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JOINT OPERATION OF THE TSTA UNDER THE COLLABORATION BETWEEN JAERI AND U.S.-DOE
—DETAIL PERFORMANCE OF THE J-FCU (25 DAYS EXTENDED TSTA LOOP OPERATION ON APRIL-MAY 1992)—

March 1993

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Joint Operation of the TSTA under the Collaboration between JAERI and U.S.-DOE
- Detail Performance of the J-FCU (25 Days Extended TSTA Loop Operation on April - May 1992) -

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A first complete integrated test of the J-FCU (JAERI Fuel Cleanup System) and the ISS (Isotope Separation System) with full four cryogenic distillation columns was performed successfully with 100 grams of tritium. This test was performed as a part of a 25 day TSTA extended loop run on April - May 1992.

Through this operation, the J-FCU was operated stably and safely. No significant problems was caused on the interaction between the J-FCU and the ISS. J-FCU processed more than 5 Nl/min of simulated fusion-fuel exhaust with wide range of impurities and transfered pure hydrogen isotopes to the ISS and exhausted tritium free impurities to the TWT (Tritium Waste Treatment System) continuously.

This report describes the detail result of the J-FCU part test under a 25 day TSTA extended loop run and discuss the JFCU performance.

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Keywords : Fusion, Fusion Fuel Cycle, Tritium, Fuel Cleanup, Isotope Separation, TSTA, J-FCU, Palladium Diffuser, Ceramic Electrolysis Cell, Cryogenic Distillation

日米協力Annex Ⅳに基づくTSTA共同試験
— J－FCUの詳細性能試験結果
（1992年4－5月のTSTAループ運転）—

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（1993年3月8日受理）

原研は日米核融合研究協力協定Annex Ⅳに基づき，米国ロスアラモス国立研究所のトリチウムシステム試験施設（TSTA）において核融合炉燃料ループの実証試験を行っている。本試験は，J－FCU（JAERI－燃料精製捕集実験装置）と全4塔を使用したISS（水素同位体分離装置）を連結した初めての試験であり，25日間連続TSTAループ運転試験の重要部分として1992年4－5月に行われた。

試験中，J－FCUは常に安定かつ安全に運転され，ISSとの連結においても大きな問題はなかった。約5NL／分程度の多岐にわたる不純物を含む模擬プラズマ排ガスを連続処理し，ISSへ純水素同位体を排出するとともにトリチウムを含まないガスはTWT（トリチウム排ガス処理設備）へ排気した。

本報告書は，上記J－FCUの性能試験に関する詳細結果をまとめたものである。

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1. SUMMARY

The JAERI Fuel Cleanup system (J-FCU) was designed, fabricated, and installed at the TSTA as a subsystem for the TSTA loop in 1990 [1-3]. After deuterium tests for about one year, the J-FCU has been in tritium test as a stand-alone mode and also as a TSTA loop operation in 1991 [4-5].

The first complete integrated loop run with the Isotope Separation System (ISS) with 4 columns and the J-FCU after replacing Ceramic Electrolysis Cell (CEC) was performed successfully with a 100 grams of tritium. This test was performed as a part of a 25 day TSTA extended loop run (Apr. 20 - May 14, 1992) [6-7]. JFCU test with TSTA loop was conducted in the 2nd week and 4th week.

Fuel processing operation was performed with various impurities, adding a few % of impurities (10 % methane and N2 mixture), a regeneration & purging of molecular sieve beds (CMSB) of the TSTA fuel clean up system (TSTA-FCU), and gases processed by Mg bed from TSTA-FCU. During these fuel processing operations, "External" Cold Trap (CT) regeneration line was selected and " Internal " Catalytic Reactor (JCR1) dilution line was used. The stream to the Tritium Waste Treatment (TWT) system was at 6 ~ 7 Nl/min. Its tritium level was low enough except at the ISS-JFCU connection and at CTs (from CT1 to CT2) switching after increasing CT1's differential pressure (> 500 torr).

The interaction between the ISS and JFCU was investigated. Loop flow was processed continuously by the Palladium Diffuser (PD) and more than 5 Nl/min of hydrogen isotopes stream was produced for feed to ISS continuously. Loop flow and ISS columns pressure were varied, however, no major operational trouble occurred if ISS column I pressure was controlled below 1000 torr.

CEC decomposed water well (max : ~ 12 A = 1.1 mol/hr). The increase of CEC current limit setting (from 10 A to 15 A) was helpful for CEC performance and control. Replaced orifice, installed at the evacuation valve of CEC O2 jacket, worked well and CEC differential pressure control was easier. After the completion of this run, a large internal leak of CEC tubes was found. Next generation cell will solve this R&D problem.

Small humidity spike at the outlet of CTs was detected again when each CT was changed (once per an hour). However, it was at an acceptable level and no problem for loop operation, even if humidity level was very high at the inlet of the CTs.

Zirconium Cobalt Bed No.2&3 (ZCB2&3) still did not work for the processing of JFCU-GC (Gas Chromatograph) gas even though the regeneration of ZCB2&3 was carried out before this loop run. Some tritium was exhausted through ZCB2&3 during GC analysis. More high temp. regeneration/activation treatment with hydrogen is needed.

At the shut down of loop operation, almost all residual gas, except ISS, and purge gas were received and processed by JFCU and about 220 Nl of total hydrogen isotope gases in the TSTA loop (include ~ 22 grams of tritium) was recovered in the ZCB1 of JFCU.

Through these operations, JFCU worked quite well as well as TSTA-FCU and all operators / staff gained much experience. In a second half of this extended loop run, JFCU and TSTA FCU were used. Comparing the TSTA-FCU, the JFCU advantage of continuous tritium recovery from impurities was demonstrated. If the processing fuel does not include a considerable amount of He and impurities, however, TSTA-FCU system will be easier to operate.

2. PURPOSES

The TSTA extended loop operation was performed during April 20 - May 14, 1992. JFCU was operated April 26 - May 1, 1992 and May 11 - 14, 1992.

The purposes of this run for the JFCU were :

1) to study the interaction between the ISS with 4 columns and the JFCU with replaced CEC,

(The effect of flow and pressure fluctuation generated by the ISS on the loop is of interest.)

2) to demonstrate the capability of the JFCU to produce a hydrogen isotope stream for feed to ISS and to process simulated impurities from torus evacuation,

3) to compare the functions between JFCU and TSTA - FCU in the same loop configuration and with the same hydrogen isotope / impurities composition,

4) to check the effect of JFCU inventory on the total loop inventory,

5) to accumulate TSTA loop operation experience with the JFCU.

3. CONFIGURATION

The fuel circulation loop was established as Transfer pump system No.1 (TP1) - JFCU - ISS - Transfer pump system No.3 (TP3), as shown in the attached fig 3-1. Tritium was supplied from Uranium Tritide Beds (UTB) to the ISS. Hydrogen isotope gases with tritium, stored in the ZCB1 of the JFCU was transferred to the JFCU-Reservoir Tank No.2 (RT2) by regeneration of ZCB1 initially. No addition of tritium from a Product Container (PC) was planned during the JFCU part.

The ISS was operated with 4 columns.

The JFCU was operated with the "External mode" of CT regeneration and the "Internal mode" of JCR1 dilution. (It was the same operation as the JFCU D2 stand-alone run on Apr.'92.) Helium at 6-7 Nl/min exhausted constantly to the TWT as a carrier gas for CT regeneration, including a small amount of tritium free impurity. Exhaust from JFCU Gaschromatographs (GCs) was also sent to TWT.

Impurities, a mixture of 10 % methane (CH_4) and nitrogen (N_2) balance, was supplied into the JFCU-Reservoir Tank No.1 (RT1), because they were expected to make a little impact on the loop operation. After checking the impurity processing situation of the JFCU, some regeneration gas of CMSB of the TSTA-FCU were introduced to the JFCU. (The Raman system in EXP2 Glove Box (GB) was used to measure the dynamic response of the ISS. The Raman flow was established ISS-Raman- FCU - TP1 - JFCU.)

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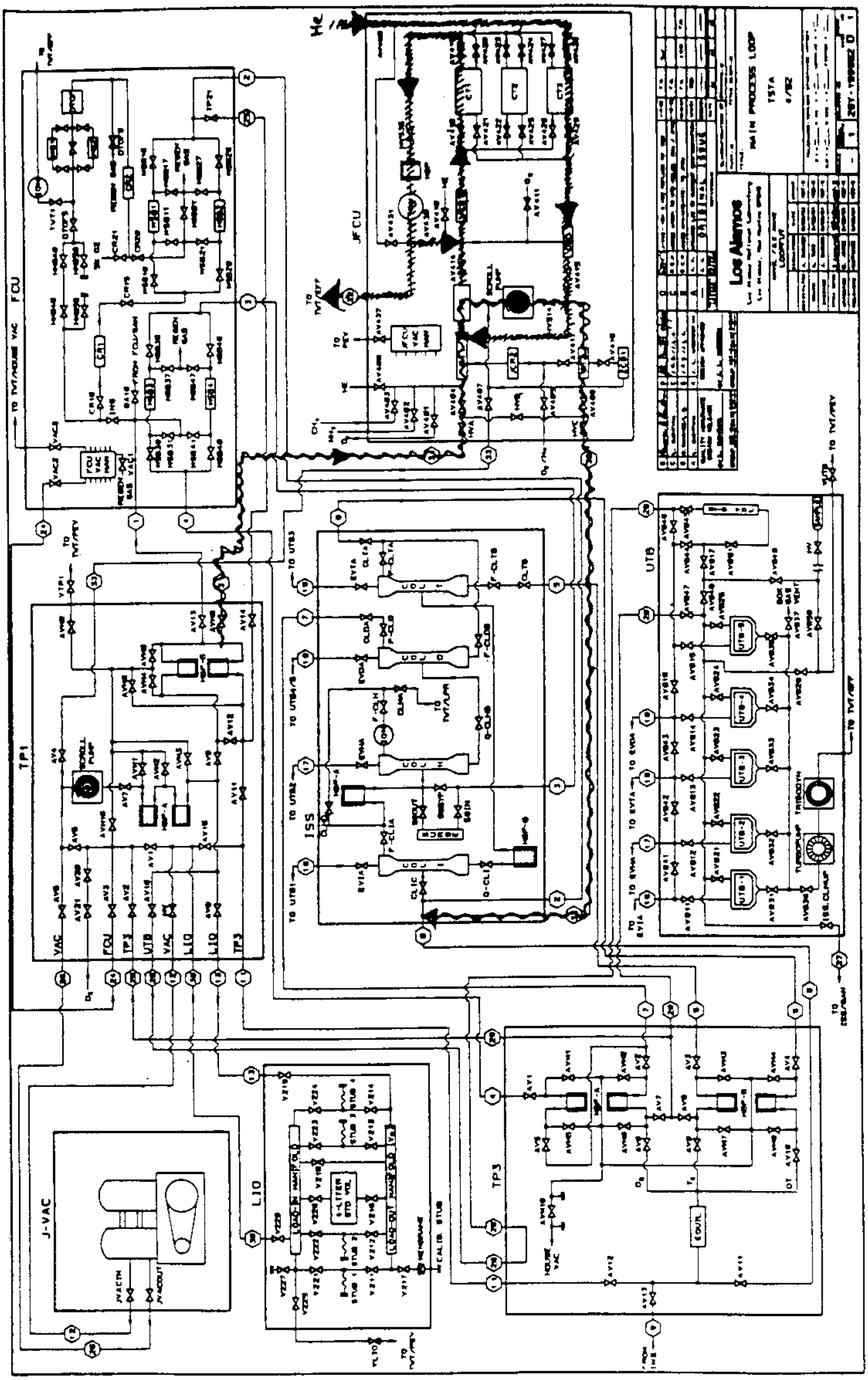


Fig. 3.1 TSTA loop configuration with JFCU

4. OPERATIONS

Main operation logs of JFCU part are summarized in the APPENDIX I.

4.1 Preparations

Following items were completed before starting JFCU part.

a) JFCU CT function test with D2 (TTA-TP-118-20),

b) Replacement of molecular sieves of JMSB3, 4 and 5,

c) O2 sensor's replacement, calibration, and check O2 flow & O2 conc. control by MDAC,

d) GC re-calibration and sampling program setting,

e) Connect impurities cylinder to the CH4 (HV005-AV003) line.

On Apr.26 morning, JFCU computer memory was cleared. Voltage of new power supply for CEC was set to 0.2 V before starting CEC heating. Then, all components were isolated, and heated (PD,JCR1,CEC) or cooled (CTs) to operation temperature during Apr. 26 after checking their heating patterns. All valve positions were checked. Zero adjustments of all flow meters/controllers and pressure sensors were carried out and O2 sensors were also calibrated again on Apr.26.

On the night of Apr.26, final regeneration of JMSB3~5 was started by heating under vacuum. Tritium, stored in the ZCB1, was supplied to RT2 by heating up ZCB1 to 723 K. This gas in the RT2 (~1050 torr) was sampled for inventory check and used for loop run on Apr.27. JFCU SAFETY Program was started by the Master Data Acquisition and Control (MDAC). CEC potentiostat was set to stand-by mode.

(After stopping impurity injection to the TSTA loop during the TSTA-FCU part of this run (Apr.24), residual impurity in the loop line was removed completely by the TSTA-FCU. The TSTA-FCU was kept situation (keep low temp. of CMSB) until the complete preparation of the JFCU.)

4.2 Connection between the ISS and the JFCU

Following the "Detail operation procedure for JFCU" (TTA-TP-118-15, R0) and test plan of this run (TTA-TP-100-24, R0), valves for loop operation and components heating/cooling and pumps situation were checked. " Heating Mode" has been established the morning of day 2 (Apr.27). On Apr. 27 morning, a lack of communication between JFCU and MDAC was found and solved by S. Cole. (data on Apr.26 was not stored in MDAC, only stored in JFCU computer.)

The JFCU was remained to isolate from the TSTA loop and in a stand-by mode. Helium, as the carrier gas of CT regeneration, was supplied to the JFCU (~ 6 Nl/min). O2 concentration for JCR1 was adjusted manually (~ 2 % at the inlet of JCR1) and was exhausted continuously to the TWT. At this time, CT regeneration mode was "External" and JCR1 dilution mode was "Internal". The JCR1 internal circulation flow was set to 5 Nl/min by Mass Flow Controller (MFC-JCR1BYP). O2 conc. control by MDAC was difficult. So, O2 flow was controlled by adjustment of the supply cylinder regulator and flow setting of MDAC.

Hydrogen isotope gases was stored in the RT2 from ZCB1. The ISS was operated in total recycle mode by circulation through TSTA-FCU and HV-A,B,C of the JFCU.

Then, CEC potentiostat was turned on by pot. mode. AV406 opened. The connection of ISS and JFCU was tried twice by opening AV404. Initial flow to the JFCU from TP3 was too large (> 10 Nl/min) because TP3 discharge pressure was more than 1200 torr and JFCU control pressure was less than 800 torr. Some amount of tritium gas was exhausted to the TWT because of insufficient O2 at the JCR1.

After huddle, TP3 discharge pressure was reduced by isolating TSTA-FCU (~ 850 torr), and RT1 pressure was increased to 900 torr . Then,

1) closed HV501,
2) opened AV404,
3) opened HV501, and
4) closed HV-B.

During the steps 3) and 4), small amount of He (carrier gas of JFCU recovery loop) flowed to the TSTA loop. However, it was no problem. JFCU was connected completely with the TSTA loop. Loop flow was controlled to ~ 4.5 Nl/min by the ISS.

GC sampling started. RT1 pressure was reduced gradually to ~ 800 torr. When the gas in the O2 jacket of CEC was evacuated, tritium spike was found in the TWT-LPR.

4.3 TSTA loop operation with JFCU on 2nd week of run 92-3

After watching the stabilized TSTA loop with the JFCU (~ 5.5 hr after connection of ISS-JFCU), JFCU received some regenerated gases from TSTA-FCU with the loop flow. The loop flow rate was increased to ~ 5 Nl/min then reduced to ~ 4.5 Nl/min by adjusting the ISS flow.

RT2 pressure was high (more than 1250 torr) and ISS feed flow rate was low. Recovery was made by reducing ISS column I pressure and re-setting of Pressure Controller (PRCA-ISSIN) of the JFCU.

At 3:00 A.M. on Apr. 28, TSTA-SCRAM signal was sent by CEC current high and JFCU was paused (isolated from the TSTA loop, stopped pumps of JFCU). Immediately, HV-B was opened. ISS was operated continuously without JFCU by using HV-A,B,C bypass line. At that time, no gases from TSTA-FCU was added in the loop. The re-connection was tried but JFCU paused again by high JCR1in O2 conc. and high JFCU exhaust tritium level. Scroll + BP pumps and MBP were turned "ON" and circulated only JCR1 dilution line. All isolation valves of JFCU were closed, and CEC was isolated. This situation was safe enough and kept until the next morning shift changing meeting.

In the morning meeting, the situation was discussed and decision was made as follows.

1) CEC current limit setting point (10 A) for sending TSTA-SCRAM was increased to 15 A,

2) before connecting JFCU to the TSTA loop, JFCU was operated by stand-alone mode for a few hrs to check the above current limit and to reduce the water inventory.

Operation started as following;

1) connected RT2 and ISS feed line (AV406 "open"),
2) CEC opened to the JFCU (HV545 & 540 "open"),
3) started recovery loop flow of the JFCU (AV409, 411, 412, 414, 415 "open"),
4) CEC potentiostat local input voltage limit set up to 10 V,
5) CT cycle operation started again, and
6) kept this situation for a few hrs.

Before noon, huddle was held and re-connection of JFCU was tried as on Apr.27. First time re-connection was completed, however, ISS column I pressure was going to high up. JFCU paused again by PRCA-ISSIN > 1000 torr. So,

1) immediately opened HV-B,
2) turned on BP and Scroll pumps,
3) opened HV575 and turned on MBP,
4) started recovery flow (AV409, 411, 412, 414, 415 "open" and HV575 "close"),
5) turned on JMSB5 heater and started CT cycle operation,
6) tried again re-connection of JFCU to the TSTA loop.

At this time, ISS column pressure was also gradually going up but was stabilized by manual ISS control.

On Apr. 28 evening, JFCU some times received TSTA-FCU's MSB gases. CT cycle was stopped manually and restarted. Water inventory of the JFCU increased slowly (max. CT differential pressure (CT-DP) = 550 torr, each 3 hr period). However, JFCU operated safely. Sometimes TWT-LPR tritium level was high when CT-DP was high. Tritium exhaust from JFCU was suspected.

On Apr. 29, GC stopped manually and TWT-LPR tritium level was watched during CEC O2 jacket gas evacuation. At that time, tritium spike was not found. No function of ZCB2 & 3 was suspected.

Impurity, 10 % methane (CH4) in N2, was suppled to the JFCU-RT1 (60 ml/min). Loop flow rate was about 5 Nl/min. PD temperature was increased to 673 K from 573 K in order to improve hydrogen permeation function.

This operation was kept until 2:30 A.M. on Apr. 30. At that time, JFCU was paused again by PRCA-ISSIN > 1000 torr. ISS He compressor was broken so ISS columns pressure was actually high up. During repair of the ISS He compressor, JFCU was isolated and HV-B was opened. MFC-JCR1BYP was broken. Pressure sensors (RT2,ISSIN,PDEX) indications seemed to be wrong.

ISS columns pressure was stabilized. Loop flow was passed through TSTA-FCU and HV-A,B,C were closed. JFCU was kept this situation until morning and dry-up operation was started because enough data with impurity injection was obtained. GC was stopped.

4.4 Tritium recovery (2nd week of run 92-3)

On Apr. 30 morning, in order to start dry up operation, hydrogen isotopes in the JFCU-RT2 were sent to the TSTA loop through AV407 & TP1.

After RT2 pressure was reduced, dry up operation started as follows (9:30 A.M. Apr.30);

1) turned on BP + Scroll pumps,
2) started circulation of JCR1 dilution line by turn on MBP,
3) started recovery loop flow (AV409, 411, 412, 414, 415 "open"),
4) connected RT2 to the TSTA loop (AV406 & HV-C "open"),
5) turned on JMSB3 heater and started CT cycle operation.

On Apr. 30 noon, CT2 plugging was found (CT-DP was immediately high, CT flow was zero, and RT1 pressure was going up.). JFCU was paused manually. After discussion , dry up operation was started again by internal circulation in the recovery loop. No He addition, no O2 addition, and no exhaust to TWT were performed. Hydrogen isotope gas generated by water decomposition in the CEC was purified, recovered to RT2 and sent to the TSTA loop continuously through AV406 & HV-C. After starting this internal dry up operation, CTs were changed manually for several hours. Then CT cycle operation was re-started. The internal dry up operation continued for a total of 30 hrs until May 1 evening.

Finally, JFCU kept under following situation until next usage (4th week);

1) all isolation AVs and HV-A,B,C were closed,
2) isolated RT2 and PD (HV512, 514 closed, RT2 pressure was ~480 torr : H.D.T) ,
3) Scroll, BP, and MBP turned off, and HV575 opened,
4) CEC isolated and potentiostat stand by mode,
5) PD temp. decreased to 573 K and kept,
6) JCR1 heater turned off,
7) CT cycle operation stop and reset, and REF of CTs turned off,
8) recovery loop pressure was 600 ~ 700 torr (He).

4.5 Preparation for the 4th week operation of run 92-3

During the 3rd week of the run 92-3, JFCU was checked again for next TSTA loop operation. This checking & preparation items were ;

1) JFCU data saved, transferred to MT, and deleted.
2) ZCB 2&3 were regenerated by heating to 673 K connecting ZCB1,
3) replaced MFC-JCR1BYP and leak checked by pressure test,
4) pressure sensors indications (RT2,ISSIN,PDEX) were checked,
(Pressure indication wrong on Apr. 30 was recovered on May 7.)
5) checked cooling function of REF for CTs,
(REF did not have enough cooling function for all 3 CTs. However, it was used for 4th week run without maintenance, because its function was enough for cooling of 2 CTs and checked enough function under CT cycle operation more than 16 hrs.)
6) CT timer settings ((R)AV-CTIN OFF delay & (R)AV-CTEX OFF delay) were changed to 11 min from 4 min in order to increase regeneration function of CTs.

4.6 TSTA loop operation with JFCU on 4th week of run 92-3

On May 11 morning, JFCU stand by operation started again as following,
1) JCR1 heater turned on,
2) PD temp. increased to 673 K from 573 K,
3) REF for CTs started and CT cycle operation started (Less cooling function was found again. After try and error for 4-5 hrs, CT cycle operation started by increasing start temp. setting of CT cycle operation. After starting CT cycle, each 2 CTs cooling function was enough.),
4) zero calibration of MFC-JCR1BYP,
5) BP and Scroll pumps turned on and opened HV512, 514,
6) CEC potentiostat turned on to pot. mode and CEC connected to the JFCU,
7) internal dry up operation mode started (AV414,415,430,431 opened, MBP turned on, HV575 closed) until the completion of the PC processing by TSTA-FCU & ISS.

On May 12 morning, JFCU was connected again to the ISS as following;
1) connected RT2 and ISS column I feed (open AV 406 and HV-C),
2) removed residual tritium in the recovery loop of the JFCU by addition of O2,
3) internal circulation stopped and checked O2 sensors,
4) replaced both O2 sensors (JCR1IN & JCR1EX) and calibrated,
(Even if the sensor replacement, O2 conc. indication of JCR1IN was still wrong. After huddle, only one O2 monitor usage during following JFCU operation was decided.)
5) closed HV501, and opened AV404,HV-A,B,
6) adjusted RT1 pressure ~830 torr because of TP3 discharge pressure was ~ 840 torr,
7) opened HV501 and closed HV-B.

Quite smooth connection of JFCU & ISS was performed without any back flow of He to the loop at this time. Loop flow rate was 3 Nl/min ~ 5 Nl/min. After this connection, TSTA-FCU's MSBs started regeneration by heating up and regeneration continued until May 13 morning. JFCU received regeneration gas with the TSTA loop flow.

On May 13 morning, loop flow stopped and ISS shut down operation started. JFCU gradually dried up by External CT regeneration adding O2. Then, JFCU received gas from TSTA-FCU through hot Mg bed and purge gas (He & H2) of TSTA-FCU & ISS several times. During these operation, recovered hydrogen isotopes was stored in RT2, and transferred to the ZCB1 (7 times). After completion of receiving ISS & TSTA-FCU purge gas (shut down), final dry up operation of JFCU was started on May 14.

4.7 Tritium recovery (4th week of run 92-3)

4.7.1 main-loop (RT-2)

As described above, JFCU received many gases from TSTA-FCU & ISS during the TSTA loop shut down, though most of hydrogen gas in ISS and TSTA-FCU MSB3 (for NBI line of the ISS) were transferred to the UTB. During these operation, recovered hydrogen gas in RT2 was transferred to the ZCB1 (7 times) for maintain RT2 pressure.

Finally, JFCU isolated from TSTA loop and internal dry up operation of JFCU was started. Recovered hydrogen isotopes in RT2 was also sent to the ZCB1.

4.7.2 recovery loop dry up operation and JFCU shut down

On May 13, loop flow was stopped, so JFCU gradually dried up receiving several gases from TSTA-FCU & ISS. On May 14, final dry up operation started by internal CT regeneration mode after isolation of the JFCU from the TSTA loop as follows;

1) isolated JFCU from the TSTA loop (closed HV-A and AV404),
2) stopped gas supply to JFCU (closed AV409,411),
3) made internal CT regeneration flow (open AV431)
4) stopped gas exhaust from JFCU (closed AV412) after checking JFCUEX pressure,
5) reduced JCR1 internal circulation flow and stopped (close AV430),
6) O2 monitors bypath valves opened and O2 monitors isolated.

For about 5~10 min after switching internal dry up operation, CEC current and voltage were fluctuated but soon stabilized. It was maybe the effect of the residual O2. This operation was continued for 6 hrs. Then, CT cycle operation stopped and manual CT regeneration started for 3 hrs, because dew point of JFCU was low enough. REF stopped and all CTs heated up.

At 7:00 P.M. on May 14, recovered hydrogen isotopes in the RT2 was transferred to the ZCB1. CEC bypath valve opened, CEC isolated, and CEC cooling down program started. CEC potentiostat turned off. CT heaters turned off. After isolation of RT2 (closed HV512,514), Scroll & BP and MBP pumps turned off. On May 15 morning, residual gases in the recovery loop (almost all Helium) was circulated through ZCB1 for a few hours and then evacuated to TWT through ZCB1. Less than 40 Ci of tritium detected in the TWT at that time. Then, PD & JCR1 heaters turned off.

4.8 Inventory check

When ZCB1 was regenerated and hydrogen isotopes was released to RT2 on the Day 1-2, gas sample in the RT2 was taken and analyzed by mass spectroscopy.

After this test, ZCB1 was regenerated again to the standard volume of UTB for inventory check on May 29 as same as general UTB inventory check after loop operation. Isotopic component were measured by mass spectrometer.

5. RESULTS AND DISCUSSIONS (part I : component performance)

5.1 Palladium diffuser

Palladium diffuser (PD) temperature was controlled at 573 K for a earlier days of JFCU operation and then increased 673 K to improve purification function during fuel processing. Except for some short period of ISS-JFCU connection, PD function was as expected. Total amount of hydrogen isotopes* purified during the TSTA loop operation with JFCU was about 21000 Nl. (16000 Nl at 2nd week, 5000 Nl at 4th week). During the TSTA-FCU & the TSTA loop shut down operation, some regeneration gas & purge gas (He, N2, CH4, Q2 etc.) were also processed by PD safely. Purification ratios** (Recovery at the PD) were about 95 % (~ mean value). Feed flow rate was 8 ~ 12 Nl/min and its hydrogen concentration** was 40 ~ 60 %. Adding impurities (10 % of CH4 in N2 balance at 0.5 % of inlet flow) did not effect PD function during this run. However, the purification was a little worse than during JFCU-ISS run (Oct. '91) and JFCU stand-alone run as shown in fig. 5-1-1 and 5-1-2. Differences from past runs were; 1) the amount of water (~ max. a few vol. %) in the PD feed was higher , 2) the isotopic composition of this test was heavier. Water content and isotopic composition of hydrogen would effect the PD function. High controlling temp. of PD (673 K) should affect better purification function, however, better function data was not obtained. There is a possibility of some impurities deposition on the surface of PD membrane during past runs. Some oxidation & reduction treatment would increase PD function to that at PD component test with H2 & D2 on Nov.-Dec.,'90 (TTA-TP-118-08).

* : calculated by the rough integration of "jfcu-f-vactpu" considering the TSTA-FCU gases and generation hydrogen isotopes in CEC.

** : calculated from the GC data.

5.2 Catalytic reactor

During this test, catalytic reactor (JCR1) was controlled at 773 K. All hydrogen isotopes and methane in the bleed gas of PD were completely oxidized by the JCR1 if there was enough oxygen. No tritiated species were found at the outlet of CT under the stabilized condition by GC and by tritium monitor of JFCU.

At the first few attempts of the ISS-JFCU connection, amounts of tritium were exhausted to the TWT. Because the initial flow to the JFCU-PD from TP3 was too large (> 10 Nl/min), less PD function & insufficient O2 for complete oxidation of impurities would happen at the JCR1. In addition, the oxygen conc. control program by MDAC did not work. O2 flow rate (400~500 sccm) was controlled manually by pressure adjustment of the O2 supply cylinder regulator & manual flow setting of MDAC.

5.3 Cold traps & small molecular sieve beds

During the stable condition, Cold Traps (CTs) collected almost all moisture and were regenerated completely and periodically by using Helium gas from outside cylinder(6 ~7 Nl/min). Trapping factor was more than 10^6 under stable conditions. Total collected water amount* in each CT within a trapping period was more than 1 mol/hr* (max.) (Design value of water trapping in each CTs is 0.78 mol/hr.). Differential pressure of CTs was controlled to 250 ~ 400 torr at this time. Feed flow rate of CTs was about 11 Nl/min . (It was same flow rate of JCR1.)

A small amount humidity spike at the outlet of CTs was detected when each CT was changed (once per an hour), even if molecular sieve was replaced with virgin sieve just before this run. However, it was acceptable level and no major problem for loop operation, even if humidity level was much high at the inlet of the CTs comparing the recent stand alone run of JFCU as shown in the figure 5-3-1.

Differential pressure at the CT1 trapping only jumped up to about 550 torr after ~ 10 hr of ISS - JFCU connection. It was suspected that some amount of gas with tritium exhausted through JCR1 dilution line during high CT differential pressure.

The inlet humidity of CT was more than upper limit (333 K Dew Point (KDP) indication) during almost loop operation period of the 2nd week (design value was ~ 297 KDP (~ 2 % water vapor) as a mean value) even if JCR1 dilution line was used. During the dry up operation on the 2nd week, CT2 was plugged because of insufficient regeneration. The change of CT timer setting made longer effective regeneration time of CTs. It would be helpful to avoid this plugging.

In the result of JFCU stand alone run on Feb. '92, the possibility of the effect of JCR1 inlet high humidity (> 300 K (indication)) on the CT plugging was discussed. However, it was found that high humidity of the JCR1 inlet (~ 320 K (indication)) did not make CT plug directly if CTs inlet piping temp. was controlled high enough.(~ 700 K (indication)). Total trapping water inventory and complete regeneration were more important rather than humidity.

* : calculated from the mean values of "jfcu-i-wece".

5.4 Ceramic electrolysis cell

The ceramic electrolysis cell (CEC B) was controlled at 1023 K. Potential between the inside and outside of cell tubes was controlled to be 1.0 - 1.4 Volt by the reference electrode of potentiostat ("jfcu-v-were"). Differential pressure between the inside and the outside of cell tubes was roughly controlled within - 50 ~ - 200 torr manually. During applying potential to the cells, it was found that the oxygen leaked from O2 side to process side was recovered back to the O2 side as during the recent stand alone runs. Another power supply was also installed and 0.2 volt was input between RE2 and ground during high CEC temp. in order to avoid the brazing disconnect problem .

During the first day after ISS - JFCU connection, operational current of CEC was restricted to below 10A (TSTA-scram setting, as same as that at the resent JFCU stand alone runs), so, there was some limit of decomposition function and control was also difficult concerning small residual JCR1 excess O2 in CT (regeneration). (Mean current was ~ 7 A = ~ 0.64 mol/hr*.) Residual JCR1 excess O2 in the CT caused current spike in CEC at just after each CT regeneration start and finally this spike was over 10 A and caused TSTA-SCRAM-JFCU-"pause". Therefor, current limit setting were increased to 15 A under some safely consideration of CECB internal leak. Then, CEC water decomposition function increased about 1 mol/hr *(Mean current = ~ 11 A.) and no trouble was happened concerning the above current spike (CEC control was much easier.). The max. current was about 12 A under "v-were" of 1 V & "v-wece" of 10 V. As shown in the figure 5-4-1, CEC function was good enough during this run comparing with the resent run data.

Unfortunately, humidity indication around CEC was out of range during most part of this run. So, decomposition ratio is difficult to calculate.

For the safety concern of CECB, the line of CT regeneration was always set to "external". This means that CEC was not always affected by excess oxygen from JCR1 directly. (When the CT regeneration line was set to "internal", excess oxygen would affect to water decomposition function of the CEC.) Therefore, CEC function would be better than that in "internal" CT regeneration.

Generated O2 was manually evacuated to the TWT. A orifice was installed and made easier O2 evacuation for control O2 jacket pressure. Though this O2 will be used for JCR1 in design, O2 was evacuated because difficulty of O2 conc. control around JCR1 and leaked CEC safety concern.

CECB has a little leak of order of 10-3 ~ 10-2 Acc/s (at delta P of ~ 50 torr). This leak did not increase at the high temperature (1023 K) as same as that at the recent runs. However, after this run, this internal CECB leak became much larger (> 5 Acc/s at 50 torr delta P). This leak level was almost same of CECA at last October. As shown in figure 5-4-2, large leak caused during the CEC cooling down operation. Concerning the leak rate, this leak maybe caused by some crack at the metal-ceramic brazing like CECA. It leak location should be checked further after decontamination as possible as we can. Accumulating operation hours (CEC temp. > room temp.) of CECA in JFCU-GB was ~ 500 hrs and that of CECB was ~ 800 hrs until developing large internal leak of CEC. CECA heat cycle was performed 5 times and that of CECB was 3. Though a little voltage input between RE2 of each cell and the ground (0.2 V) would be effective on CECB, CEC tubes tightness would have a life time of several hundred hours at the metal-ceramic brazing. Next generation CEC will be solved this R&D problem under the scale up.

* : calculated from the mean value of "jfcu-i-wece".

5.5 Gaschromatographs

Sampling program and analysis program worked automatically. Several samples at the sampling points #2, #3, #5 were taken periodically. The peaks, that were missed to calculate by the GC during the run, were recalculated manually after the run. Some results of GCs were shown in APPENDIX II.

A CO2 detection was difficult during this run, because CH4 conc. in the feed of JCR1 was ~ 0.05 % and #5 normal sampling pressure was about 50 torr.

During this test, some times GC timer stopped automatically because of interlock, paper out, data disk full, and unknown factor. Retention times became a little longer in the later part of this run. More calibration operation would be needed during the long-term run. It was suspected that a pretty amount of tritium was exhaust to the TWT from GC through ZCB2 &3. Need closely watching GC situation and complete activating of ZCB 2&3 in the future run. GC columns aging and molecular sieves (JMSB1 & 2) regeneration will be also recommended before next run.

5.6 Zirconium cobalt beds

As described above, ZCB 2&3 was less function. This function did not recover after regeneration (673 K, evacuating to the ZCB1). As ZCB3 (for GC sample gas) was always opening/connecting to the JFCU vacuum manifold, O2 evacuated from CEC would affect ZrCo alloy by back diffusion. Some reasonable evacuation manual will be need with complete activation of ZCB2&3 by hydrogen.

During the hydrogen supply&recovery operation of the TSTA loop, dry up operation of the JFCU, and inventory check operation, the zirconium cobalt bed (ZCB1) worked well. Almost all hydrogen isotopes were recovered safely and quickly . The amount of tritium that exhausted to TWT during shut down operation was less than 50 Ci through ZCB1. Almost all stored hydrogen isotopes was released to the standard volume of UTB by regeneration of ZCB1. The amount of hydrogen isotopes stored in ZCB1 after this extended loop run was about 220 Nl including 22 grams of tritium.

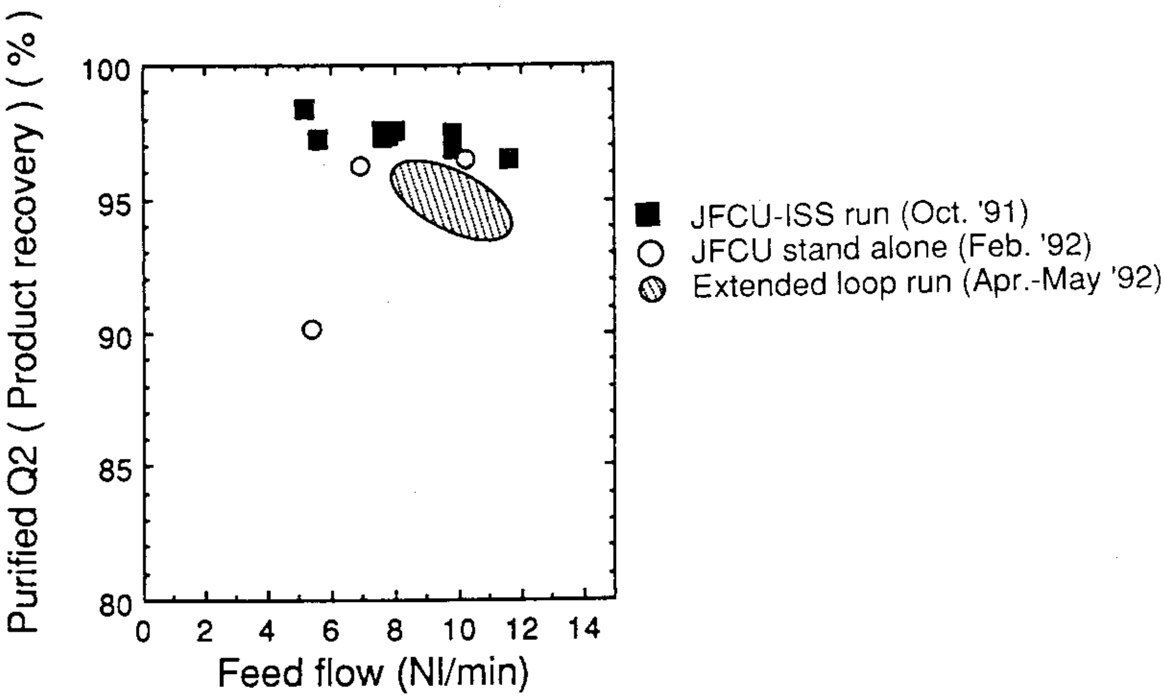


Fig. 5. 1. 1 Hydrogen isotopes gases (Q_2) purification percent in the Palladium Diffuser as a function of the feed flowrate.

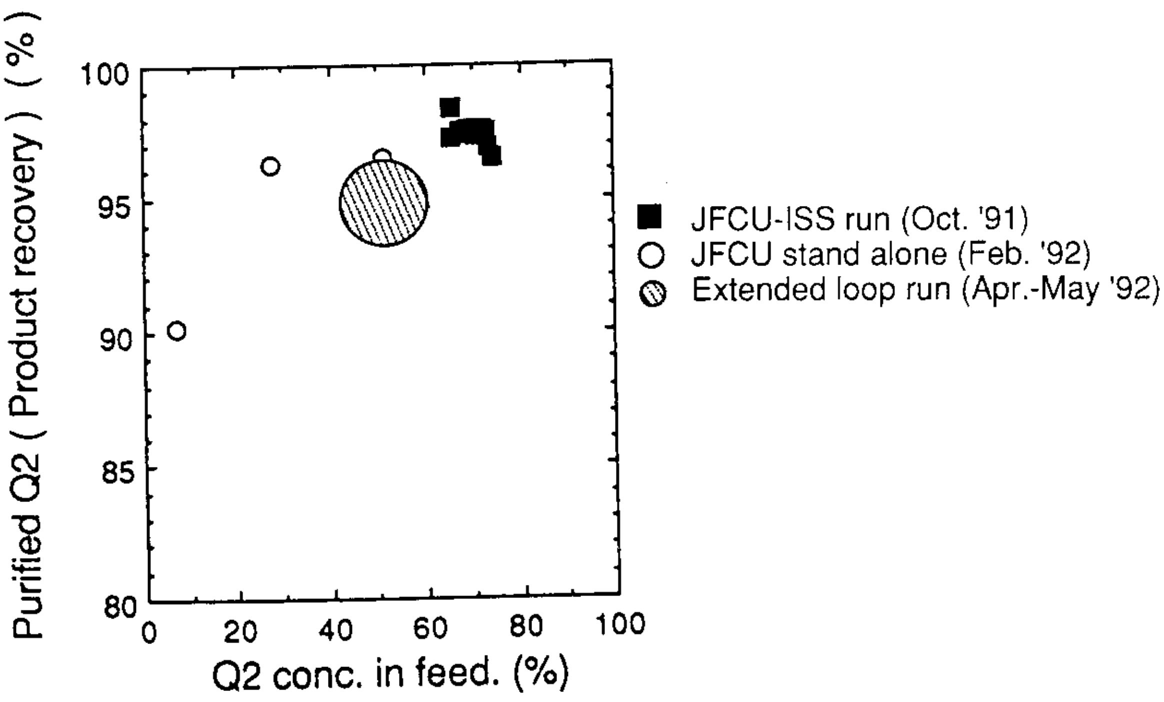


Fig. 5. 1. 2 Hydrogen isotopes gases (Q_2) purification percent in the Palladium Diffuser as a function of the Q_2 conc. in the gas.

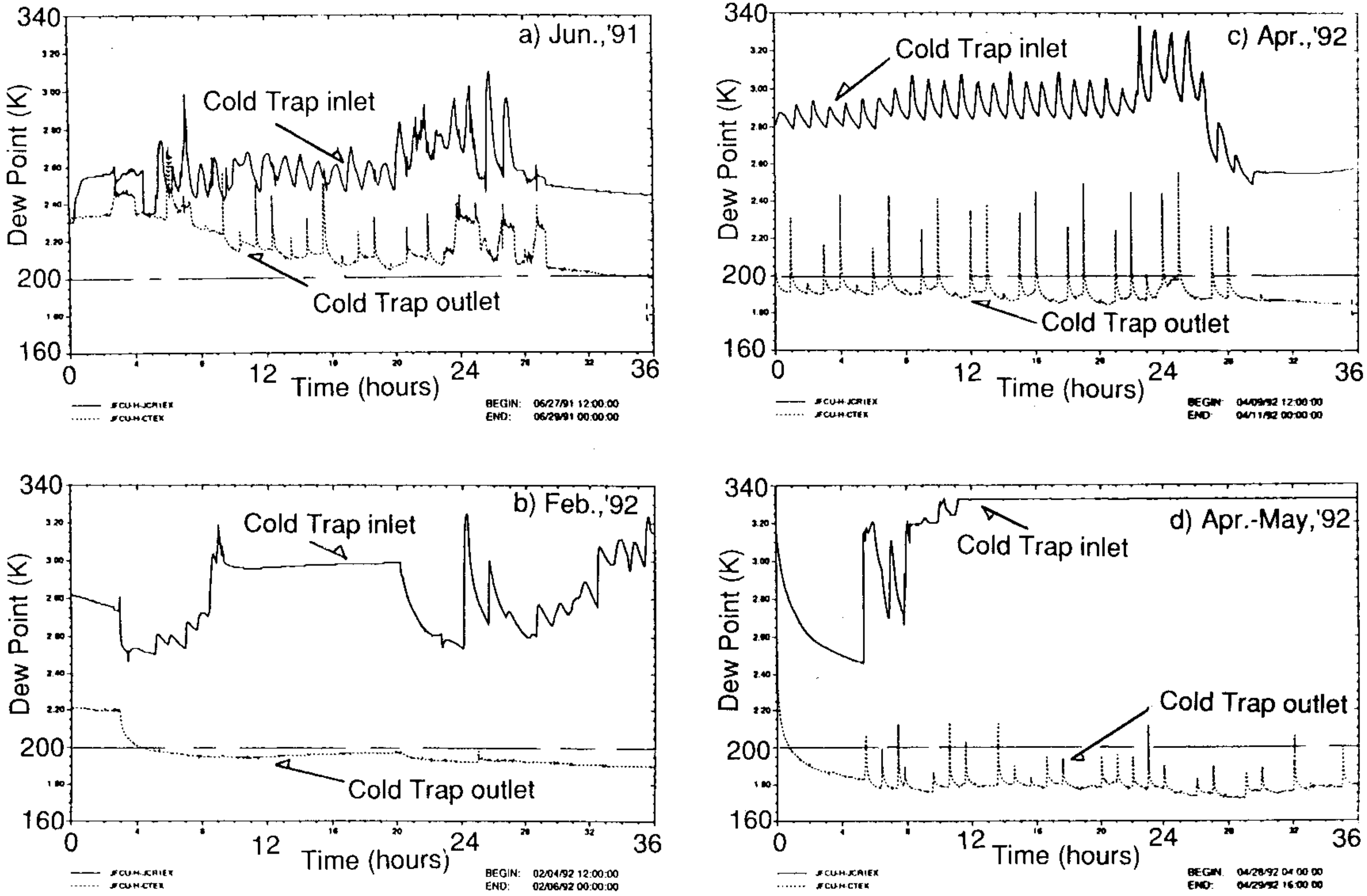


Fig. 5. 3. 1 Humidity fluctuation of JCR1－CTs with JMSBs
a) Jun.,'91 b) Feb.,'92 c) Apr.,'92 d) Apr.－May,'92

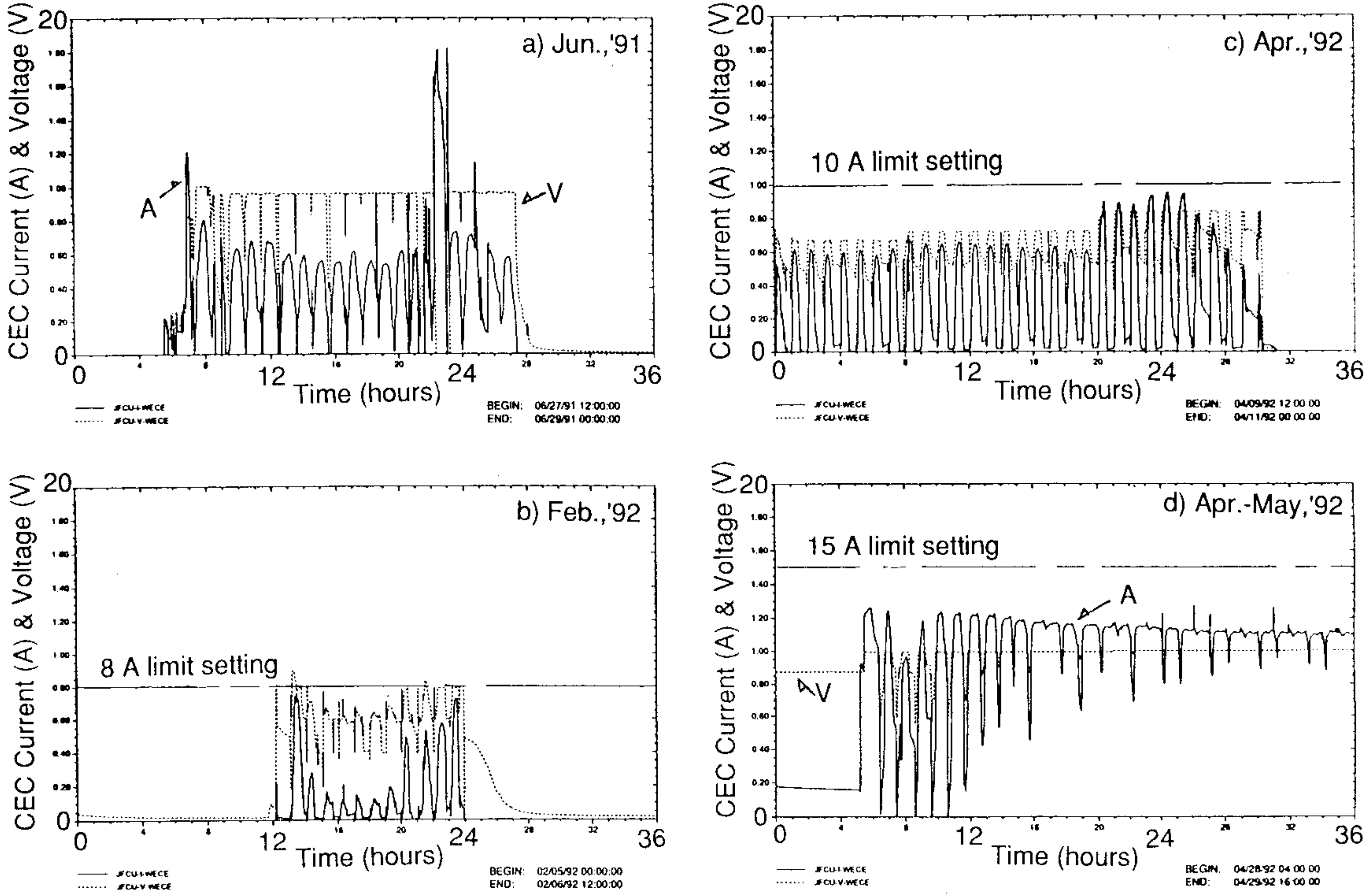
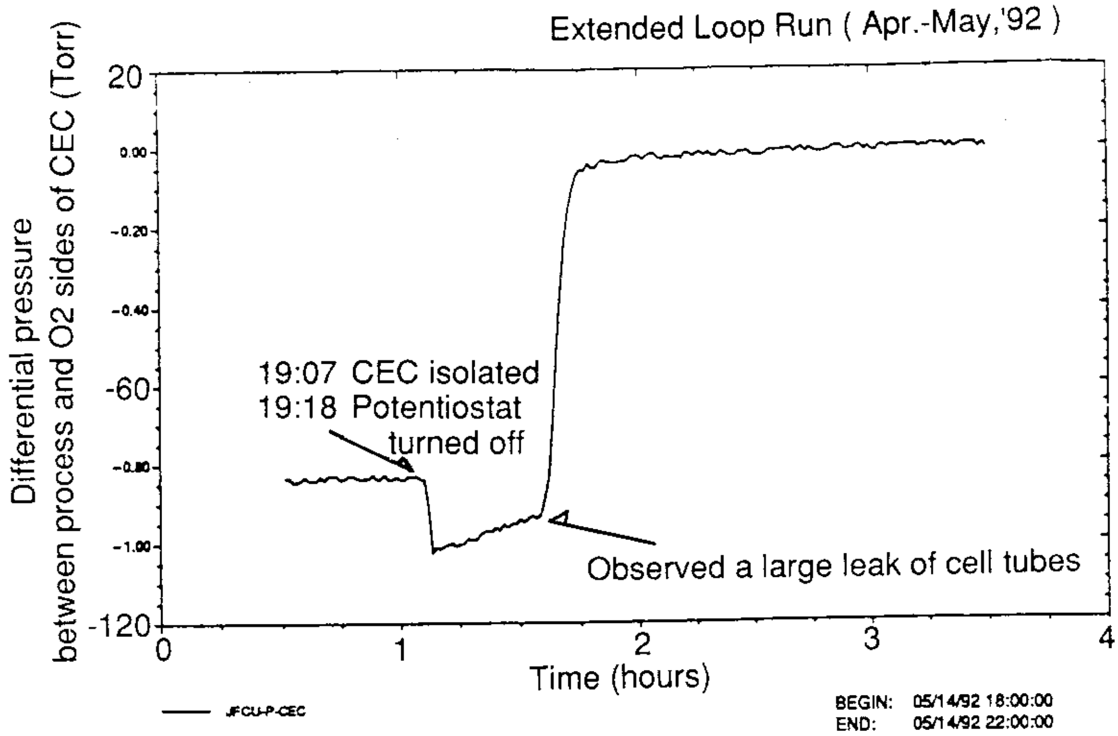


Fig. 5. 4. 1 CEC water decomposing situation
a) Jun.,'91 b) Feb.,'92 c) Apr.,'92 d) Apr. − May,'92



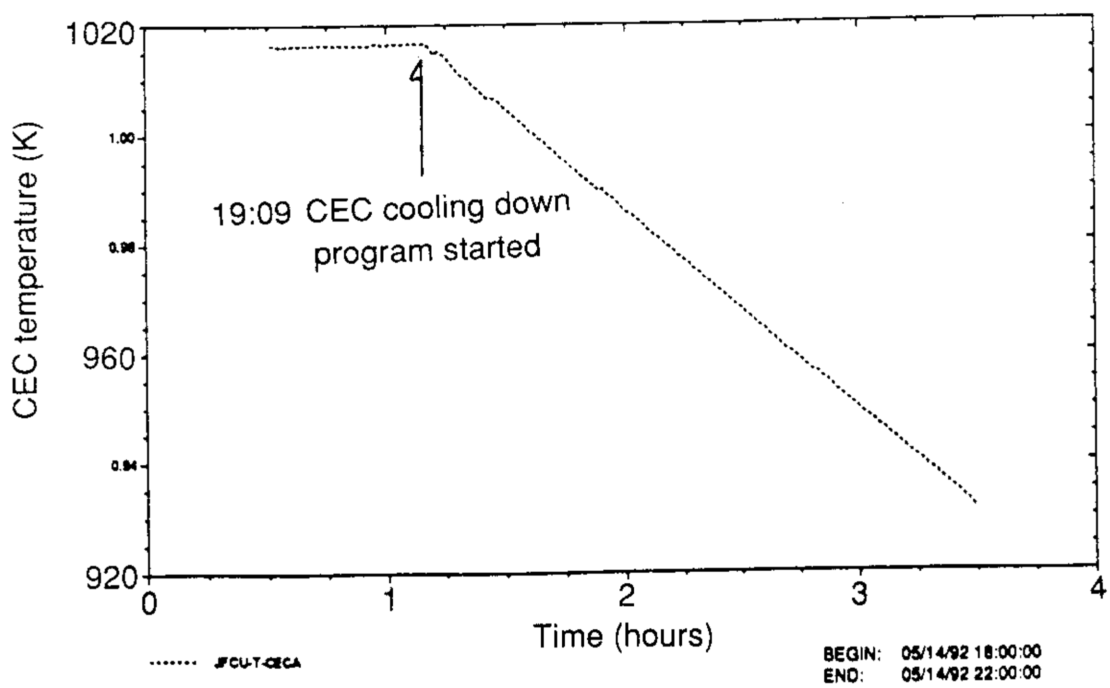


Fig. 5. 4. 2 CEC−DP fluctuation during cooling down of CEC

6. RESULTS AND DISCUSSIONS (part II: total system performance)

6.1 System performance

As described above, all components were operated safely during these operations.

Fuel processing operation without additional impurity injection was performed for about two days. Fuel processing operation with regeneration&purge gas of FCU molecular sieve beds and with a few % of impurities (10 % methane in N2) was demonstrated for about three days during 2nd and 4th week.

"External" CT regeneration line and "Internal" JCR1 dilution line were used. The stream to the TWT was at about 6 ~ 7 Nl/min and its tritium level was low enough except the short period of ISS-JFCU connection and CTs (from CT1 to CT2) switching.

The adjusting of the pressure between TP3 discharge and RT1 allowed smooth connection of ISS-JFCU. Best pressure setting of RT1 was about 10 ~ 20 torr lower than that of TP3. Loop flow was processed continuously by the PD. More than 5 Nl/min of hydrogen isotopes stream was produced for feed to ISS. Loop flow and loop pressure fluctuated however, no major operational trouble occurred if ISS column I pressure was controlled blow 1000 torr.

When ISS column I pressure became larger than 1000 torr, RT2 outlet pressure (P-ISSIN) was also > 1000 torr. At that time, JFCU was automatically paused by its interlock. Setting of 1000 torr is maximum. Even if column I pressure was ~ 1200 torr, JFCU could be operated safely if the interlock was turned off. Though this 1000 torr setting will be changed, it is better keep pressures below 1000 torr.

The change of CEC current limit setting (10 A to 15 A) was helpful for CEC performance and control. The higher current setting will reduce/maintain the total water inventory in the JFCU.

A small humidity spike at the outlet of CTs was detected when each CT was changed (once per an hour). However, it was at an acceptable level and no problem for loop operation, even if humidity level was very high at the inlet of the CTs comparing the recent stand alone run of JFCU.

ZCB2&3 still did not work for the processing of JFCU-GC gas even after the regeneration of ZCB2&3. Some amount of tritium was exhausted through ZCB2&3 during GC analysis. More high temp. regeneration/activation treatment with hydrogen is needed.

At the shut down operation of loop run, JFCU was effectively used to process residual gas of the TSTA loop (except liquid hydrogen in the ISS) and purge gas. About one sixth of total hydrogen isotope gases in the TSTA loop (include ~ 22 grams of tritium) was recovered in the ZCB1 and tritium exhausted to the TWT through JFCU was less than 50 Ci during shut down operation.

Through these operations, JFCU worked well as well as TSTA FCU and all operators / staff gained much experience. In a second half of this extended loop run, JFCU and TSTA FCU were used for the loop as described above. Comparing the TSTA-FCU, the JFCU advantage of continuous tritium recovery from impurities was demonstrated. If the processing fuel does not include a considerable amount of He and impurities, however, the TSTA-FCU system is easier to operate.

6.2 Tritium recovery and Inventory in the JFCU

The volume of initially supplied hydrogen isotopes from ZCB1 was about 31 Nl, including 1.4 g tritium. Compared with the last inventory check data of ZCB1(Feb.'92 & Apr.'92), about 5 Nl remained in ZCB1. During the TSTA loop shut down and JFCU dry up, hydrogen isotopes recovered were transferred to the ZCB1 (7 batch operations). Total transferred hydrogen isotopes was about 200 Nl.* Some gas regenerated from ZCB2&3 was also transferred to the ZCB1 in the 3rd week, however, this amount could not be measured. (it was about 10 Nl concerning ZCB2&3 's capacity.) Therefor, total amount of hydrogen isotopes stored in the ZCB1 was calculated at about 215 Nl.

After this run, ZCB1 was regenerated and gases were transferred to the standard volume of the UTB for inventory check. Recovered gas was about 217 Nl and included about 22 grams tritium. Tritium conc. in the hydrogen isotopes was about 38 %.

More than 200 Nl of hydrogen isotopes with 20 grams or more tritium was recovered in the ZCB1 during this TSTA loop shut down operation. Comparing with UTB inventory, about 15 % of total hydrogen isotopes of TSTA loop was stored in the ZCB1. If raman data of ISS column I feed before loop shut down was obtained and compared, some information of tritium distribution in the loop would be obtained.

Using the above tritium conc. of ZCB1 inventory result (~ 38 %) as final tritium conc. in the JFCU, residual tritium amount would be estimated about 0.8 gram in JCR1 and about 0.4 gram in JMSBs. Depending on the regeneration situation of ZCB1, it is a possibility that some amount of tritium remained in the ZCB1. (This ZCB1 residual inventory will be checked by adding D2 in near future. Therefor, total residual tritium inventory in the JFCU would be about 1.2 gram.

* calculated from RT2 pressure, volume, and temp.

6.3 System improvements

1) The increase of the CEC current limit setting increased CEC function, CEC control, and JFCU safety.

2) Replaced orifice worked effectively to evacuate gas in the CEC O2 jacket slowly. CEC differential pressure was controlled easier.

3) During this run, CT timer setting was changed as described above. Effective regeneration time was about 7 min. longer sufficient for compete regeneration of CTs.

6.4 Difficulties and problems

6.4.1 O2 control

O2 conc.& flow could not be controlled by the MDAC, though it was checked before this run. Manual O2 flow control using the O2 cylinder regulator was performed. However, insufficient O2 occurred at the connection of ISS & JFCU. O2 cells were replaced just before this run. All cells were broken again physically. O2 monitors should be calibrated periodically and cells should be handled more carefully. (There was a possibility that O2 sensors were evacuated again.) The cases of O2 sensors should also be checked.

6.4.2 Tritium exhaust to the TWT

Tritium was exhausted for the following reasons;

1) [the lack of pressure adjusting at the connection time of ISS & JFCU] plus [less O2 control at the JCR1, as described above,

2) [lack of ZCB2&3 regeneration] and [their less regeneration],

3) [high CT differential pressure caused by high water inventory], and

4) [a little less function of JMSBs (small humidity spikes at the CT changing)].

6.4.3 JFCU application software and hard disk

JFCU had only one hard disk of VAX computer. So, its data storage area was limited about 4~5 days and VAX computer hung up if data was full. Therefor, another hard disk and new application software installation was planned. However, installation was not completed before this run.

During the short period JFCU operation, this limited data area will be not so worse. But, it was the difficulty during the long period operation like this extended loop run.

Fortunately, the above installation was completed after this run. So, more than 2 weeks data volume is available and no computer hang up would be happened even if JFCU will be kept continuously without manual data deletion. New computer software will delete data automatically before complete data full. It makes much easier to maintain JFCU computer and JFCU data is always watched/stored by the MDAC without additional manual operation on JFCU.

6.4.4 Internal CEC leaks

As CECB has a leak of 10-3 ~ 10-2 Acc/s (at delta P of ~ 50 torr), JFCU operation was limited to only "external" CT regeneration. After this run, this internal CECB leak became much larger (> 5 Acc/s at 50 torr delta P). This CECB can not be used further.

During past 2 years, the tightness of CEC tubes was improved on the ceramic-ceramic connection. However, disconnection of metal-ceramic brazing was found on CECA in last October. This CECB leak rate was almost same of CECA and this leak occurred during cooling of the CEC. Its leak location should be checked further.

Next generation CEC tubes will be developed within this year using new technique of metal-ceramic brazing and solve this R&D problem under the scale up. Long term reliability of CEC tube tightness should be checked under actual operation condition for the next generation cells.

If it is solved, JFCU will be operated by "internal" CT regeneration mode. So, the amount of exhaust to the TWT will be much decreased, though residual O2 effects the CEC function. CEC current limit setting will be eliminated from the JFCU SAFETY program.

6.4.5 Other

REF of CTs cooling function was decreased. At the start of cooling, some freezing of freon could have occurred in the REF. So, CT was not cooled enough because of less freon flow. If CT cycle operation could be started, REF was enough to cool CTs. During this run, REF operated without any maintenance. However, freon gas should be replaced.

The mass flow meter/controllers (MF/MFC) sensors' zero was stable, MFC-JCR1BYP (flow controller) broke & was replaced again during this run. This reason for the break could be the effect of water (back flow). It is suggested to keep JCR1 flow proper direction.

Indications of pressure sensors, that connected to MKS 260 controller, were jumped up ~ plus 100 torr. The temperature around 260 controller was high (> 313 K) at that time, so, some cooling with room air was tried. It seemed to be recover when the above broken MFC-JCR1BYP cable was disconnected for replacement, after a few days cooling. Though some reason may exist in the broken of MFC, another fan for cooling instrumental panel of the JFCU should be installed.

In the JFCU-GB, temperature was measured several times. During this run, the max. temp. was more than 320 K. Some cooling apparatus in the JFCU-GB like Scroll pump box should be installed.

There was some lack of operation logging on the JFCU log book. All operations of JFCU should be logged on the JFCU log book

7. CONSIDERATIONS AND IMPROVEMENTS FOR FUTURE TEST

In order to perform future JFCU test more successfully and more safely, the following items should be considered.

1) Next generation CEC tubes fabrication & installation in the JFCU-GB.

Before the next CEC tubes installation, CECB will be decontaminated and disconnected from the JFCU. If it is possible, CECB will be opened and its leak location will be checked. As the next generation tubes will be shipped within this year, welding of tubes will be performed at TSTA using CECA or CECB vessel.

2) O2 control

O2 flow should be controlled by the MDAC. Therefore, program and signal wiring should be checked again. Hopefully, O2 conc. control should also be improved by re-considering MDAC program and testing. New type O2 sensor should be located and careful handling during JFCU operation is needed to prevent cell failure. The pressure reduce valve for O2 line should be replaced.

3) Minimum tritium exhaust

a) At the connection of ISS & JFCU, RT1 pressure should be adjusted to about 10 torr higher than that of TP3 discharge.

b) ZCB2&3 should be activated with hydrogen before next use. O2 evacuation procedure will be considered.

c) If CT differential pressure becomes high, stop He supply and stop exhaust for a few minute after CT changing.

d) Replacement of molecular sieves in the JMSBs and further testing will be planned in order to complete elimination of humidity spikes. Moderation of regenerated water concentration from CT to CEC will be tried.

4) General maintenance of JFCU

Following maintenance work will be planed in addition to the above.

a) replacement of freon gas in the REF of CTs.

b) installation some cooling apparatus for JFCU-GB & instrumental panel of JFCU.

c) fix the AV403, 404, 406 internal leaks.

d) check & replacement of hygrometer sensors

e) aging of GC columns and regeneration of JMSB1&2.

f) adjusting the indication setting of hand valves.

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APPENDIXES

1. JFCU operation log

Day and Time	Explanation
--------Apr.17	- Checked CT function by D2 run
	- Installation and check out new power supply for CEC,
	- replacement of the molecular sieve of JMSB3, 4 and 5
	- replacement of the O2 sensors and its calibration,
	- GC column aging, A part of re-calibration, and program timer setting,
	- Check quantity of gas cylinders and its lines to the JFCU.
Apr.21	- found RT1 & 2 pressure increase
	- PD heating up avoiding membrane failure (but it was OK)
	- found AV404 & 406 internal leak (This is the reason of the above)
Apr.22	- found computer hung up during data transfer to MT
	- manually "shut" "down" of VAX computer and re-boot + "warmstart"
Apr.26 08:20	- JFCU computer memory cleared.
10:00	- new power supply for CEC turn on
	- Checking component isolation situation & heating/cooling parameters
	- Checking CEC cooling water flow & O2 jacket pressure
10:15	- JCR1, PD,and CEC heater turn on.
11:20	- All valve positions checked.
11:30	- Scroll + BP pumps turn on
12:00	- Evacuation of RT1,2, and HV-A,B,C line thru ZCB1 to TWT
12:15	- Isolate ZCB1&CEC&JCR1&O2 sensors from the JFCU
	- TMP turn on and start high evacuation of JFCU
13:30	- Zero adjustment of pressure sensors & mass flow meters/controllers
14:20	- Checking alarm&interlock setting
16:15	- start O2 sensors calibration with 5% O2/He balance gas
16:45	- potentiostat turn on by stand by mode
18:15	- start JMSB3~5 regeneration
20:55	- turn on ZCB1 heater and regenerated gas stored in the RT2
22:45	- isolate PRCA-ISSIN
Apr. 27 00:06	- isolate ZCB1 and turn off ZCB1 heater
04:44	- Refrigerator(REF) turn on.
06:20	- start cooling CTs
08:00	- start checking the communication wrong between JFCU and MDAC
08:18	- stop JMSB3~5 regeneration
08:30	- set small sample bottle to HV053 and take sample from RT2
	- repairing of PEV
09:00	- solved communication problem
09:30	- start O2 sensors calibration again with 5 % O2
10:00	- connect pure O2 cylinder
10:30	- open CEC to the JFCU
11:00	- start CT cycle operation
11:15	- start regeneration flow (He & O2)

13:00 - potentiostat turn on by pot. mode
- tried to connect ISS-JFCU two times but did not complete
- huddle
- increased RT1 pressure by increasing PD bleed press. control

setting.

14:10 - tried again and completed connection of ISS-JFCU
(JFCU on the TSTA loop)

17:10 - GC started

18:00 - decreased PD bleed control pressure gradually to ~800 torr

19:40 - start receiving FCU gases

22:20 - found RT2 pressure range over (>1250 torr)
- increase PCRA-ISSIN setting and decrease RT2 within range

22:40 - found GC stopped and restart

Apr.28 00:10 - Pd-CT setting increased to 280 from 250 torr.

03:00 - JFCU "pause" by fluctuation of CEC current (TSTA-SCRAM)
- open HV-B

03:10 - Scroll + BP pumps turn on again
- open AV404, 406, and HV575
- turn on MBP and open AV409,411,412,414,415.

03:21 - JFCU "pause" again by high O2 conc. at JCR1 in

03:23 - Scroll + BP pumps turn on again
- try again re-start up

03:30 - JFCU "pause" again by high T2 conc. at JFCUex

03:40 - Scroll + BP pumps and MBP turn on again and isolate CEC
- keep situation until next shift change meeting

08:00 - start JFCU SAFETY program change
(CEC current limit setting increased to 15 A from 10 A)

08:50 - huddle

09:00 - AV406 open and HV540,545 open (open CEC)
- open AV409,411,412,414,415. (start recovery flow)
- CEC pot. local V-WECE limit setting increase to 9.95 V
- CT cycle operation start again
- keep this situation (dry up) for a few hours

09:30 - CEC-DP adjusting

10:00 - CT regeneration flow high up to 6~7 Nl/min

10:10 - CEC-DP adjusting

11:10 - CEC-DP adjusting

11:25 - huddle
- try to connect ISS & JFCU
- adjust RT1 press. ~ 850 torr, HV501 close, AV404 open,
- HV501 open again, HV-B close
- found ISS column I pressure was going to high up
- JFCU "pause" again by PRCA-ISSIN > 1000 torr
- immediately open HV-B
- turn on BP and Scroll pumps
- open HV575 and turn on MBP
- start recovery flow
(AV409, 411, 412, 414, 415 "open" and HV575 "close")
- turn on JMSB5 heater and start CT cycle operation
- open AV406
- tried again re-connection of JFCU to the TSTA loop

12:15 - CEC-DP adjusting

13:40 - CEC-DP adjusting

14:00 - loop flow jumped up to ~ 8 Nl/min, request low down to ~ 5

Nl/min

14:35 - H2 addition start in the loop from IMS for the ISS

14:42 - CEC-DP adjusting

17:50 - received FCU MSB gases

	18:12	- CT-DP jumped up to 450 torr, so, CTin heater power increased
	22:00	- CEC-DP adjusting
	22:30	- CT cycle manually stopped for a 10 min. and restart
		- received again FCU MSB gases
Apr.29	01:48	- JFCU data saved & transferred to MT from JFCU & deleted
	08:00	- CEC-DP adjusting
	08:45	- CEC-DP adjusting
	09:10	- GC timer manually stopped
	09:20	- CEC-DP adjusting
	10:05	- CEC-DP adjusting
		(At this time, no tritium spike was found in the TWT-LPR)
	10:25	- try to reduce loop flow to ~ 5 Nl/min to ~ 4.5 Nl/min
	10:33	- impurity injection start (10 % CH4 in He balance, inject to the
RT1)		
	10:40	- start again GC timer
	10:50	- CEC-DP adjusting
	13:40	- gradually increase loop flow for the ISS request
	13:50	- CEC-DP adjusting
	14:30	- CEC-DP adjusting
	14:50	- found HLR-CECIN seemed to be broken
	15:25	- CEC-DP adjusting
	16:25	- increased PD temp. to 673 K from 573 K
	20:00	- CT1 regeneration continued ~ 80 min. manually
	21:20	- CT2 regeneration continued manually
Apr.30	00:40	- found pressure sensor indication jumped up (RT2, ISSIN, PDEX
)		
		- failure of MFC-JCR1BYP
	02:27	- JFCU "pause" again by PRCA-ISSIN > 1000 torr
		- HV-B open
		- found ISS REF was broken, so, PRCA-ISSIN > 1000 torr
		- found GB temp. = 327 K and instrument panel temp. = >313 K
		- isolate CEC
	03:01	- interlock of JFCU off, "pause" reset
	03:59	- ISS REF temporally recovered
		- decided JFCU did not connect again to the loop and closed HV-
A,B,C		
		- main loop flow thru MSB1 of FCU
	08:18	- RT2 gas transferred to the loop thru AV407, TP1
		- BP and Scroll pumps turned on
	08:31	- start JCR1 dilution "internal" flow, open CEC
	09:10	- start CT regeneration "external" flow (recovery loop flow)
	09:20	- CEC pot. "remote" on
	09:25	- HV-C and AV-406 open
	09:40	- CT cycle operation started
	10:20	- CEC-DP adjusting
	11:10	- CEC-DP adjusting
	11:50	- found CT2 plugging
		- manually JFCU "pause"
		- huddle
		- BP and Scroll pumps turned on
		- HV-C and AV-406 open
	12:45	- CT cycle operation "reset"
	13:25	- start internal dry up operation with manually changing CT cycle
		(no O2 & He addition, no exhaust , CT1 hold, CT2 heating,
		CT3 trapping)
	14:00	- CEC-DP adjusting

	14:50	- CEC-DP adjusting
	15:20	- start CT1 heating, CT2 cooling, CT3 trapping
	17:34	- start CT1 cooling, CT2 trapping, CT3 heating
	19:52	- start CT1 trapping, CT2 hold(cool), CT3 heating
	21:13	- start CT cycle operation
May 1	08:20	- CEC-DP adjusting
	08:23	- JFCU SAFETY program stopped
	11:45	- CEC-DP adjusting
	16:50	- open O2 sensors and bypath closed
	17:15	- finish internal dry up operation
		- isolate CEC, pot. off
	18:30	- RT2 gas transferred to the loop thru AV407 & TP1
		- isolate RT2 & turn off Scroll + BP
	22:17	- turn off MBP and open HV575
		- JCR1 heater turn off
		- PD temp. decreased to 573 K from 673 K
		- keep this situation
May 4	09:20	- CT3 feed stop
		- HV072 close and TMP turn off and AV437 close
		- found RT2 pressure increase (because HV-C opened, RT2 press. increased by internal leak of AV406)
		- closed HV-C
	23:55	- data saved, transferred to MT, and deleted
May 5	11:30	- JFCU-GB temp. = ~ 308 K
May 6	09:00	- line setting for the regeneration of ZCB2&3 to ZCB1
	09:10	- start evacuation of ZCB2&3 vacuum jackets by PEV
	09:20	- finish evacuation of ZCB2&3 vacuum jackets by PEV
	09:25	- start evacuation of residual gas in ZCB2&3 thru ZCB1
	09:45	- finish evacuation
	09:57	- start heating up of ZCB2&3 (regenerate to ZCB1)
	10:03	- interlock on
	17:51	- ZCB2&3 heater turn off and ZCB1- ZCB2&3 line isolate
May 7	09:00	- check valves for replacement of MFC-JCR1BYP
	09:30	- evacuate replacement section
	10:00	- start replacement of MFC
	10:40	- evacuation again the replaced MFC section
		- watch pressure JCR1IN
	14:00	- found pressure indication drop (ISSIN, RT2, PDEX, JFCUEX, that all connected MKS 260 controllers and this drop happened
10:00		
		just after disconnect cable of wrong MFC)
		- maybe recovered the happening on Apr.30, 20:40.
	16:20	- data saved, transferred to MT, and deleted
	16:30	- check CT cooling function
	17:30	- REF of CTs was off by failure alarm
	18:00	- REF of CTs on again but failure again
		- keep REF off , stop suppling liq. N2 for REF, and watch freon
temp.		
	20:23	- no pressure increase found in the replaced MFC area
		- flow control test of replaced MFC
May 8	07:30	- still watch freon temp. and press.
	13:30	- CT temp.=292 K, and freon temp.=280 K

		- start supply liq. N2 for REF
	14:30	- turn on REF and watch CTs temp. (cooling down situation)
	17:00	- found less cooling function for 3 CTs
		- CT cycle operation setting of temp. increased and cycle operation start
		- watch CT cycle situation for evaluation of CTs function
May 9	10:15	- checked enough function of CTs
		- decided the usage CTs without maintenance
		- stop/reset CT cycle operation and REF off and stopped liq. N2
May 11	07:40	- data saved, transferred to MT, and deleted
	07:50	- CT timer setting changed
		- JCR1 heating program turn on
		- PD temp. increase to 673 K
	08:00	- REF liq. N2 supply start
		- GB temp. 306 K
	10:20	- found again the less cooling function of REF
	12:10	- stop liq. N2 flow
	12:50	- try REF on without liq. N2 supply
		- then start supply of liq. N2 again
		- after try and error, finally REF on with liq. N2
	13:15	- start CT cycle operation
	13:40	- MFC-JCR1BYP zero calibration
	16:20	- BP and Scroll pumps turn on
		- HV512 open
		- CEC pot. on by pot. mode manually
	16:40	- CEC open
		- AV414, 430, 431 open
		- internal recycle dry up operation started.
	21:00	- flow of the JCR1BYP adjusted
May 12	04:31	- CEC-DP adjusting
	05:00	- JFCU-GB temp. 322 K
	08:24	- open AV406 and HV-C
	09:00	- some amount of O2 injected to the JFCU to remove residual T
	10:00	- O2 monitor calibration using 5% O2 in He balance
	10:20	- O2 sensor cell (JCR1IN) replaced (found cell broken physically)
		- still no indication of JCR1IN O2 conc.
	10:30	- replaced O2 sensor cells (JCR1EX and JCR1IN)
		- JCR1EX indication recovered but still wrong JCR1IN
	11:00	- huddle
		- decide JFCU usage without O2 indication of JCR1IN
	11:45	- start connection of ISS-JFCU
		- adjust RT1 press. ~ 830 torr (PRCA-PDEX set = 800 torr)
		- TP1 press. was ~840 torr
		- close HV501, open AV404, HV-A,B,C
		- open HV501, close HV-B
	12:15	- stop FCU-MSB1 liq. N2 supply, so gas from MSB1 receiving start
	14:10	- stop FCU-MSB2 liq. N2 supply, so gas from MSB2 receiving start
May 13	00:26	- CEC-DP adjusting
	02:33	- CEC-DP adjusting
	05:14	- CEC-DP adjusting
	06:22	- CEC-DP adjusting
	07:20	- CEC-DP adjusting

	08:30	- CEC-DP adjusting
	09:25	- TSTA loop flow stopped, start loop shut down
	09:30	- close HV-C and AV406
		- RT2 gas evacuate to ZCB1
	09:45	- CEC-DP adjusting
		- PEV stopped
	09:50	- PEV recovered
	10:40	- CEC-DP adjusting
	11:50	- CEC-DP adjusting
	11:55	- RT2 gas evacuate to ZCB1
	13:05	- CEC-DP adjusting
	13:20	- received some residual gas from the ISS
	14:28	- CEC-DP adjusting
	14:44	- RT2 gas evacuate to ZCB1
	16:30	- CEC-DP adjusting
	17:05	- start receiving FCU-Mg bed gas ~ 40 min.
	18:00	- RT2 gas evacuate to ZCB1
	18:05	- CEC-DP adjusting
	18:07	- receiving FCU gas again
	18:30	- finish FCU gas pumping
	19:50	- receiving purge gas of FCU-MSB (He)
	20:35	- ISS residual gas receiving again
	21:40	- receiving purge gas of FCU-MSB (H2) after stop of He purge
	21:54	- RT2 gas evacuated to ZCB1
	22:05	- receiving purge gas of FCU-MSB (He) again after stop of H2
purge		
	23:07	- RT2 gas evacuated to ZCB1
	23:11	- CEC-DP adjusting
May 14	04:50	- CEC-DP adjusting
	05:00	- data saved, transferred to the MT, and deleted
	07:50	- stopped He purge of FCU-MSB
	08:10	- receiving final pumping gas of FCU-MSB
	09:15	- receiving ISS He purge gas
	09:50	- CEC-DP adjusting
	10:10	- close AV404 and HV-A
		- start internal dryup operation of JFCU
		- decreased PRCA-PDEX to 650 torr
		- decreased CT-DP to 300 torr
		- O2 sensors isolated
	12:12	- CEC-DP adjusting
		- RT2 gas evacuated to ZCB1
	16:30	- CT cycle operation stopped and continue manual dry up of CTs (CT1&2 heating, and CT3 trapping)
	17:45	- CT2 isolated after checking regeneration situation
	18:05	- CT3 heating start under keeping high temp. of CT1
	18:10	- REF off and stopped liq. N2 supply
	19:03	- RT2 gas evacuated to ZCB1
		- isolated CEC
		- turned off CEC pot.
		- start CEC cooling down program
	19:10	- CT heaters turned off
		- Scroll + BP pumps turned off
		- MBP also turned off
	19:15	- MFC-CTIN and MFC-PDEX manual opened
May 15	10:40	- start circulation of recovery loop thru ZCB1
	after noon	- start system evacuation to TWT thru ZCB1

- evacuate PD and RT1 &2 with TMP
- isolate PD & JCR1 and heaters turned off
- set CEC cooling flow minimum

May 18 - cooling flow of CEC stop

May 29 - ZCB1 regenerated to the UTB standard volume

2. GC analysis results (%)

Time		4/27 18:30 18:20	19:40	23:33	4/28 00:45	13:30	14:40	
Sampling # and Species								
#2	Q_2	42	45	49	49	43	45	42
#3	Q_2	3.5	4.5	5.3	5.2	4.5	4.8	5.1
#5	O_2	2.7	3.2	2.5	1.8	3.0	2.3	1.5
	Ion ch.	---	---	---	---	---	---	---

Time		4/29 16:40	19:00
Sampling # and Species			
#2	Q_2	41	40
	N_2	0.7	0.6
	CH_4	0.1	0.1
#3	Q_2	5.2	4.9
	N_2	1.0	0.9
	CH_4	0.1	0.1
#5	O_2	2.0	2.4
	N_2	0.8	0.7
	CO_2	---	---
	Ion ch.	---	---

Q : H, D, T
--- : Not Detected