

DEVELOPMENT OF A TEST SYSTEM FOR HIGH LEVEL LIQUID WASTE PARTITIONING

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The partitioning and transmutation strategy has increasingly attracted interest for the safe treatment and disposal of high level liquid waste, in which the partitioning of high level liquid waste is one of the critical technical issues. An improved total partitioning process, including a tri-alkylphosphine oxide process for the removal of actinides, a crown ether strontium extraction process for the removal of strontium, and a calixcrown ether cesium extraction process for the removal of cesium, has been developed to treat Chinese high level liquid waste. A test system containing 72-stage 10-mm-diam annular centrifugal contactors, a remote sampling system, a rotor speed acquisition-monitoring system, a feeding system, and a video camera-surveillance system was successfully developed to carry out the hot test for verifying the improved total partitioning process. The test system has been successfully used in a 160 hour hot test using genuine high level liquid waste. During the hot test, the test system was stable, which demonstrated it was reliable for the hot test of the high level liquid waste partitioning.

Key words: test system, annular centrifugal contactor, high level liquid waste, extraction, total partitioning process

INTRODUCTION

The safe treatment and disposal of high level liquid waste (HLLW) are crucial to sustainable development of nuclear energy [1, 2]. The partitioning and transmutation (P&T) strategy for converting long-life nuclides from HLLW into short-life radioactive or stable species constitutes an advanced nuclear fuel cycle, and has increasingly attracted interest, in which the partitioning of HLLW is one of the critical technical issues of the P&T strategy [3-5]. In recent years, a number of partitioning processes for HLLW by means of solvent extraction technology have been proposed and studied, such as the DIAMEX process in France, the DIDPA process in Japan, the TRUEX process in the USA, and the TRPO process in China, *etc.* [6-13]. In these processes, different kinds of extractants have various advantages used in the partitioning processes.

An old total partitioning process, including the removal of actinides by the trialkylphosphine oxide process (TRPO), the removal of Sr by the crown ether strontium extraction (CESE) process, and the removal of Cs by ion exchange using potassium titanium

hexacyanoferrate (II) (KTiFC) was developed to treat Chinese highly saline HLLW on the basis of the original TRPO process in the 1990 [14]. In particular, the old total partitioning process was verified by a hot test for laboratory-scale with 50-stage 10-mm-diam annular centrifugal contactors (ACC) with 10 mm of the rotor diameter in 1996 [15, 16]. In the hot test, the decontamination factors (DF) for total α activity, ⁹⁹Tc, ⁹⁰Sr, and ¹³⁷Cs were 588, 125, >2500, and >200, respectively. After partitioning, HLLW was transformed into a non-, low and intermediate level radioactive waste that was suitable for shallow-land disposal to reduce the uncertainties associated with geologic disposal and the disposal cost of HLLW because the actinides, and the short-term heat generators in HLLW, such as Sr and Cs were removed from HLLW.

Recently, an improved total partitioning process as shown in fig. 1, including the TRPO process for the removal of actinides, the CESE process for the removal of Sr, and the calixcrown ether cesium extraction (CECE) process using iPr-C[4]C-6 (25,27-bis (2-propyloxy)calix [4]-26,28-crown-6) as the extractant and *n*-octanol as a diluent for the removal of Cs, has been developed to treat Chinese HLLW. In comparison to the old total partitioning process, the most important improvement is that the

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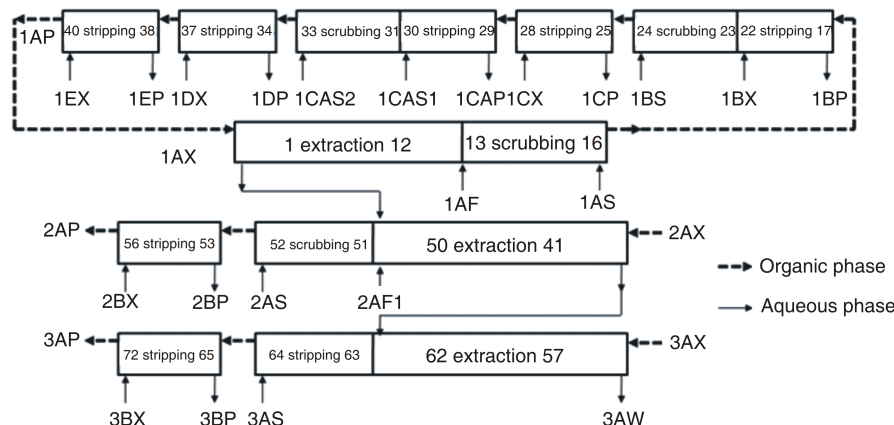


Figure 1. The improved total partitioning process

ion exchange process is replaced with the CECE process for the removal of Cs [17, 18]. Moreover, a 160-hour hot test has been successfully carried out to verify both stability and reliability of the improved total partitioning process using a self-developed test system and genuine HLLW [19]. In the hot test, 4.2 L of genuine HLLW was treated, and the decontamination factors of total α activity, Sr, and Cs were $3.57 \cdot 10^3$, $2.25 \cdot 10^4$, and $1.68 \cdot 10^4$, respectively. Compared with the results of the hot test of the old total partitioning process in 1996 [15], the DF of total α activity, Sr, and Cs had increased, so the improvements of the total partitioning process proved effective. Although the process and results of the hot test have been reported in [19], the self-developed test system has not been reported. In this paper, the self-developed test system containing 72-stage 10-mm-diam ACC, a remote sampling system, a rotor speed acquisition-monitoring system, a feeding system, and a video camera-surveillance system was thoroughly introduced.

THE TEST SYSTEM

Layout of the self-developed test system

According to the requirements of the hot test for the improved total partitioning process as shown in fig. 1, the self-developed test system contained 72-stage 10-mm-diam ACC. In addition, the self-developed test system also contained the remote sampling system, the rotor speed acquisition-monitoring system, the feeding system, and the video camera-surveillance system to successfully carry out the hot test. The layout of these systems is shown in fig. 2. The rotor speed acquisition-monitoring system, the monitor of the video camera-surveillance system, and the non-radioactive feeds were placed in the manipulation room where the radioactivity was very low. The operators in the manipulation room operated all devices in the hot test cell. 72-Stage 10-mm-diam ACC were placed in the hot cell where the radioactivity was the highest. The diluted genuine HLLW (1AF) tank, the aqueous phase waste tank, the organic phase waste tank, the Cs product tank, and the Sr product tank were

placed in the back zone where the radioactivity was higher.

Several ports were provided in the hot cell through the hot cell wall. They were used for the transfer lines of the feeds, for the electrical connections of both the rotor speed acquisition-monitoring system and the video camera-surveillance system, for transfer of non-radioactive equipment into the hot cell, and for transfer of radioactive materials out of the hot cell. A pair of manipulators was located in the manipulation room, while the paws of the manipulators were in the hot cell. A wall with a heavily shielded glass window was placed between the manipulation room and the hot cell. At this station, operators could handle devices in the hot cell by means of the manipulators, and observe the movements of the paws of the manipulators in the hot cell through the window.

Arrangement of 72-stage 10-mm-diam ACC

The space of the hot cell is limited. Moreover the operation space of the manipulators in the hot cell is also confined. However, both assemblies and disassemblies of the ACC by the manipulators in the hot cell should be made easy. On the other hand, the improved total partitioning process including the TRPO process, the CESE process, and the CECE process, require the use of 72-stage 10-mm-diam ACC. So the 10-mm-diam ACC needs to be improved to enable a smooth operation of the improved total partitioning process, remote-handling situations, an easy use of manipulators, a more reliable and simple maintenance, in a confined space of the hot cell. Moreover, the arrangement of 72-stage 10-mm-diam ACC should be reasonable to meet the operation requirements of the hot test in the hot cell.

The self-developed 10-mm-diam ACC was made up of two modules as shown in fig. 3 to facilitate their remote maintenance in the hot cell. Modules were installed together to form a complete ACC by simply inserting one module into the other one, and the modules were fitted without screws and nuts. In this way, it was much easier to manipulate ACC. For in-

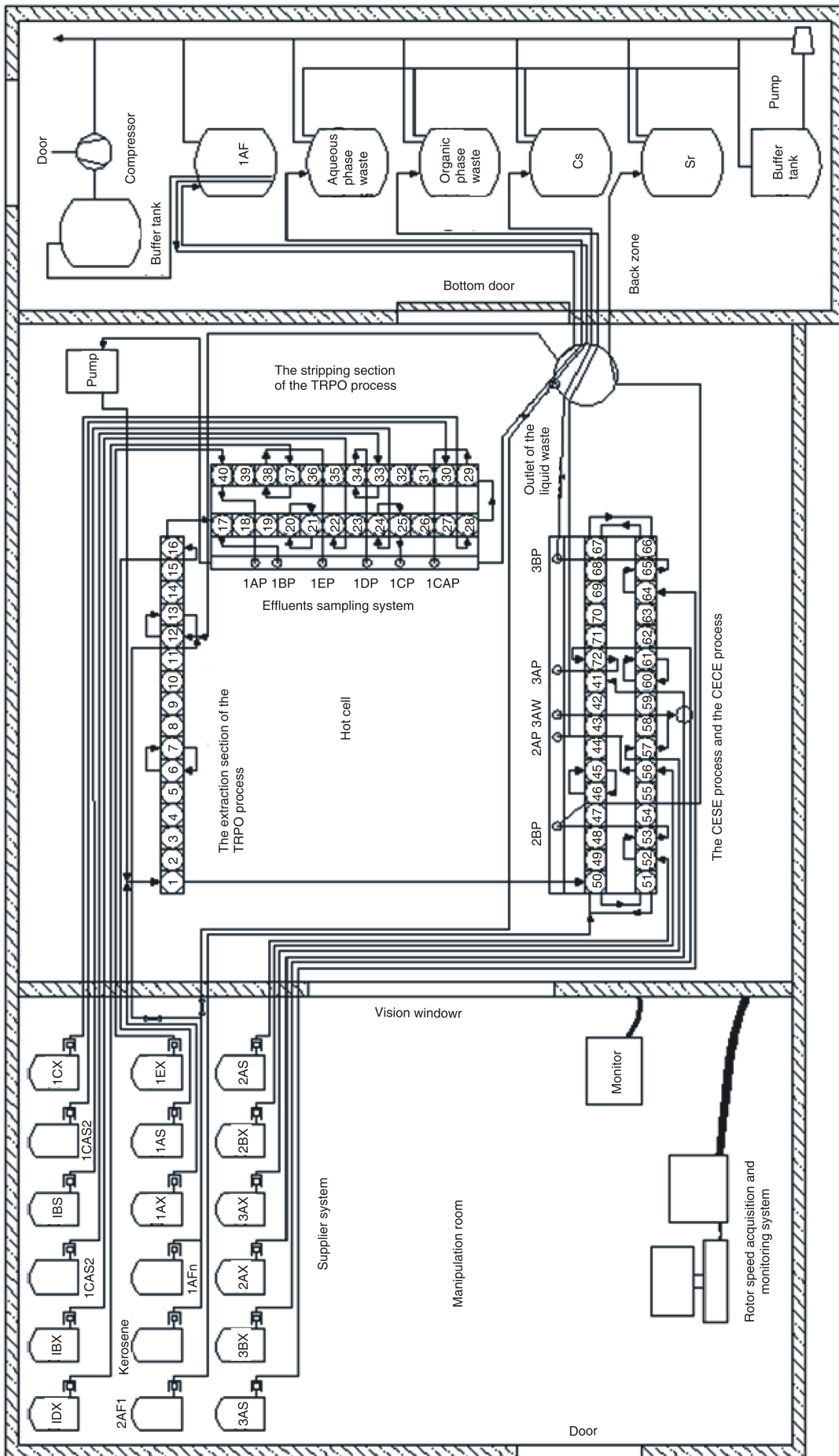


Figure 2. The test system

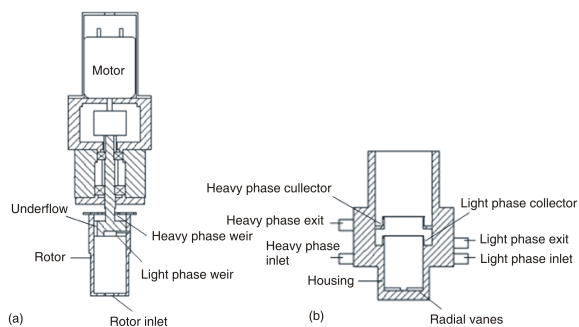


Figure 3. The 10-mm-diam ACC, (a) – the rotor module, (b) – the housing module

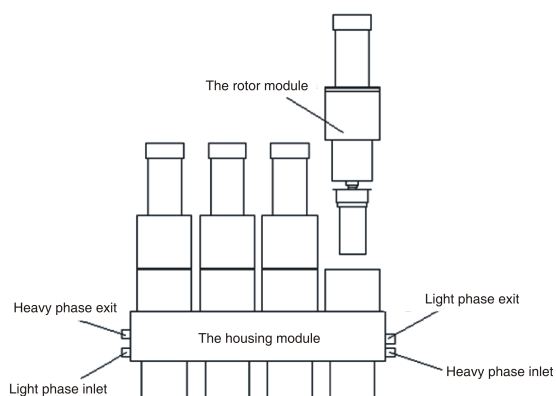


Figure 4. The multi-stage group housing structure

stance, if one of the rotor modules failed (such as the motor or the bearing failed) or any other unexpected situation occurred, when a multi-stage ACC system was being tested in the hot cell, the facility could be rapidly shut down, and the rotor module with a problem could be promptly replaced by the manipulators, and the hot test could be quickly restarted. Moreover, to further reduce the liquid hold-up volume of the 10-mm-diam ACC, a multi-stage group housing structure containing multiple stage housings (*e. g.*, 6, 5, 4, 3, or 2 stages) in a set as shown in fig. 4 was developed. The principal part of the set was a whole stainless steel block, which consisted of heavy phase collecting rings, light phase collecting rings, and internal interstage lines. One of advantages of the set was that there were no external interstage lines between two stages in the set, thus ensuring very small liquid hold-up volume and no risk of leakage in interstage lines. The multi-stage group housing structure also made multi-stage cascade unit more compact for multi-stage processes.

The arrangement of 72-stage 10-mm-diam ACC is shown in fig. 2. The extraction section of the TRPO process was arranged in one row containing 16-stage 10-mm-diam ACC. The stripping section of the TRPO process was arranged in two rows containing 24-stage 10-mm-diam ACC. The CESE and CECE processes

were arranged in two rows containing 32-stage 10-mm-diam ACC. There was no 10-mm-diam ACC in the hot cell to block the view of the operators through the window during manipulators operation. Moreover, there was sufficient room in the middle of the hot cell for repairing equipment, for preparing sample cups, and transferring them into and out of the hot cell by the manipulators. So the arrangement of 72-stage 10-mm-diam ACC was reasonable for remote-handling situations, for easy use of the manipulators, and for the limited space in the hot cell. Three supporting structures were fabricated for the 10-mm-diam ACC of the extraction section of the TRPO process, the stripping section of the TRPO process, and the CESE and CECE processes, respectively. Every supporting structure contained leveling screws to adjust unevenness in the hot cell floor.

Remote sampling system

Measuring component concentration in the exit effluents can give a correct evaluation as to whether the processes achieved the partitioning goal. It is very difficult to sample from the exit effluents of the improved total partitioning process for concentration analysis during the hot test. A remote sampling system for the exit effluents has been developed as shown in fig. 5. In the remote sampling system, two linear bearings were installed in two stainless steel rods, and a stainless steel plate was fixed on the two linear bearings. Several openings were provided in the stainless steel plate for placing the sampling cups made of organic glass. The sampling process comprised of the following steps: (1) the stainless steel plate with the sampling cups was shifted underneath the exit effluents outlet pipes by means of the manipulators, so that the exit effluents flowed separately into the sampling cups, (2) after the designed sampling time, the stainless steel plate was moved away from the outlet pipes by the manipulators, (3) the sampling cups were transferred to the small flat car by the manipulators, and (4) the small flat car with the sampling cups was transferred to the laboratories for analysis. Two remote sampling systems for the exit effluents were installed for the TRPO stripping sec-

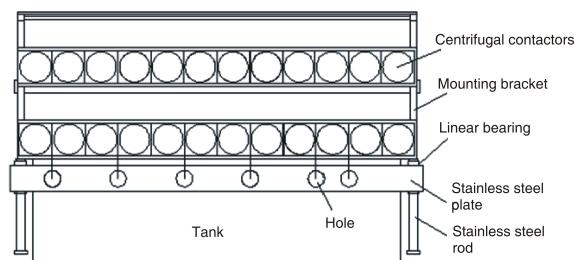


Figure 5. The remote sampling system for effluents

tion, and the CESE and CECE processes as shown in fig. 2, respectively.

The liquid left in the ACC after the hot test also needs sampling for analysis. Obtaining samples from multi-stage ACC using the manipulators also proved difficult. Leonard *et al.* brought up and tested six stage-sampling methods [20]. The method that they recommended provided a quick shutdown when the ACC reached steady-state. During a quick shutdown, all of the ACC motors and pumps were turned off at once. Two phases were drained from each stage, and their volumes were measured. The phases were then equilibrated by shaking. The problem with the quick shut down arose when pumps and motors were turned off, the rotors continued to pump liquid from stage to stage for a short period of time. Stage volumes and concentrations were thus impacted to some degree. However, measuring component concentration in stage samples gives a general understanding of the stage-to-stage concentration profile. The error in this analysis can be estimated by comparing the stage samples to the external effluent in stages having an external effluent. The method that Leonard *et al.* recommended was also adopted to sample the liquid left in the ACC after the hot test of the improved total partitioning process. Prior to sampling the liquid from the ACC after the hot test, the rotor module was first lifted and transferred by means of the manipulator into a supporting cylinder, and a plastic straw was used to drain the liquid from the ACC using the manipulator. After sampling, the rotor module was transferred into the housing module to form the complete ACC again.

Rotor speed acquisition-monitoring system

A rotor speed acquisition-monitoring system is practical and necessary to control and monitor operations of multi-stage ACC for laboratory-scale in the hot tests. The rotor of the 10-mm-diam ACC was directly driven by a DC motor with a tachometer (Maxon, Swiss). The rotor speed depended on the voltage of the power supply. So the rotor speed was simply controlled by adjusting the voltage of the power supply using an adjustable voltage controller. The output voltage of the DC motor was obtained by the tachometer, and was proportional to the rotor speed. The flowsheet of the rotor speed acquisition-monitoring system for 72-stage 10-mm-diam ACC is shown in fig. 6. The system consisted of an integrated workstation with the control software written in VB.NET, a controller, 50-core color cables, and transfer boxes. The adjustable voltage controller was used to directly adjust voltages of the motors while the rotor speeds were changed accordingly. The speed acquisition system was used to acquire the signals of the

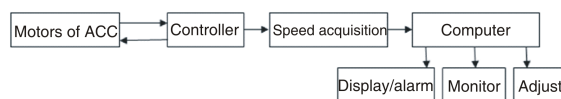


Figure 6. The flowsheet of the rotor speed acquisition-monitoring system

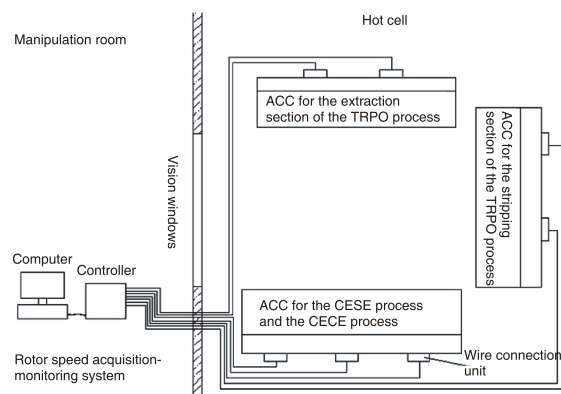


Figure 7. Layout of the rotor speed acquisition-monitoring system

output voltages and process them by a computer to be at the speeds of the ACC.

The layout of the rotor speed acquisition-monitoring system is shown in fig. 7. The electrical plug for the motor of every stage 10-mm-diam ACC went into an electrical junction box. The electrical junction box had a recessed male plug that fits the female plug on the electrical cord. This design, which was used in most computer equipment, kept electrically hot prongs from being exposed. It also eliminated any wires dangling from the rotor module of the ACC as it was being removed or resealed. The electrical junction boxes were placed in the hot cell. Both the computer and the controller were placed in the manipulation room. 50-Core color cables were used to connect the electrical junction boxes in the hot cell with the controller in the manipulation room.

Using the rotor speed acquisition-monitoring system, the operation of 72-stage 10-mm-diam ACC was controlled remotely. The computer outside the hot cell could discover problems in the 10-mm-diam ACC operated in the hot cell by detecting changes at the speeds of the 10-mm-diam ACC. The systems could give an alarm in a sufficient time after one or multi-stage 10-mm-diam ACC changed at the speed.

Feeding system

The layout of the feeding system is shown in fig. 2. The non-radioactive feed pumps and vessels were located in the manipulation room. There were 18 non-radioactive solutions for the hot test. Non-radioactive solutions were pumped by precision metering

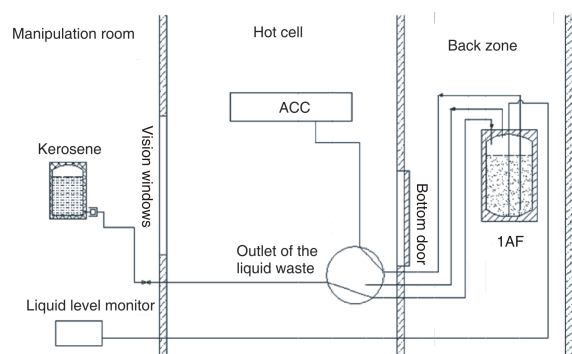


Figure 8. The feeding system of the diluted genuine HLLW

pumps (GALa1000SST00, ProMinent Fluid Controls Co. Ltd., Germany) to the ACC through penetrations in the wall of the hot cell. To start the hot test at the correct flowrates, all of the pumps were calibrated. Once the hot test was underway, minor adjustments to the flowrates could be made after monitoring the liquid levels of the vessels. These flowrates could be determined by monitoring the change in the liquid levels of the vessels over a time period. The diluted genuine HLLW (1AF) located in the back zone was pumped by the volume displacement method with kerosene as shown in fig. 8. The kerosene located in the manipulation room was first pumped by the precision metering pump into the 1AF tank located in the back zone, and then the diluted genuine HLLW in the 1AF tank was pressed into stage 12 of the TRPO process in the hot cell. A liquid level monitor located in the manipulation room was used to monitor the liquid level of the diluted genuine HLLW in the 1AF tank.

Video camera-surveillance system

The video camera-surveillance system was used to observe operations of all devices in the hot cell and the movements of the paws of the manipulators, and record these operations and movements. The system consisted of a camera, a monitor, and a cable. The layout of the system is shown in fig. 2. The camera was installed above the heavily shielded glass window in the wall of the hot cell. It could move with 270-degree rotation in the horizontal direction and with 90-degree rotation in the vertical direction. All of devices in the hot cell could be videoed through the camera. The monitor located in the manipulation room was used for display, record, and storage of the digital videos. The cable was used for the connection of the camera and the monitor through a penetration in the wall of the hot cell.

CONCLUSION

The self-developed test system containing 72-stage 10-mm-diam ACC, the remote sampling sys-

tem, the rotor speed acquisition-monitoring system, the feeding system, and the video camera-surveillance system was successfully developed. It has been successfully used in the 160-hour hot test of the improved total partitioning process, consisting of the TRPO process for removal of actinides, the CESE process for the removal of Sr, and the CECE process for the removal of Cs with genuine HLLW. During the hot test, the test system worked smoothly without failing or interruption of the system operation. So the test system was reliable for the hot test of the HLLW partitioning.

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AUTHORS' CONTRIBUTIONS

72-stage 10-mm-diam ACC and their arrangement, and the remote sampling system were developed by W. H. Duan. The layout of the hot test system was designed by J. Chen. The rotor speed acquisition-monitoring system was developed by S. W. Wang. The feeding system and the video camera-surveillance system were designed by J. C. Wang and X. H. Wang. The manuscript together with figures was prepared by W. H. Duan.

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РАЗВОЈ ТЕСТ СИСТЕМА ЗА РАЗДВАЈАЊЕ ТЕЧНОГ ОТПАДА ВИСОКОГ НИВОА РАДИОАКТИВНОСТИ

Ради безбедног руковања и одлагања течног отпада високог нивоа радиоактивности, стратегија раздвајања и трансмутације све више привлачи пажњу, при чему је раздвајање течног отпада високог нивоа један од критичних техничких проблема. При руковању кинеским течним отпадом високог нивоа развијен је унапређени тотални процес раздвајања који укључује: три-аликилфосфин оксидни процес за уклањање актинида, процес уклањања стронцијума крунским етром и уклањање цезијума применом каликсцикличног етра. Тест систем састоји се од кружних центрифугалних контрактора пречника 10 mm подељених у 72 нивоа, даљинског система за узорковање, система за аквизицију и надзор, система за снабдевање, као и система за видео надзор ради спровођења врућег теста за потврду унапређеног тоталног процеса раздвајања. Систем је успешно испробан током врућег теста у трајању од 160 часова при чему је коришћен прави течни отпад високог нивоа. Током теста систем је био стабилан, што је потврдило његову поузданост за раздвајање течног отпада високог нивоа.

Кључне речи: шести систем, кружни центрифугални контактор, течни отпад високе радиоактивности, екстракција, тотални процес раздвајања