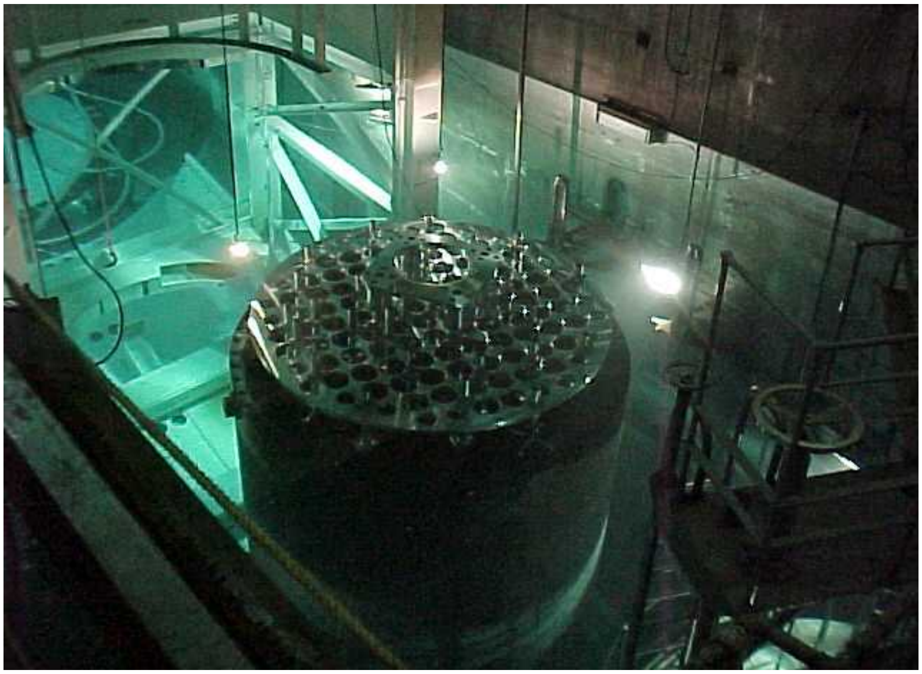
2nd EC/ISOE Workshop on Occupational Exposure Management at NPPs
(Tarragona, Spain, 5-7 April, 2000)



ALARA Approach on the Reactor Lower Internals Recovery Service of Qinshan Unit 1

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Background

Qinshan unit-1 of Qinshan Nuclear Power Company (QNPC) is a 300MWe prototype PWR in China. It has been operating for 4 fuel cycles about 10 years.
March 1997， leakage from guide tube of the reactor core neutron flux measurement thimble were observed.
January 1998, fuel assembly failure was observed.
July 1998, some loose parts were observed on the lower structure of core barrel due to the failure of the guide tube of the reactor core neutron flux measurement thimble during periodical inspection after unloading all fuel assemblies.
September 12-25 1998, ABB performed visual inspection to the core barrel and RCCS. October-December 1998, ABB, WESTINGHOUSE, FRAMATOM, and MITSUBISHI bid for the recovery contract.
On December 8, 1998, QNPC selected WESTINGHOUSE Electric Company as contractor.
March 3 1999-June 18 1999, Site efforts.

1.0 Job Preparation

1.1 Main Working Steps

The main steps of the Qinshan Unit 1 lower internals recovery project are outlined below.

Step 1. Operations with lower internals on storage stand

Remove/store surveillance capsules
Stabilize/remove debris on lower internals
Install cavity vent covers and floor decking
Perform vessel penetration gauging and install reactor vessel cover
Inspect/replace core barrel former bolts
Perform Core Baffle cavity functional gauging
Repair surveillance capsule holder and bolt
Machine lower core plate counter bores (12)
Install lower internals braces (spider)
Assemble top structure on lower internals and install lower internals lifting rig (standard)

Step 2. Stage & assemble inside containment

Refueling cavity floor protective deck assembly
Reactor vessel cover
Internals storage stand adapter and upender support
Upender assembly and reactor internals braces
Work platform, diver platform and segmentation platform

Step 3. Assemble lower internals into upender

Install external redundant support, top structure beams and lift rod beam end
Position top structure jacking screws (4)
Install special lifting rig/slings with chain fall (short)

Step 4. Lift lower internals and upender assembly

Adjust load into refueling cavity floor decking and sidewise orientation using chain falls
Initiate rotation to horizontal position

Step 5. Lower internals and upender horizontal

Install storage stand adapter and upender support and special lift rig with chain fall (long)
Lift
Position to lower internals storage stand support
Change special lift rig/chain fall to (short)

Step 6. Invert lower internals

Position special cavity bridge
Install temporary radiation shield (if needed) and special lift rods (4 required)
Remove upender support from storage stand

Step 7. Lift lower internals to storage stand

Rig and remove upender lower support structure
Assemble work platform
Position cutting/machining equipment and assemble segmentation platform

Step 8. Initiate machining/removal of in-core instrumentation

MDM cutting energy absorber/columns (remove energy absorber assembly and move to segmentation platform)
MDM cutting of type 1 and type 2 columns below lower core support plate
Remove tie plate & column remnants to segmentation platform
Remove nut and cruciform remnants at lower core support plate

Step 9. Final machining and assembly type 1 and type 2 columns

Torque sleeve adjustment nuts
Refurbish threads on upper column type 1
Machine column flange holes into lower core support plate (drill and tap new M-18 holes)
Machine jam nut locking dentents and install new jam nuts (seat and crimp)

Step 10. Assemble tie plate/energy absorber

Assemble columns to lower core support plate and install tie plate
Install locking device and column bolts at tie plate
Install energy absorber columns and base plate
Perform column functional gauging for true position tolerance
Perform drag load gauging using BMI thimble gauge
Crimp all bolt locking devices
Remove segmentation platform, work platform and diver platform

Step 11. Re-install lower internals into upender

Install cavity shield and position external supports to lower internals
Install redundant support (2)

Rotate assembly to correct orientation

Step 12. Re-invert internals to normal orientation
Remove redundant supports and lift rods
Remove cavity vents and reactor cavity deck plate
Remove storage stand adapter

Step 13. Install lower internals to storage stand
Remove top structure and reactor internals braces
Perform functional gauging core cavity
Install type 2 column nuts (12) & lock and remove reactor vessel cover

1.2 Survey Data

Table 1 shows the dose rates in the water at various heights and distances from the core barrel in the cavity. Locations of the points are diagrammed in Figure 1. These data were used for estimating the exposures and designing the upender. Figure 2 presents dose rates measured at various points on the surface of the lower internals. Dose rates as high as 660 Sv/hr were found inside the barrel. Caution must be observed that sufficient water shielding between divers and the activated part of the barrel maintained at all times.
Figure 3 shows the reactor pressure vessel structure and dose-rate at some key points.
Figure 4 presents additional exposure data taken during the movement of the lower internals. During this process, the top of the internals was above the water by about 2 m. These high exposure values indicated the danger in raising the assembly more than necessary and the effectiveness of the water shielding in the normal configuration.

1.3 Dose Estimates

1.3.1 Dose-rate and Man-hours Estimates for Each Step

The estimated dose-rates, man-hours, and total dose for each step outlined in Section 1.1 are given in Table 2. The divers would work with long-handled tools at a distance from the activated material of more than 6 feet in the water. Care must be taken to ensure that the divers do not get closer than six feet to the high radiation levels emanating from the barrel and surveillance capsule assembly. In addition, finger rings will be used to monitor exposure to the divers' hands, which will generally be closer to the radiation source than their bodies.
Steps 3-7 describe the tasks involved in upending the internals. These tasks were broken down into 33 detailed sub-steps. Detailed exposure evaluations for each step are given in Section 1.3.2. Steps 11-13 repeated in reverse the upending process. Because the contaminated structures at the bottom of the internals were replaced, radiation exposure should be reduced for the steps where this region was exposed or near the top of the water. In addition, lessons learned from the earlier steps should enable this operation to be carried out more efficiently.

1.3.2 Dose Estimate Details

Table 3 gives the radiation field and dose estimates for the detailed steps of the internals upending process. Table 3 assumes that the most exposed worker is rigger number 1 in all cases. This exposure would be divided amongst several workers. The estimates of dose were most uncertain when radiation sources extend out of the water without shielding. Steps of particular concern were the steps when the internals were tilted during the upending process, and the steps when the internals were removed from the upender (and shield) after inversion. Special care would be taken to monitor dose and minimize exposure time during these steps.

Table1 The Dose Rate of Cavity

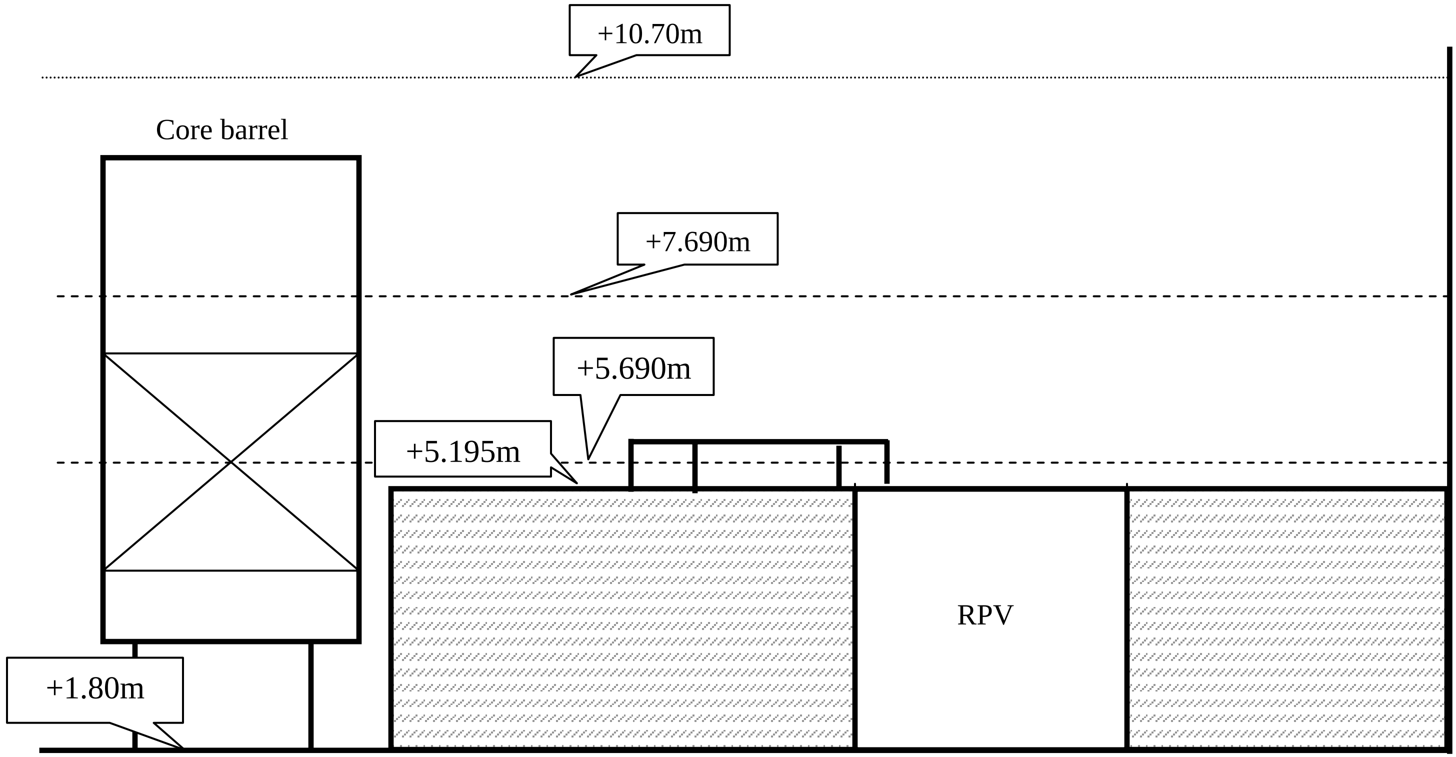
Unit: *mSv/h*

Distance from the edge between +5.19m and +1.80m	Elevation	Deviation from EW axis of Core Barrel				
		I +2.40m (N)	II +1.50m (N)	III 0.00 m	Ⅳ -1.500m (S)	V -2.40m （S）
A 0.0m	+5.195m	0.180	8.00	200	9.00	0.162
	+5.690m	0.200	14.0	600	9.00	0.180
	+7.690m	0.045	1.10	28.0	1.30	0.060
	+10.72m	ND	ND	0.011	ND	ND
B 1.0m	+5.195m	0.043	0.086	0.480	0.080	0.025
	+5.690m	0.010	0.068	0.880	0.070	0.015
	+7.690m	0.005	0.030	0.115	0.017	0.007
	+10.72m	ND	ND	0.015	ND	ND
C 2.0m	+5.195m	0.500*	0.040	0.040	0.040	0.026
	+5.690m	0.021	0.014	0.009	0.010	0.016
	+7.690m	0.015	0.009	0.010	0.015	0.010
	+10.72m	ND	ND	0.020	ND	ND
D 3.0m	+5.195m	0.085	0.065	0.045	0.035	0.026
	+5.690m	0.016	0.008	0.013	0.013	0.060
	+7.690m	0.007	0.015	0.007	0.010	0.005
	+10.72m	ND	ND	0.007	ND	ND
E 5.0m	+5.195m	ND	ND	0.070	ND	ND
	+5.690m	0.200	0.013	0.008	0.040	0.036
	+7.690m	0.005	0.012	0.009	0.017	0.013
	+10.72m	ND	ND	0.018	ND	ND

*Why this data higher than expected was due to debris existed under this point.

Water level: *10.70m*, Data collected on *26 January 1999*
Using very-high level gamma-radiation probe, type STHF
With RADIAGEM type dose-rate meter, Sensitivity: 17c/s per mSv/h (^{137}Cs)

Figure 1 Locations



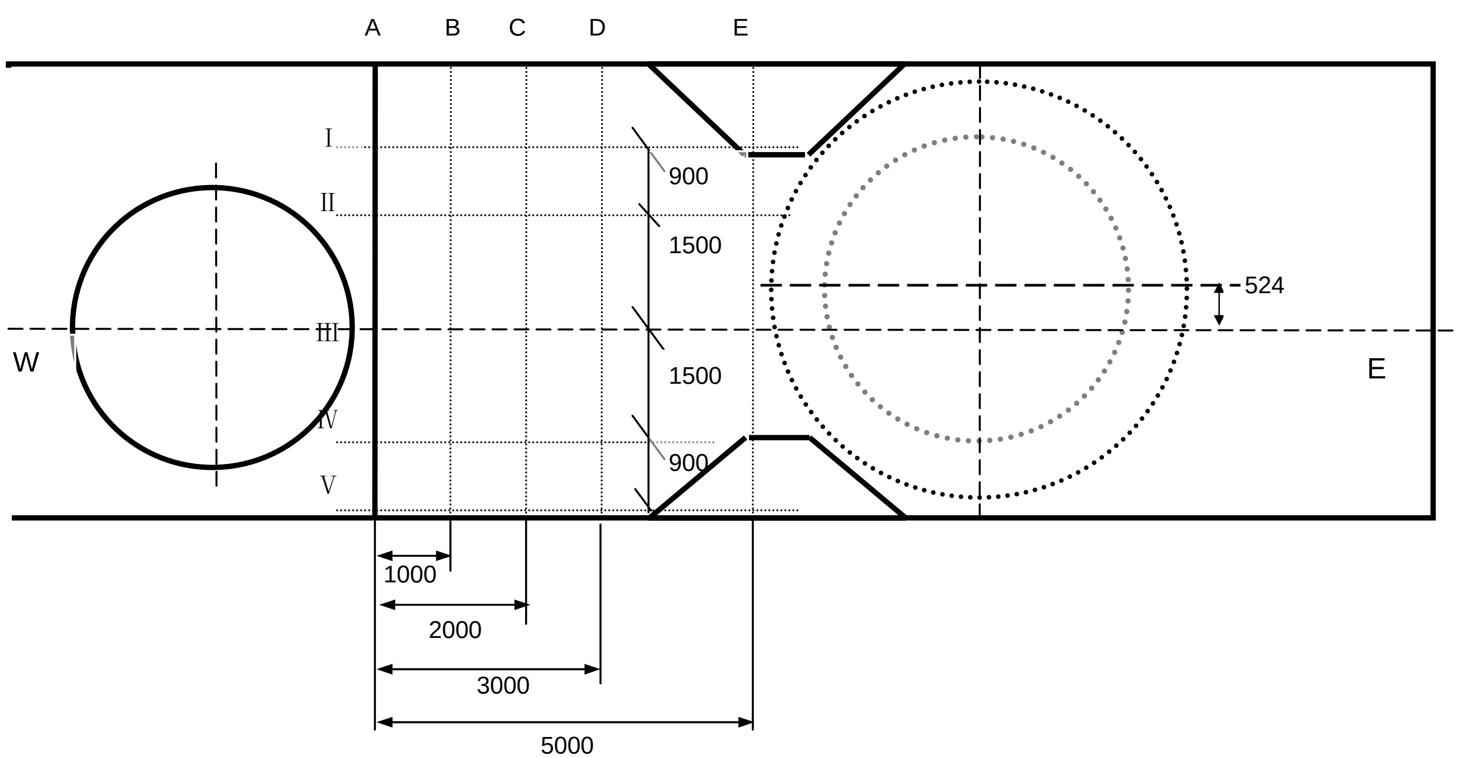


Figure 2 Core Barrel Dose rate Map

Measuring on Dec. 17, 1998. Water level at cavity: 11.50 m

Using very-high level gamma-radiation probe type STHF, With RADIAGEM type dose-rate meter, Sensitivity: 17c/s per mSv/h (^{137}Cs)

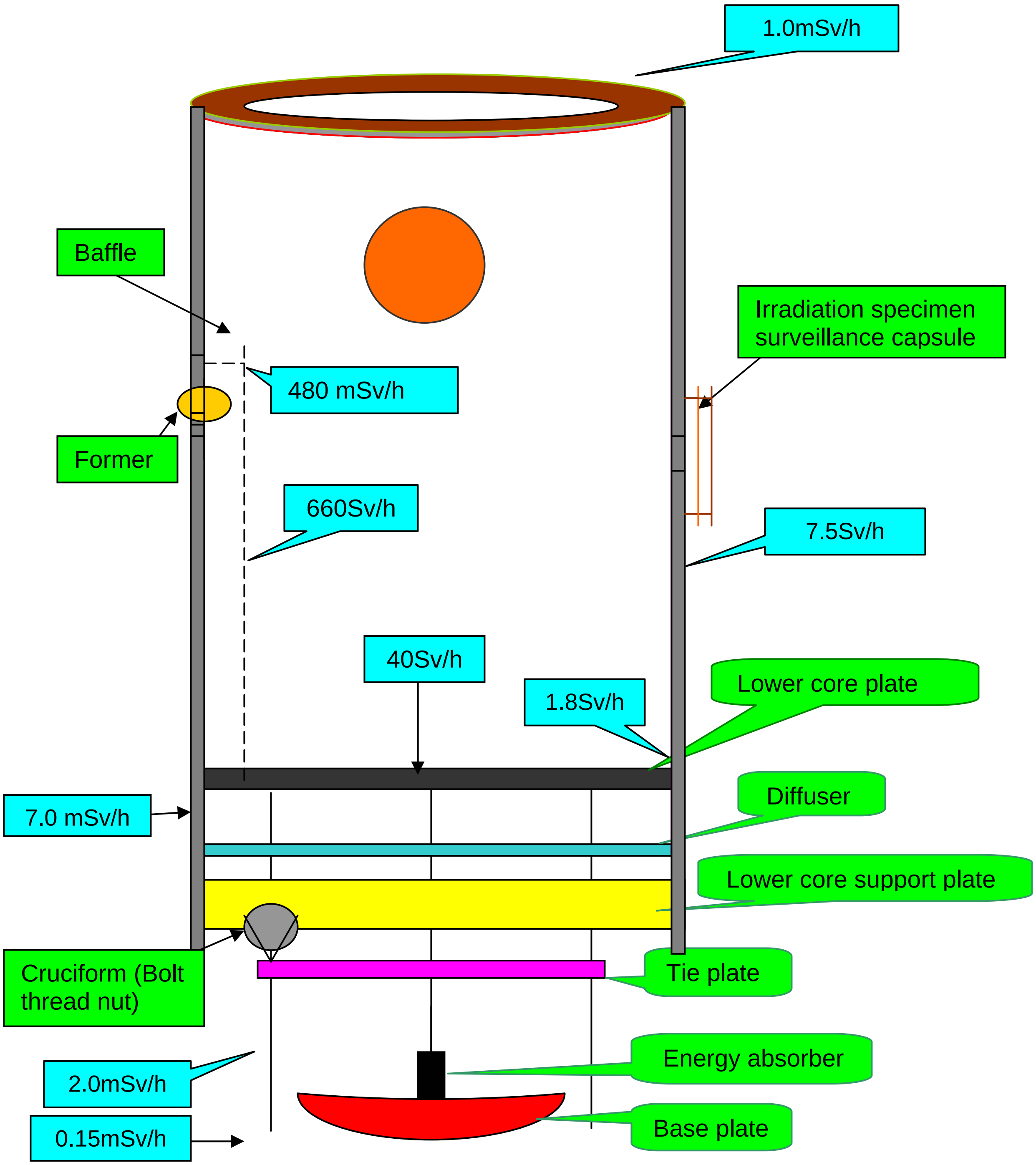
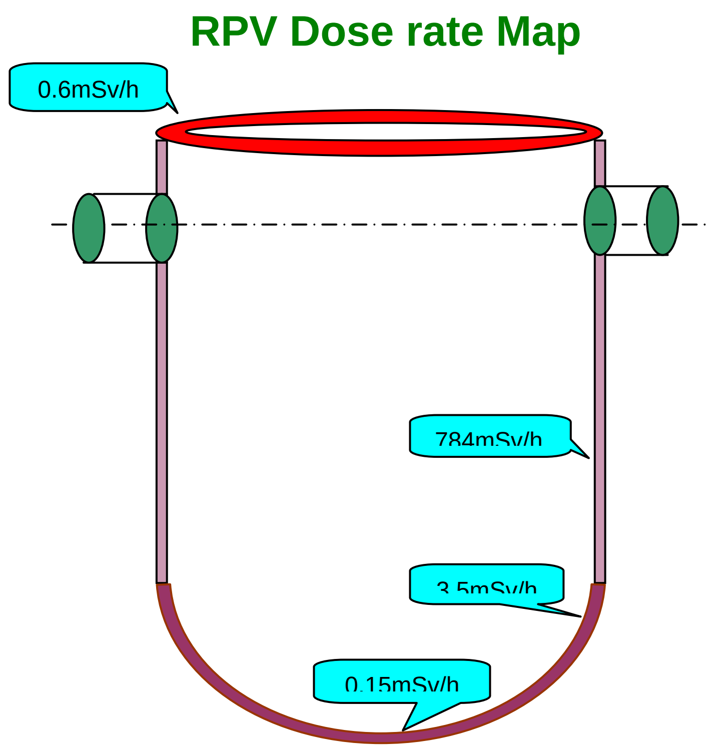


Figure 3

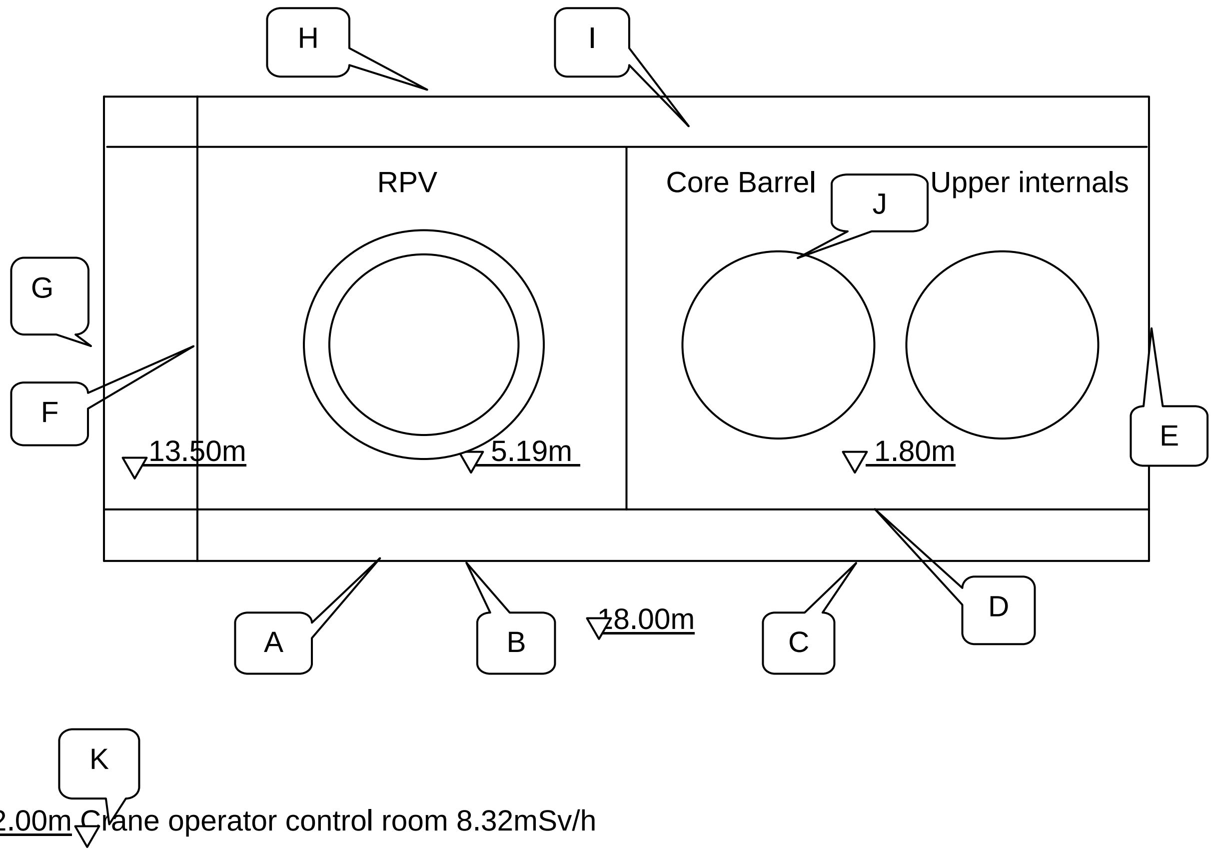


Measuring on Dec. 17, 1998, Water level at cavity: 11.50 m
Using very-high level gamma-radiation probe type STHF, With RADIAGEM type dose-rate meter, Sensitivity: 17c/s per mSv/h (^{137}Cs)

Table 2. Exposure Estimates

Job Step	Description	Exposure Hours	Total Man Hours	Average Dose Rate mSv/hr	Total Dose mSv
1	Lower Internals on Stand	504	3561.6	0.007	24.93
2	Stage and Assemble	120	600.0	0.007	4.20
3	Lower Internals into Upender	11	66.0	0.008	0.44
4	Lift Lower Internals	0.5	4.0	1.000	1.28
5	Upender Horizontal	4.75	28.5	0.428	4.41
6	Invert Lower Internals	4.25	26.8	1.176	10.75
7	Lift to Storage Stand	3	19.5	1.510	28.06
8	Segmentation	720	2880.0	0.007	20.16
9	Inspection	120	480.0	0.007	3.36
10	Removal/Installation	1152	6912.0	0.007	48.38
11	Re-Install into Upender	3.5	66.0	0.087	28.06
12	Re-Invert Internals	9.5	59.3	0.305	16.43
13	Place Internals on Storage Stand	4.15	19.5	0.009	0.44
	TOTAL		14723.2		190.9

Figure 4 The maximum dose rate during core barrel removal from RPV to support stand



Unit: *mSv/h*

Point	A	B	C	D	E	F	G	H	I	J*	K
Level (m)	18.0	18.0	18.0	14.3	14.3	13.5	18.0	18.0	14.3	*	52.0
Dose-rate	43.1	49.5	46.0	382.0	16.3	30.1	2.8	30.5	79.2	40	8.32

*Dose-rate at a distance (10cm) on the top of core barrel

Measuring date: Aug. 26, 1998
Water level: 12.15 m

Table 3. Radiation Exposure Estimate for Qinshan Internals Up- Ending

Step No.	Exposure time Hours	Rigger No. 1		Rigger No. 2		Rigger No. 3		Rigger No. 4		Crane Operator	
		Dose Rate mSv/hr	Dose mSv	Dose Rate mSv/hr	Dose mSv	Dose Rate mSv/hr	Dose mSv	Dose Rate mSv/hr	Dose mSv	Dose Rate mSv/hr	Dose mSv
1	8.00	0.007	0.056	0.007	0.056	0.007	0.056	0.007	0.056	0.001	0.011
2	0.50	0.007	0.004	0.007	0.004	0.007	0.004	0.007	0.004	0.001	0.001
3	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
4	1.00	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.002	0.002
5	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
6	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
7	0.50	1.000	0.500	0.250	0.125	0.250	0.125	0.250	0.125	0.050	0.025
8	0.25	1.000	0.250	0.250	0.063	0.250	0.063	0.250	0.063	0.050	0.013
9	0.50	1.000	0.500	0.250	0.125	0.250	0.125	0.250	0.125	0.050	0.025
10	0.50	2.500	1.250	0.625	0.313	0.625	0.313	0.625	0.313	0.125	0.063
11	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
12	1.00	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.002	0.002
13	*	0.010		0.010		0.010		0.010		0.002	
14	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
15	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
16	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
17	0.50	0.010	0.005	0.010	0.005	0.010	0.005	0.010	0.005	0.002	0.001
18	0.25	1.000	0.250	0.250	0.063	0.250	0.063	0.250	0.063	0.050	0.013
19	0.50	2.500	1.250	0.625	0.313	0.625	0.313	0.625	0.313	0.125	0.063
20	0.50	1.000	0.500	0.250	0.125	0.250	0.125	0.250	0.125	0.050	0.025
21	*	1.000		0.250		0.250		0.250		0.050	
22	0.50	1.000	0.500	0.250	0.125	0.250	0.125	0.250	0.125	0.050	0.025
23	2.00	1.000	2.000	0.250	0.500	0.250	0.500	0.250	0.500	0.050	0.100
24	0.50	1.000	0.500	0.250	0.125	0.250	0.125	0.250	0.125	0.050	0.025
25	*	1.000		0.250		0.250		0.250		0.050	
26	*	1.000		0.250		0.250		0.250		0.050	
27	*	1.000		0.250		0.250		0.250		0.050	
28	*	1.000		0.250		0.250		0.250		0.050	
29	0.50	6.000	3.000	6.000	3.000	6.000	3.000	6.000	3.000	1.200	0.600
30	0.50	3.000	1.500	3.000	1.500	3.000	1.500	3.000	1.500	0.600	0.300
31	1.00	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.003	0.003
32	0.50	0.015	0.008	0.015	0.008	0.015	0.008	0.015	0.008	0.003	0.002
33	0.50	0.015	0.008	0.015	0.008	0.015	0.008	0.015	0.008	0.003	0.002
Total	23.5		12.15		6.52		6.52		6.52		1.30

* Exposure times during these steps assumed to be included in other steps. Steps 21 and 27 were optional.

2.0 Dose Reduction Measures

The followings are the dose reduction measures that had been taken to achieve ALARA.

2.1 Temporary Shielding and Preset Shielding

Shielding was used to minimize exposure when feasible. In order to provide additional shielding water, the water level was raised by a minimum of 800 mm from 12.150 m to 12.950 m during the process of inverting the lower internals. The inverting process were carried out using an upender frame which had shielding of 4 inches (101.6 mm) of iron on the top and 3 inches (78.2 mm) on three sides to shield the part of the lower internals where the energy absorber was located.

The dose-rate on the cavity pool surface reduced from 5.0mSv/h to 0.05mSv/h by the shielding and saved about 800man.mSv.

The actual dose-rates refer to figure 5 and 6.

Temporarily shielding was also used around the reactor vessel head.

2.2 Clean-up Refueling Water

A temporary underwater vacuum pump and filter system were setup to purify the debris arise from underwater EDM cutting. Meanwhile the refueling pool purification system was kept on operating to reduce the dose-rate of the cavity area. These 2 systems were effective cleanup the hotspot and great reduce the dose-rate from 1~330mSv/h in filter area to below 0.1mSv/h of the cavity working area.

The pool water radioactivity was successfully kept under 1.5E+03Bq/l and surface dose-rate of the most pool area was less than 5uSv/h.

2.3 Use of Cameras and Long-handle Tools

Inspection and repair activities were carried out using surface cameras and long-handle tools to the extent practicable. Diver was used for some of these activities and he was required to be offset a safe distance from the activated materials using water as shielding.

2.4 Very Low Dose-rate Standby Area Established

Radiation survey maps of the work area in containment were used to define areas of low exposure and all personnel were instructed to use these areas when not required to be actively involved in activity. Ropes and barriers were used to identify high-dose areas during each step of the work.

2.5 Use of Mock-ups and Training

All personnel had received ALARA training pertinent to their job. Mock-ups were extensively used to test procedures and minimize time in radiation fields.

2.6 Continuing ALARA Communications

Each job step received an ALARA review taking into account the radiation fields at that time and lessons learned from previous steps. Each meeting to discuss the work progress (e.g. at shift turnover) has an ALARA agenda item.

In the event that radiation levels were significantly different that predicted, or if an unusual number of contaminations occurred, the job would be halted and corrective actions taken. If necessary the job step might need to be re-engineered.

The dose-rate on the deck +18m was up to 6mSv/h, obviously higher than 1.3mSv/h on +13 m refueling machine level due to gamma scatter effort when the core barrel upending to certain position. The RP technician requested the chain pull workers change working plain to save the dose and actually saved about 40man.mSv from this effort.

3.0 Control of Contamination

More than 20 smear contamination checkpoints were set up on the deck and pool areas. The RP foremen checked and segregated the contaminated area each shift to preventing spread of contamination.

3.1 Protective Clothing Requirements

Protective clothing was used when workers handle tools out of pool. To conform to ALARA, protective clothing was minimized in order to allow efficient functioning in the radiation field.

3.2 Segregation with Plastic Paper

All radiation areas subject to contamination were segregated with step-off pads in conformance with contamination control requirements.

3.3 Decontamination Service

Divers exiting the pool were step onto a herculite pad and sprayed off with clean water that will drain into the pool.

All tools which used underwater were flashed by water jet and then mopped by cotton paper to preventing body contamination and/or cross contamination，plastic paper were used to package the contaminated items to preventing spread of contamination.

3.4 Ventilation

Adequate containment ventilation was provided to prevent airborne contamination. Respirators had been used whenever there was a possibility of airborne contamination.

4.0 Waste Disposal

Radioactive waste was collected into a red bag and non-radioactive wastes into a black bag after segregate by meter and disposal by decontamination team in accordance with plant procedures.

4.1 Power Cutting and Container Process

Cutting and handling of irradiated components were done under water. The segmentation of the tie plate was performed underwater in the segmentation tank. All radioactive debris were collected and placed in appropriate containers for disposal.

4.2 Waste Transfer Process

All waste was disposed of in casks and debris containers. Waste was transferred from underwater to the temporary storage area for disposal using remote camera system in accordance with plant procedures. This minimized the exposure and potential for contamination.

4.3 Use of Casks and Waste Containers

Radioactive wastes were placed in casks and waste containers. Filters from the Tri Nuc were placed underwater in a cask for disposal

5.0 Cost-Benefit Analysis

5.1 Shielding

Shielding was extensively used as outlined above to minimize exposure. Use of this shielding was required to minimize the total number of personnel and minimize their exposure.

5.2 Remote Tools

Use of remote tools has been found to be cost effective in terms of efficiency and reduced exposure.

5.3 Camera Monitoring

Camera monitoring was used where feasible for monitoring job progress and inspection. Use of both underwater and surface camera has been included.
More than 11 electronic dose-meters were setup on the deck and pool areas to get the maximum dose-rate during upending. A RP technician used long hand meter to monitor the dose-rate during this process.
All other personnel were evacuated to the low dose-rate standby area except crane command and operators.

5.4 Protect divers

The platform was setup 3m away from the core barrel. The underwater vacuum pump retrieved debris to prevent any hot spot deposit on body. The cavity water radioactivity controlled below 1E+04Bq/l, pressurized water jet sprayed onto diver when he was out of pool and cotton paper used to dry the suit.

The diver equipped with wireless radio, EPD, TLD and ring TLD. The highly dose-rate 800 uSv/h has been observed when diver approach to RPV but he was notified immediately and avoided.
There were not any body contamination happened and diver received dose was successful controlled below 50 uSv in each single diving.

6.0 Results and assessment

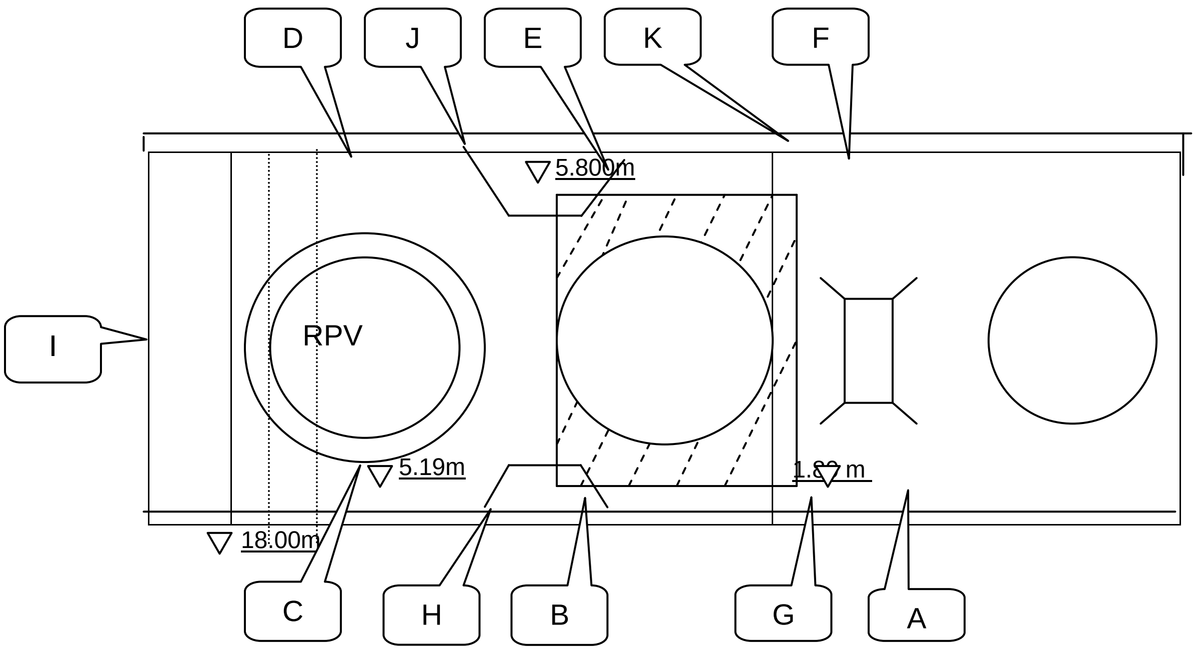
6.1 Management targets and final results

	Collective dose (man.mSv)	Maximum personal dose (mSv)	Body contamination (case)	Internal contamination (case)
Target	200	<18	<10	0
Result	70.059	3.485	4	0
Ratio	35%	19.4%	40%	/

6.2 Projected dose compare with actual dose

Job Step	Description	Start Time	End Time	Projected Dose (man. μ Sv)	Actual Dose (man. μ Sv)
1&2	Lower Internals on Stand, Stage and Assemble	3-19 0:00	04-25 06:59	29,130	27,350
3	Lower Internals into Upender	4-25 7:00	04-26 06:59	440	1,563
4	Lift Lower Internals	4-26 7:00	04-26 23:59	1,280	2,171
5	Upender Horizontal	4-27 0:00	04-27 11:59	4,410	90
6	Invert Lower Internals	4-27 12:00	04-27 23:59	10,750	2,517
7	Lift to Storage Stand	4-28 0:00	04-29 06:59	28,060	5,257
8	Segmentation	14-29 7:00	05-29 06:59	20,160	13,464
9&10	Inspection & Removal/Installation	5-29 7:00	06-04 18:59	51,740	2,424
11	Re-Install into Upender	6-4 19:00	06-05 18:59	28,060	1,114
12	Re-Invert Internals	6-5 19:00	06-08 06:59	16,430	3,808
13	Place Internals on Storage Stand	6-8 7:00	06-17 23:59	440	10,301
	TOTAL			190,900	70,059

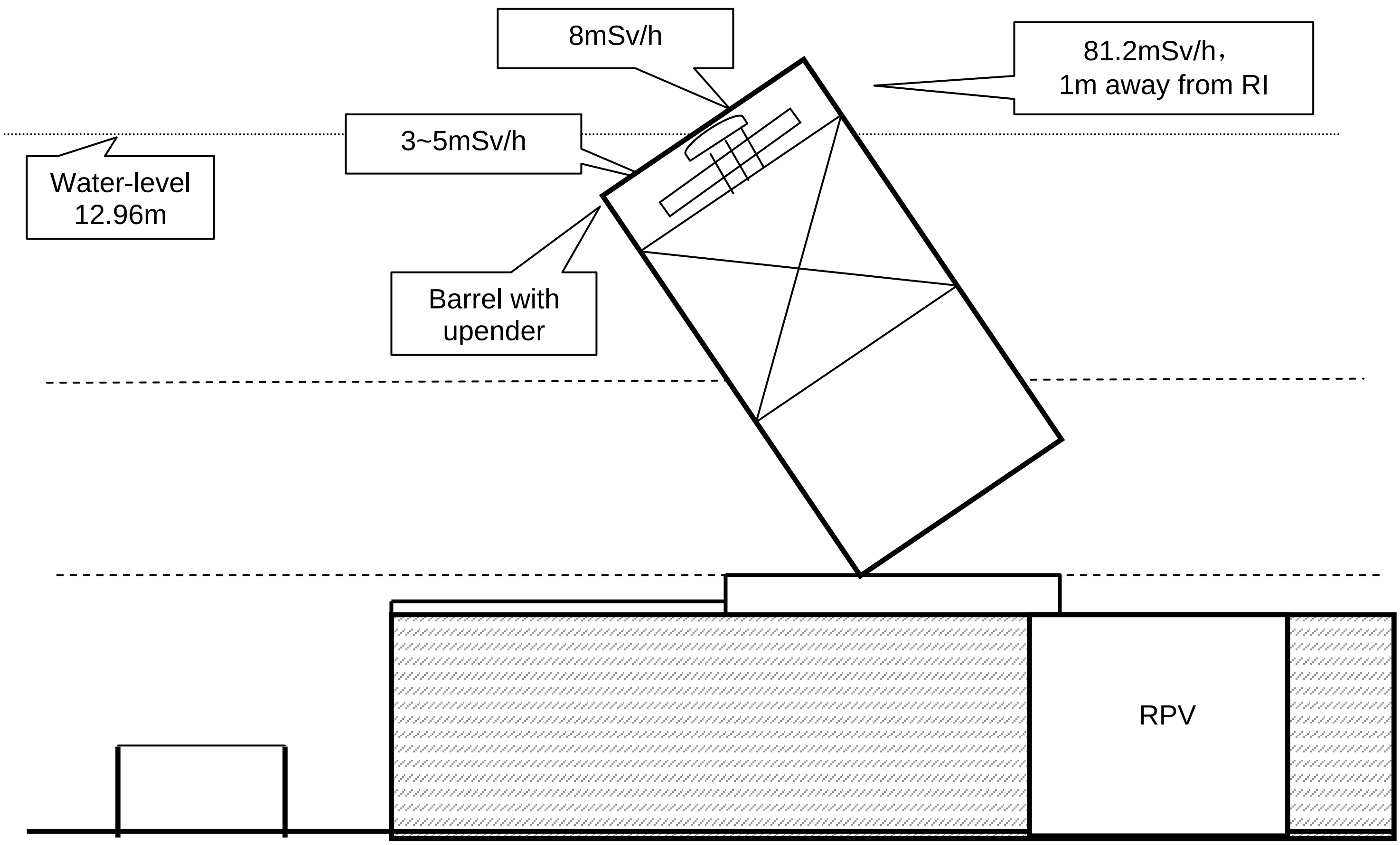
Figure 5 Maximum Dose-rate after Upend of Lower Internals



Water level: 12.96m, core barrel out of water, on April 28, 1999.
By DMC-100

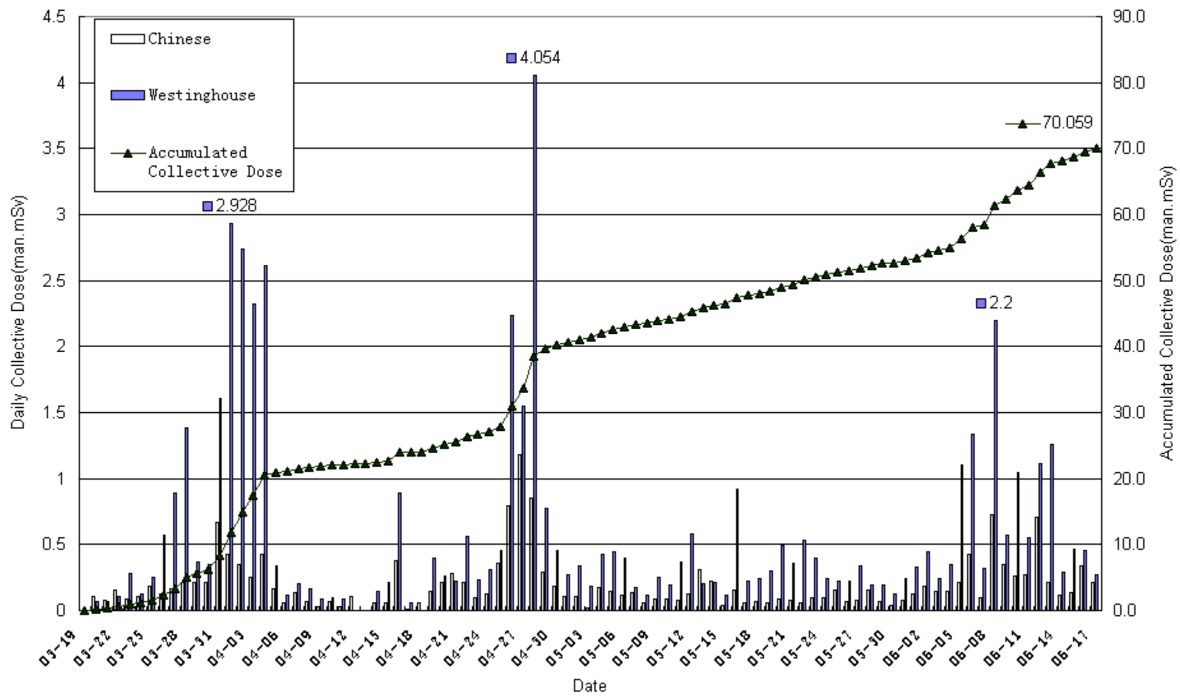
Point	A	B	C	D	E	F	G	H	I	J	K
Elevation (m)	14.3	14.3	14.0	14.3	14.3	14.3	18.0	18.0	18.0	18.0	18.0
Dose-rate （mSv/h）	1.26	28.0	18.2	29.6	51.2	1.72	6.0	15.8	7.3	29.1	10.3

Figure 6　　Contacted Dose-rate of Core Barrel Parts



Measured on April 28,1999. By PERM

6.3 Daily Collective Dose Trending Chart



6.4 Assessment

Temporary shielding significantly reduced the dose rate. That was achieved by arising cavity water level from 11.0 to 12.95 meters high, and putting 3 inches of steel on three sides and 4 inches of steel on the top of the up-ender.

Riggers are always away from the open side of the up-ender. Diver is away from opened RPV when approach to the underwater work platform. Continue fuel pool cleaning greatly benefits to reduce dose of divers.

Water jet to the long hand tools when they are out of pool and mop dry before leave pool were considered to be a successful control of contamination.

Scattering from the cavity and working level concrete walls has been detected during upending.

Underwater transfer high level waste to drum was a good practice for dose and contamination control.

Communication between contractors and plant proved to be a good way to approach the ALARA.

The projected collective dose on ALARA plan was calculated nominate to Co-60, compare to the actual contributed nuclides Co-60, Co-58, Fe-59, and Sb-124. This gave the preservative estimate of the dose.

QNPC and Westinghouse worked together to approach the ALARA by increasing water shielding, adding additional steel shielding, fuel pool cleaning and using the long handle tools and remote camera system. The training, mock-up exercise, good personal behavior was also greatly contributed to the ALARA approaching.

The collective dose and personal exposure of this job were successful controlled by implementing the preset ALARA program. The job was done by the cost of 70 man.mSv collective dose and 3.5mSv maximum personal exposure despite of the high dose-rate which hot spot in some place is up to several hundred Sv per hour.