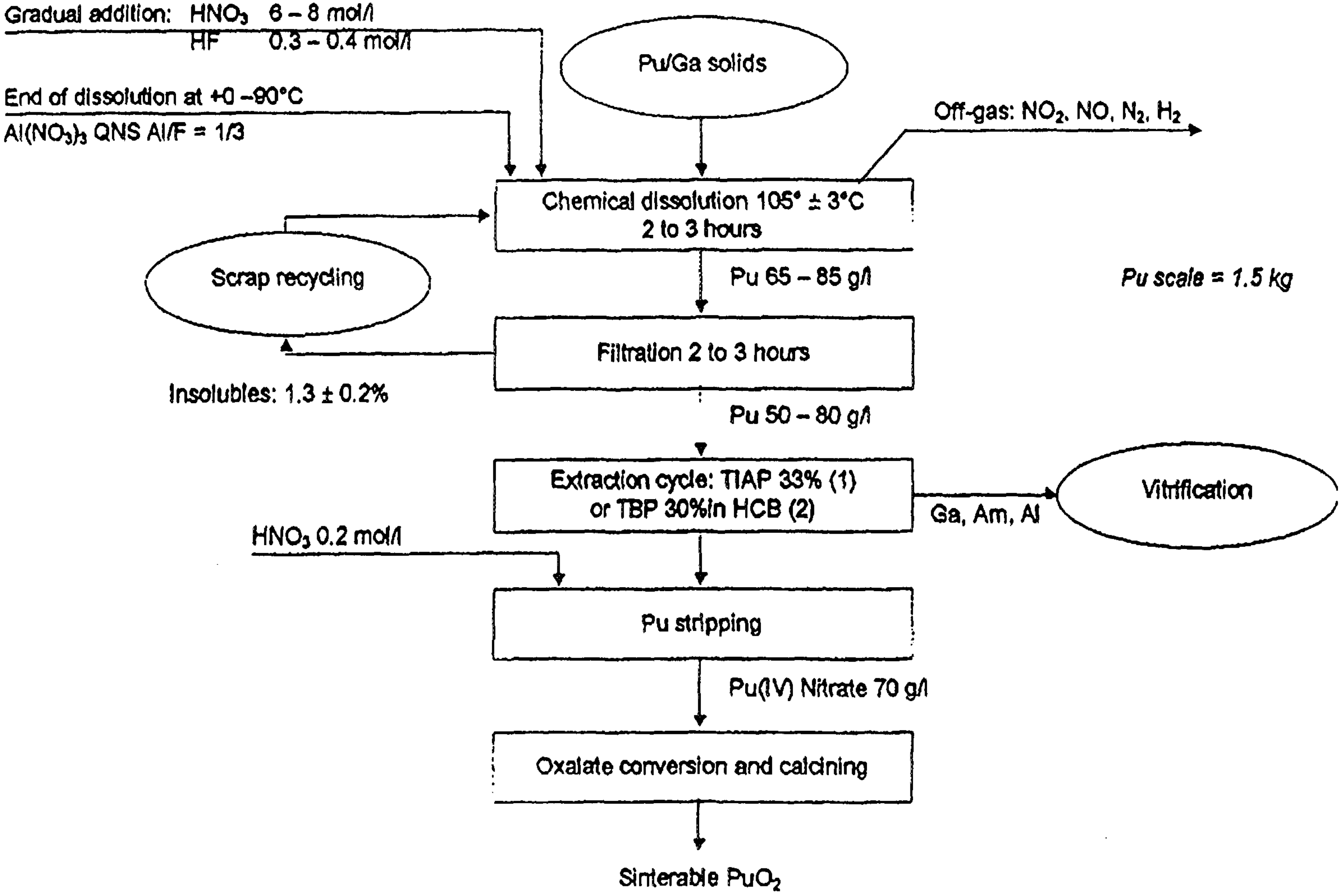

FIG. 3. AIDA/MOX reference flowsheet for converting W-Pu into PuO_2

(1) TIAP: triisoamylphosphate
(2) HCB: hexachlorobutadiene

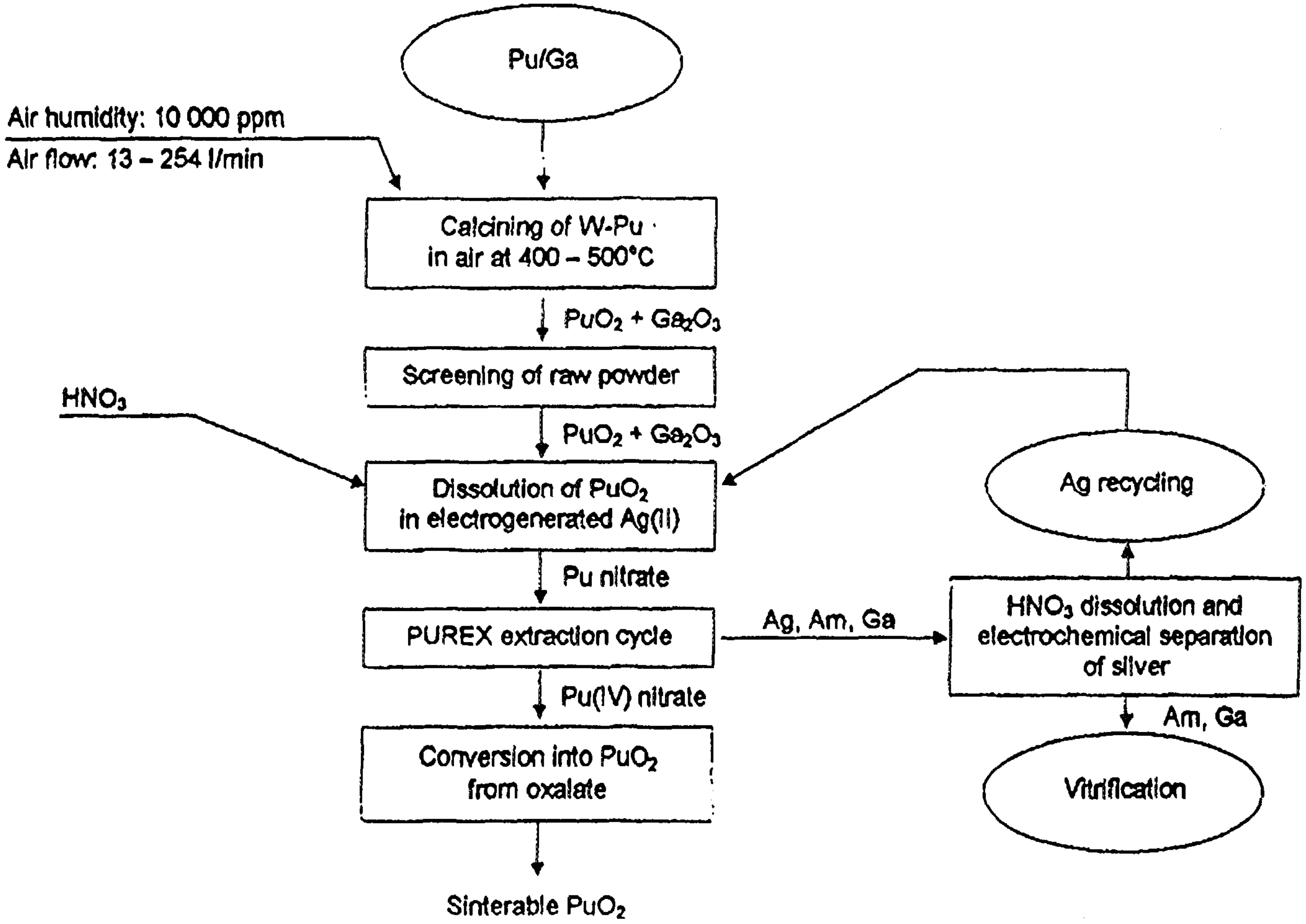

FIG. 4. Variant b of AIDA./MOX reference flowsheet: W-Pu calcining, dissolution, PUREX extraction, oxalate conversion

4) The capacity of a MOX facility to be built in Russia was determined by the possibility of consuming MOX fuel in existing Russian BN 600 and WWER 1000 reactors. The AIDA/MOX Coordinating Committee initially selected the following Russian reactors:

- BN 600 hybrid core option (=> 240 kg of W-Pu per year), as the first step toward the final objective of 100% MOX fuel in the BN 600 reactor core (1310 kg of W-Pu per year) and gradual removal of all the blankets,

- four WWER 1000 reactors at the Balakovo NPP (=> 4 x 270 kg of W-Pu per year), hence a total capacity of around 1300 kg of W-Pu for the TOMOX 1300 facility, i.e. approximately 30 metric tons of MOX per year.

5) Preliminary design work on the TOMOX 1300 facility implementing glove-box handling technology is underway in Russia with French participation by the CEA, COGEMA and SGN. The results will be available by mid-1997, together with a preliminary estimate of the total cost and itemized cost of the plant components; allowance will be made for the basic facilities already in place at Russian nuclear sites, including Chelyabinsk 65 and Krasnoyarsk 26.

6) A detailed proposal for the TOMOX 1300 plant will be required in 1997-1998 before construction begins in the Russian Federation. The detailed proposal is planned for the AIDA/MOX 2 program stipulated in the proposed Trilateral Agreement between France, Germany and the Russian Federation. The TOMOX 1300 project will be implemented in two separate entities: TOMOX and DEMOX.

- TOMOX plant (transformation of military objects into sinterable weapons-plutonium oxide): Bilateral Cooperation: France-Russia

- DEMOX plant (fabrication of MOX fuel from sinterable W-Pu oxide powder): Trilateral cooperation: France-Germany-Russia (COGEMA-SIEMENS-MINATOM).

4. INTERNATIONAL COOPERATION (Beginning in 1997)

Following the International Workshop in Bonn (May 19-21, 1996) on the dismantling and destruction of nuclear, chemical and conventional weapons, Germany and France decided for greater effectiveness to investigate the possibility of coordinating and integrating their actions with the Russian Federation in the area of dismantling and destruction of nuclear weapons beginning in 1997.

In their final statement, the participants in the Moscow Summit Meeting of April 19-20, 1996 on nuclear safety and security notably requested that a meeting of experts from the G7+1 countries, together with representatives of Belgium, Switzerland, the European Union and the IAEA, be held in Paris in late October 1996 to examine and propose measures for ensuring safe and effective management of military fissile materials identified by their owners as no longer required for defense purposes.

At the experts meeting in Paris (October 28-31, 1996), the German, French and Russian governments issued a joint statement of cooperation for 1997 and 1998, and justified their choice of MOX fuel as the most effective means for eliminating weapons plutonium recovered from nuclear weapons under cost-effective and safe conditions; this cooperation remains open to any country interested in the project, whose pertinence is now universally acknowledged.

This joint action announced by the Germans, French and Russians can thus constitute the groundwork for a broader cooperation mobilizing international financing, both for the construction of the MOX-fabrication pilot plant (which at the turn of the century could convert 1300 kg of weapons plutonium from dismantled Russian warheads into commercial reactor fuel) and for the equipment modifications that will no doubt prove necessary in the Russian BN 600 and WWER 1000 reactors.

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