中广核 CGN

Nuclear Power Services

China Nuclear Power Engineering Co.,Ltd.

The Establishment and Application of Dedicated Dose Evaluation Models of HPR1000

Xiong Jun

China Nuclear Power Design Company(CNPDC)

2019 ISOE INTERNATIONAL SYMPOSIUM

Natural Energy Powering Nature

CONTENTS

/1/ Introduction

HPR1000 The Gen III nuclear power technology with independent IPR of China

Thanks to 30 years of experience and expertise in NPP design, construction and operation, HPR1000, with completely independent IPR, has successfully been developed, based on the proven and safe technology and mature nuclear power equipment manufacturing system and capacity. HPR1000 is one of the most recognized Gen III technology in nuclear power market

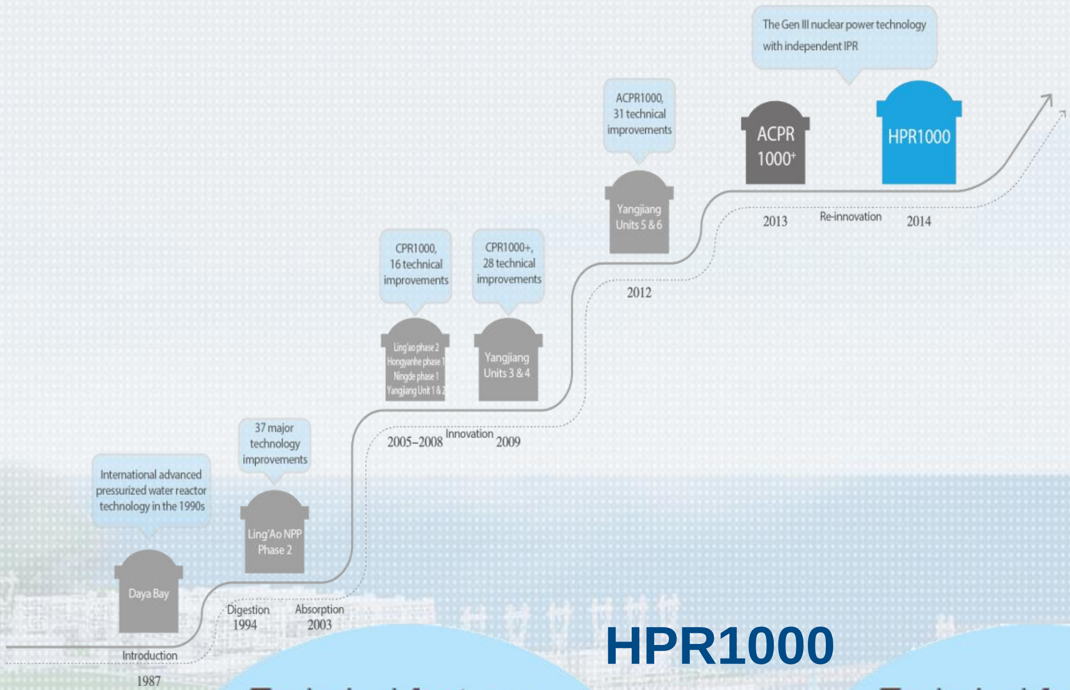
/1/ Introduction

On Dec.24, 2015
FCG Phase 2 started its construction.

On Sep.29, 2016
After the Launching of HPR1000 in the agreements of UK projects, GDA was accepted in January, 2017.

Main Technical Features
The reactor core is composed of 177 fuel assemblies and 3 physically isolated safety trains.

Applications for intellectual property rights **475** = Chinese domestic patents **373** + PCT international patents **11** + Software copyright **91**



HPR1000

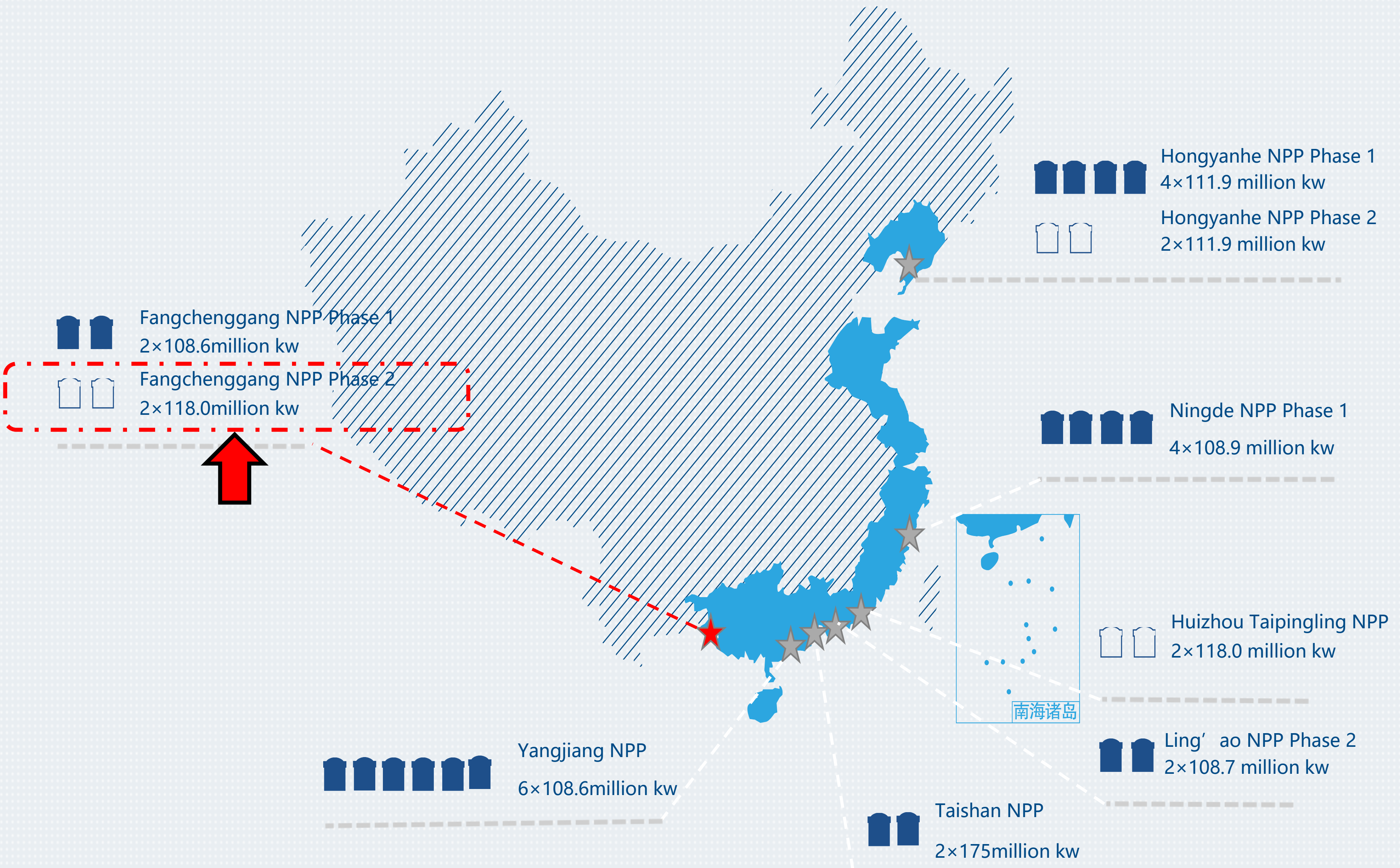
Technical features

Design life	60 years
Plant layout mode	Single reactor
Reactor core	177 advanced fuel assemblies STEP-12
Core Damage Frequency (CDF)	$< 1\times10^{-6}$/reactor year
Large Release Frequency (LRF)	$< 1\times10^{-7}$/reactor year

Technical features

Design basis seismic	0.3g
Generator output	1150MW
Double containment	Able to withstand crash of large commercial plane
Nuclear DCS platform	FirmSys, which boasts independent IPR
Plant availability	Up to 90%

/1/ Introduction



/1/ Introduction

- Collective dose target value is ***also an important element/indicator*** for the optimization of radiation protection design of nuclear power plants.

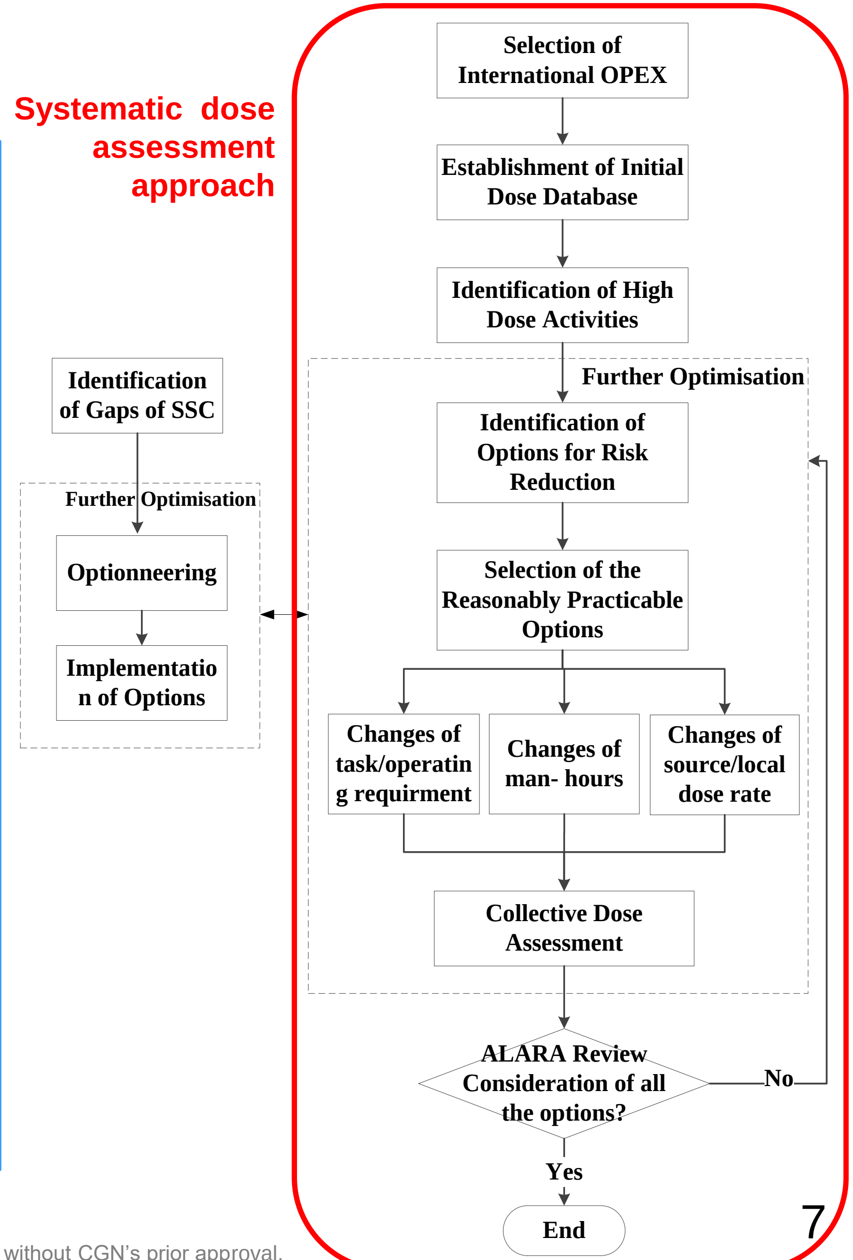
- The dedicated collective dose evaluation model for the new design reactors should be established for ALARA analysis ***(Benchmark or Baseline).***

- Based on the dose evaluation model, the ***systematic approach*** should be established and applied to evaluate all the relevant design features to achieve ALARA of the exposures ***(optimization).***

/2/ Method - *Considerations*

- **Compliance requirements** – follow the codes, standard and guidelines(China, IAEA, etc.)
- **Based on operation experience(OPEX) feedback** – adopts relevant dose data from operating plants to predict and assess the collective dose; find and use good practice….;
- **Identification of potential improvements** – shortfalls identification;
- **Prioritization of the potential improvements** - high dose tasks are higher priority**;**
- **Identification the options for dose reduction** – hierarchy of control;
- **Continuous Optimization** – initial dose, optimized dose, further optimized dose;

Systematic dose assessment approach



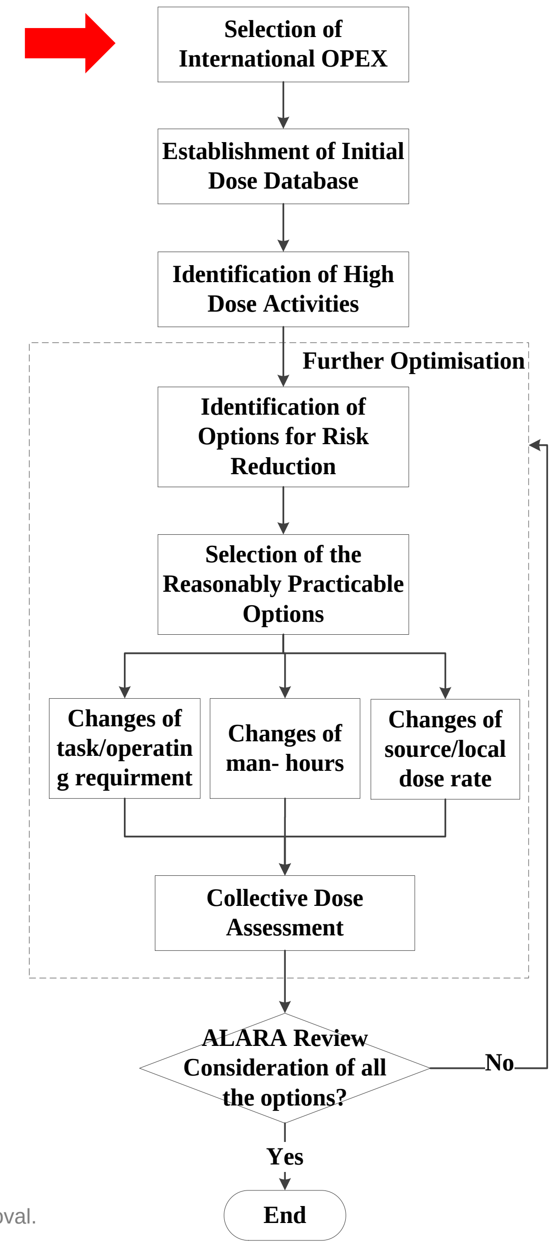
/2/ Method - *Steps and Key Points*

Step1 Selection of International OPEX

***Objective**: use to establish the initial database, help to screen in the relevant good practice.*

OPEX data mainly drawn from:

- Dose data from CGN OPEX units (M310 and CPR1000) in commercial operation in China;
- Operating experience data from NPPs around the world that has similar advanced design with HPR1000;
- Historical annual dose data for PWR plants in the world;



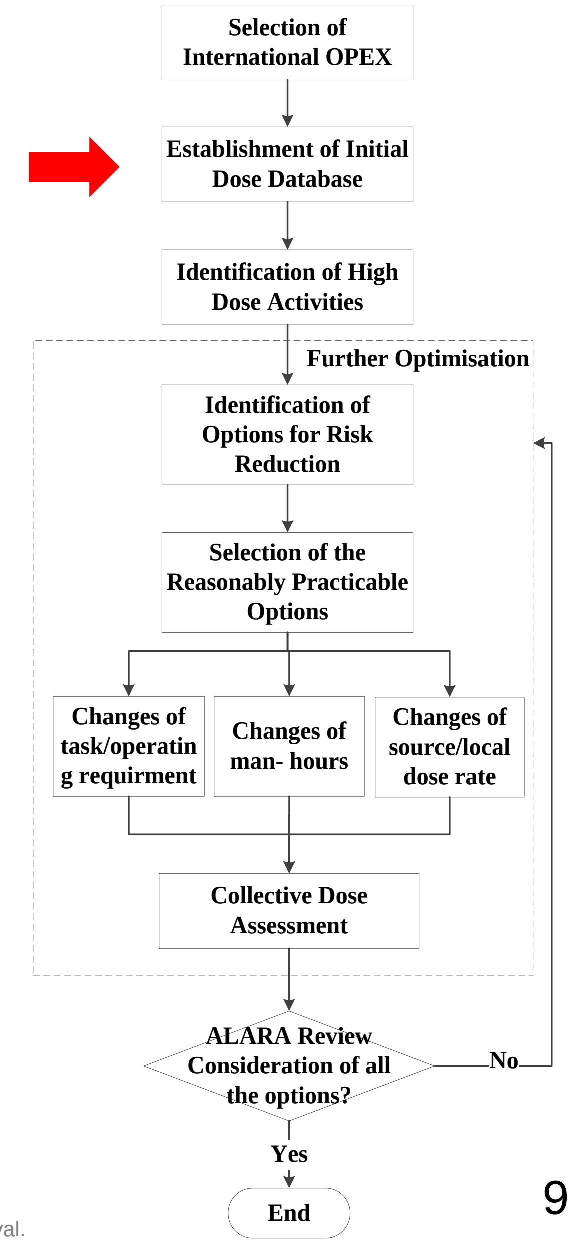
/2/ Method - *Steps and Key Points*

Step2 Establishment of Initial Dose Database

Objective: *use to identify the high-dose activities / obtain ref dose for each tasks.*

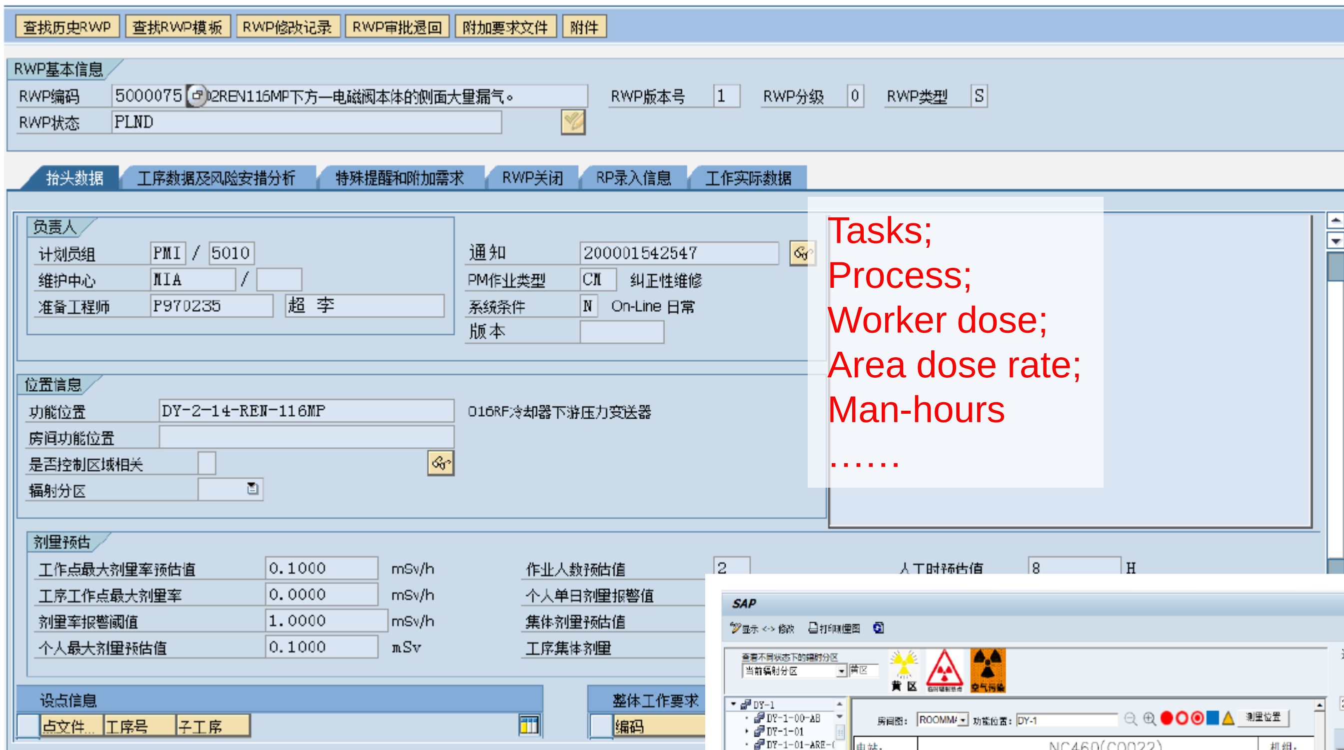
Database includes:

- Description of tasks related to dose activities;
- Exposed doses for each task;
- Exposed man-hours for each task.

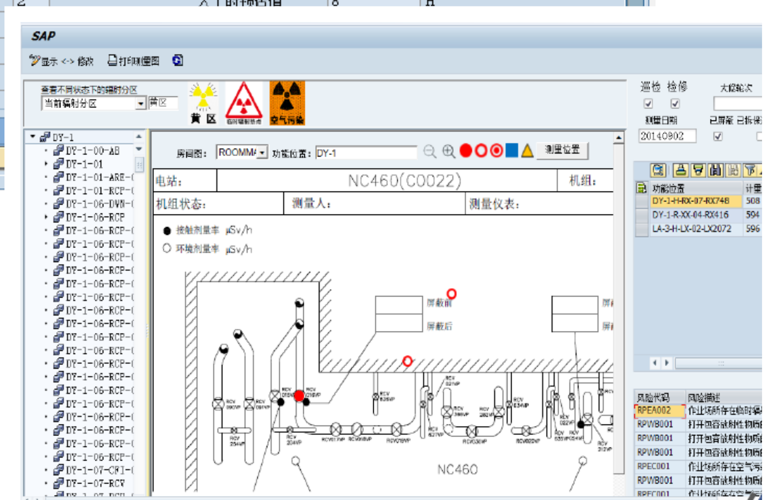


RWP：Radiation Work Permit

- **KZC**
- **TLD/WBC**
- **PDUS**
- **Work Allocation**

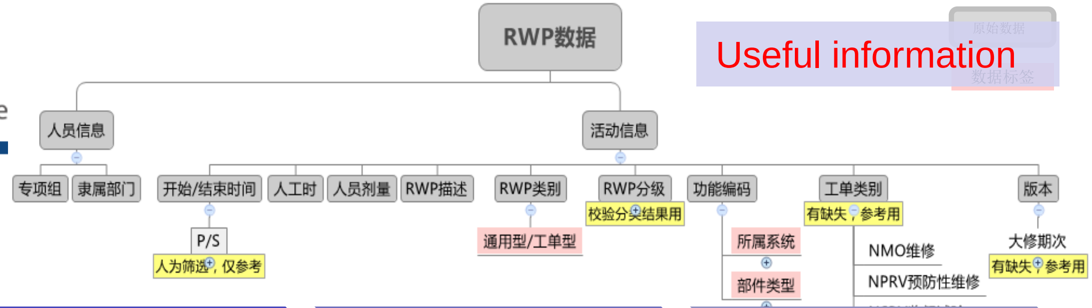


Tasks;
Process;
Worker dose;
Area dose rate;
Man-hours
……

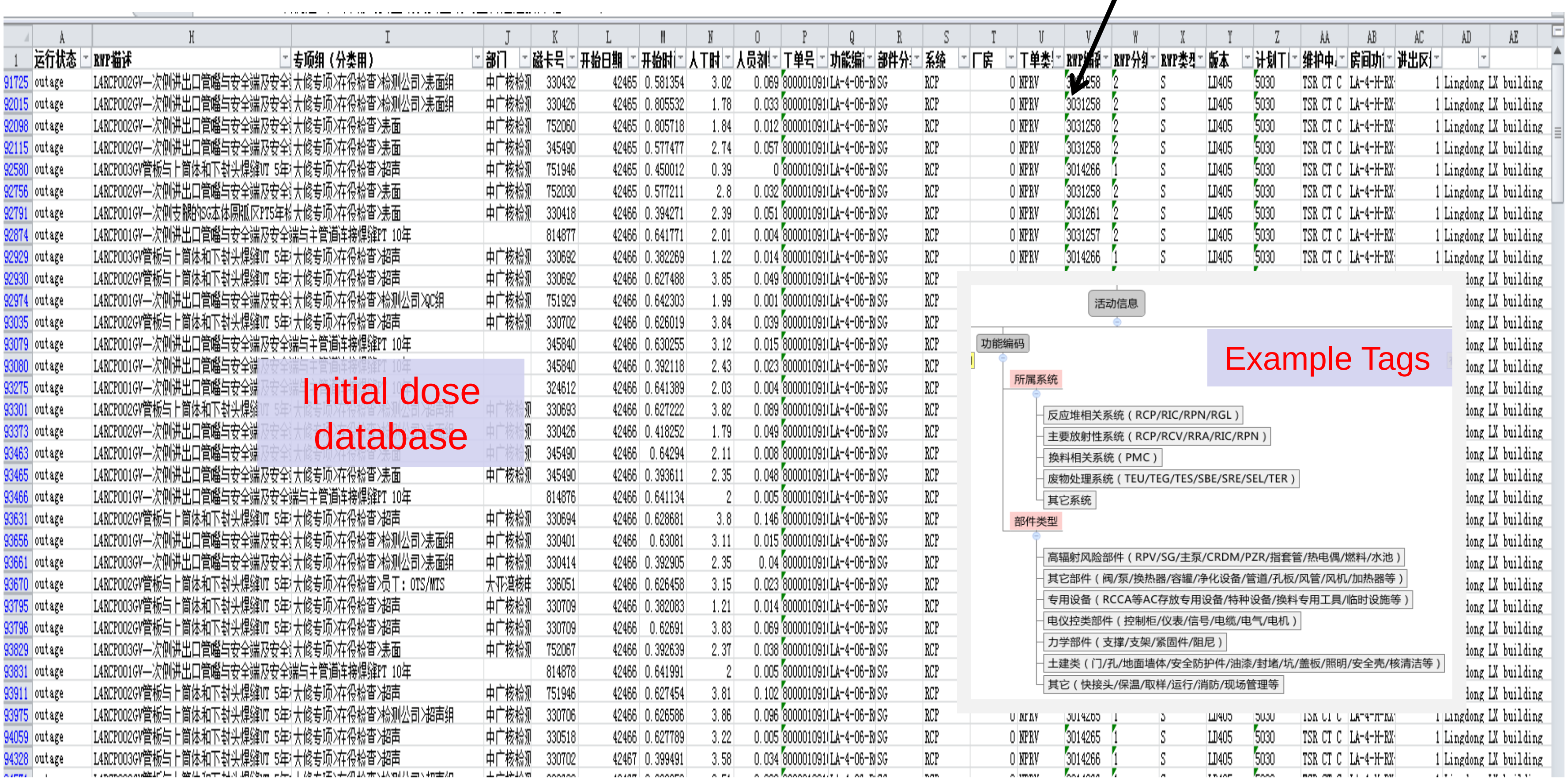


中广核 CGN Nuclear Power China Nucle

Initial Dose Database



- Collect data from RWP/PDUS
- Analyze the data
- identify the key information as category of tag
- Establish the tag
- Classify the data by activities categories



Step2 Establishment of Initial Dose Database

Initial data includes 2 parts:

Initial annual collective dose | **Initial distribution of collective dose**

① Eliminate the inapplicable data;

② Classify the data into power, NRO, ISIO, and calculate the mean value to each category data;

③ Analyse the average value in an comprehensive outage arrangement of the plant;

	Collective dose in power operation	Collective dose in NRO	Collective dose in ISIO
Statistic of collective dose	0.104 man•Sv/yr	0.609 man•Sv/outage	1.357 man•Sv/outage
A comprehensive inspective cycle including	9 years	5 outages	1 outage
Initial annual collective dose	0.594 man•Sv/yr		

NRO: normal refueling outage

ISIO: in-service inspection outage

Annual Collective dose for each plant

电厂机组	大亚湾1	大亚湾2	岭澳1	岭澳2	岭澳3	岭澳4	红沿河1	红沿河2	红沿河3	红沿河4	宁德1	宁德2	宁德3		阳江1	阳江2	阳江3	阳江4	防城港1	防城港2
1994年	0.201	0.201																		
1995年	0.990	0.990																		
1996年	0.520	0.520																		
1997年	0.750	0.750																		
1998年	0.660	0.660																		
1999年	0.670	0.670																		
2000年	0.560	0.560																		
2001年	0.680	0.680																		
2002年	0.370	0.370	0.026																	
2003年	0.920	0.920	0.761	0.761																
2004年	0.910	0.910	0.500	0.500																
2005年	0.640	0.640	0.540	0.540																
2006年	0.600	0.600	0.360	0.360																
2007年	0.530	0.530	0.620	0.620																
2008年	0.410	0.410	0.890	0.890																
2009年	0.632	0.084	0.864	0.667																
2010年	0.556	0.391	0.519	0.407																
2011年	0.060	0.933	0.859	0.534	0.701	0.004														
2012年	1.161	0.074	0.468	0.479	0.284	0.645														
2013年	0.892	0.877	1.861	1.377	0.252	0.325														
2014年	0.052	1.460	0.612	0.246	0.302	0.322	0.742	0.260												
2015年	0.990	0.045	1.285	0.334	0.312	0.285	0.347	0.671	0.008											
2016年	0.449	0.583	0.080	1.038	0.319	0.709	0.286	0.543	0.059											
2017年	0.056	0.656	0.809	0.108	0.729	0.471	0.626	0.029	0.549											

- 非自然年数据
- 12个月换料
- 18个月换料
- 意外事件
- 十年大修数据
- 商运前数据

Collective dose for each Outage

	A	B	C	D	E	F	G	H
1		大修代号	大修工期					剂量/(人·mSv)
2			解列日期	并网日期	达满功率日期	解列至并网/天	解列至满功率/天	
3								
49	46	L109	2011/1/26	2011/2/23		29		765.338
50	47	L301	2011/8/25	2011/11/14		79.03		726.124
51	48	D215	2011/10/26	2011/12/11		46		839.669
52	49	L209	2011/12/12	2012/1/10		30		560.235
53	50	L110	2012/1/21	2012/2/10		21		379.359
54	51	D115	2012/4/8	2012/6/2		[illegible]		1090.362
55	52	L401	2012/5/10	2012/7/17		68		620.477
56	53	L302	2012/8/1	2012/9/6		35.93		257.022
57	54	L210	2012/12/12	2012/12/30		19		303.318
58	55	L111	2013/1/21	2013/3/21		59		1759.747
59	56	L402	2013/3/6	2013/4/16		36.68		266.279
60	57	D216	2013/4/12	2013/5/30		48.13		828.16
61	58	L303	2013/4/30	2013/5/31		30.99		216.595
62	59	D116	2013/10/17	2013/12/10		44.93		822.678
63	60	L211	2013/11/22	2014/1/17		56.29		1428.688
64	61	L403	2014/1/15	2014/2/16		32.88		273.489
65	62	L304	2014/3/21	2014/4/19		28.98		215.918
66	63	L112	2014/5/23	2014/6/23		31.78		525.388
67	64	D217	2014/10/4	2015/1/3		91.38		1394.286
68	65	L305	2014/12/25	2015/1/31		37.51		309.233
69	66	L404	2015/2/17	2015/3/22		33.2		238.946
70	67	L212	2015/4/18	2015/5/8		19.92		267.795
71	68	D117	2015/3/10	2015/5/24		75.3		937.126

Step2 Establishment of Initial Dose Database

Initial data includes 2 parts:

Initial annual collective dose | **Initial distribution of collective dose**

Identify typical distribution of collective dose based on CPR1000 by analysing the OPEX data of the plant with relative long operation and good performance. (from RWP code)

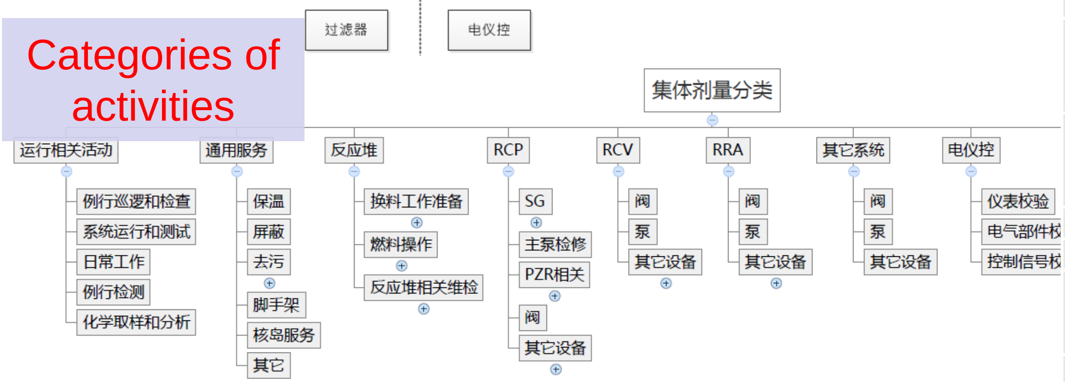
① Identify the tasks performed during normal operation;

② Classify the dose data by tasks;（*according to: radioactive risk, organisation of work*）

③ Calculate the proportion of collective dose.

Classification of activities	Percentage of each classify activity	Initial annual collective dose
Reactor operations & surveillance	17.49%	594 man•mSv/yr
Worksite logistics	18.52%	
Reactor Coolant System	12.99%	
……	……	

Collect data from RWP/PDUS → Analyze the data → identify the key information as category of tag → Establish the tag → **Classify the data by activities categories**



Initial distribution of collective dose

Classification		dose proportion
Reactor operations & surveillance		17.49%
On-site Service	Scaffolding	2.18%
	Thermal insulation	7.31%
	Decontamination	2.31%
	Shielding	1.02%
	Working support	2.42%
	Others	3.28%
Operation & maintenance related to the reactor	Prepare For Refuelling Work	6.05%
	operation related to fuel assembly	2.58%
	maintenance related to the reactor	3.33%
RCP	Steam Generator(SG)	6.40%
	Reator coolant pump	1.36%
	Pressurizer(PZR)	0.08%
	Valves	4.60%
	Other equipment	0.56%
RCV	Pump	0.20%
	Valves	4.83%
	Other equipment	1.27%
RRA	Valves	2.61%
	Pump	1.22%
	Other equipment	0.33%
Other systems	Valves	7.54%
	Pump	0.81%
	Other equipment	1.75%
Electrical, instrumentation and control		2.21%
In-service inspection		2.77%
Waste treatment	Radwaste handling	1.12%
	Radwaste system adjustments/repairs	0.21%
others		12.16%
total		100.00%

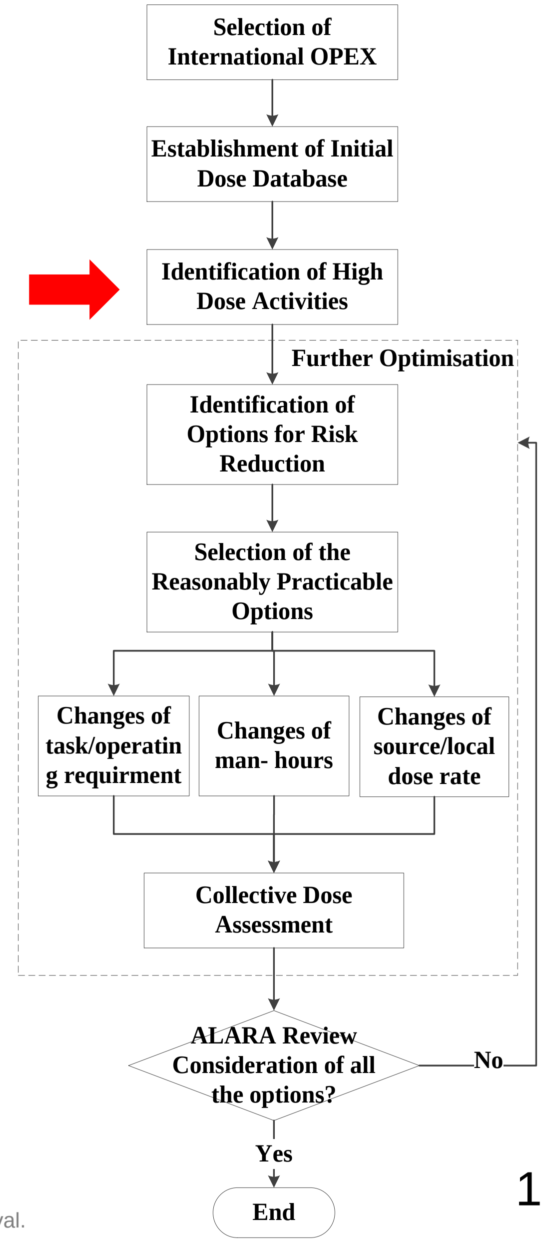
/2/ Method - *Steps and Key Points*

Step3 Identification of High Dose Activities

High dose tasks are with higher priority;

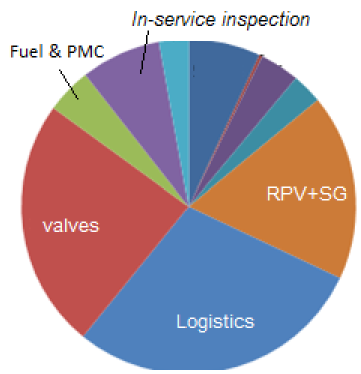
- *The single activity with high individual dose;*
- *The most exposed group activities that contribute significantly to collective dose*

Identification of high-dose activities	HPR1000	CPR 1000	HPC	NEA No.6975
Works involved SG	√	√	√	√
On-site service (including insulation)	√	√	√	√
Works involved valve inspection and maintenance	√	√	√	√
Works involved reactor pressure vessel	√	√	√	√
Waste processing	√		√	
In-service inspection	√	√	√	√



Identified high-dose activities:

- *Works involved reactor pressure vessel;*
- *Works involved steam generator;*
- *Works involved valve inspection and maintenance;*
- *In-service inspection;*
- *Waste processing;*
- *On-site service*
- *……….*

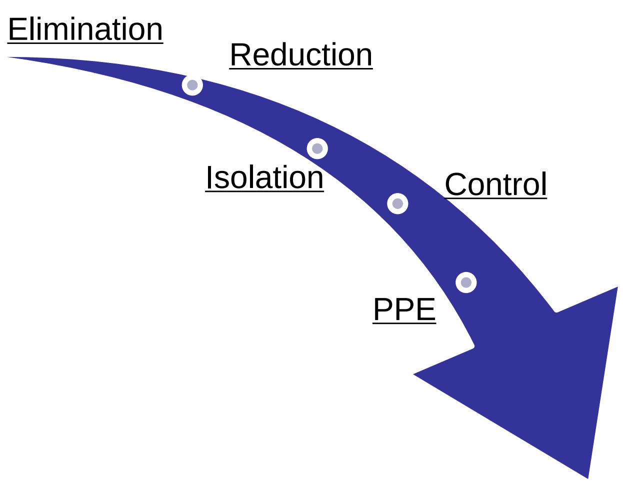


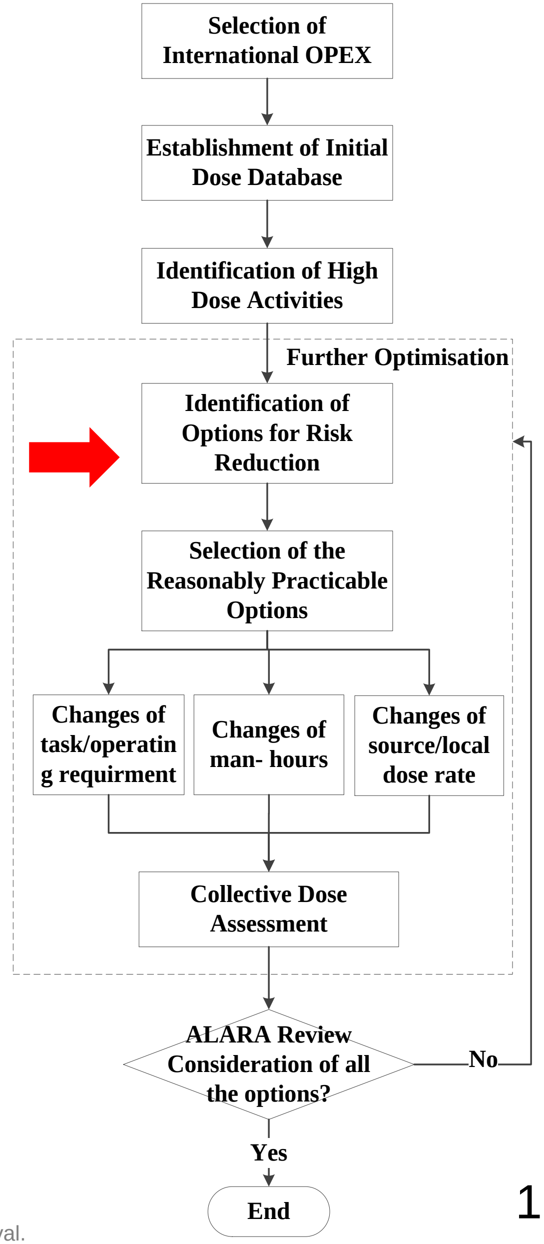
tasks	Man-hours (h)	Worker dose (mSv)	Proportion	Collective dose TOP10	Average personal dose mSv/h TOP10
SG/开关手眼孔	229.83	8.18	0.80%	4.78	0.0356
RCV/其它设备/换热器维检	287.75	9.26	0.90%	5.41	0.0322
RCP/其它设备/管道检修	429.67	11.04	1.08%	6.45	0.0257
RCV/其它设备/容控箱维检	107.47	2.66	0.26%	1.55	0.0248
SG/二次侧检查	533.53	12.49	1.22%	7.30	0.0234
在役检查/支撑和支架	323.75	7.47	0.73%	4.36	0.0231
RRA/换热器维检	139.79	3.18	0.31%	1.86	0.0227
SG/冲洗和干燥	812.13	18.32	1.78%	10.71	0.0226
通用服务/保温	3281.35	70.95	6.91%	41.46	0.0216
废物处理/放射性废物处理/工作准备	9.8	0.21	0.02%	0.12	0.0214
RCV/阀相关维检	3439.35	71.54	6.97%	41.81	0.0208
RCP/阀门相关工作	3113.17	44.79	4.36%	26.17	0.0144
其它系统/阀相关维检	8843.13	86.66	8.44%	50.64	0.0098
压力容器开关盖	6299.91	48.62	4.74%	28.41	0.0077
例行检测	15271.23	84.07	8.19%	49.13	0.0055
杂项	16017.75	38.44	3.74%	22.46	0.0024
其它工作	36994.08	65.84	6.41%	38.47	0.0018
系统运行和测试	36662.51	63.01	6.14%	36.82	0.0017
通用服务	36981.79	31.77	3.09%	18.57	0.0009

/2/ Method - *Steps and Key Points*

Step4 Identification of Options for Risk Reduction

Key point： establish an systematic method to identify the options: ***Hierarchy of control:*** *（ERIC/PPE）*





Elimination:

Eliminate the radiation sources or exposed activities to avoid the radiological risk.

- Remove the radiation source around the area of activities;
- Replace the manual tasks by fully automatic tasks; or
- Replace the near-distance operation by remote operation.

Reduction:

Reduce the source term or the frequency and duration of the dose activities.

- Optimise the material selection, surface finishes, primary coolant chemistry control and decontamination to reduce the source term;
- Optimise the process design, system design and equipment design to be more convenient and robust to reduce the frequency and duration of the operation and maintenance.

Isolation:

Isolate the radiation sources or contaminations from workers.

- Perform radiation zoning to isolate the high radiation areas from low radiation areas;
- Adopt appropriate shielding or containment to isolate the sources from workers.

Control:

Implement administrative control to avoid unauthorised entrance or spread of contamination.

- Temporary access control to avoid unauthorised entrance;
- Ventilation control to avoid spread of contamination;
- Monitoring and alarm on radiation and contamination level to avoid excessive doses.

Personal Protective Equipment (PPE):

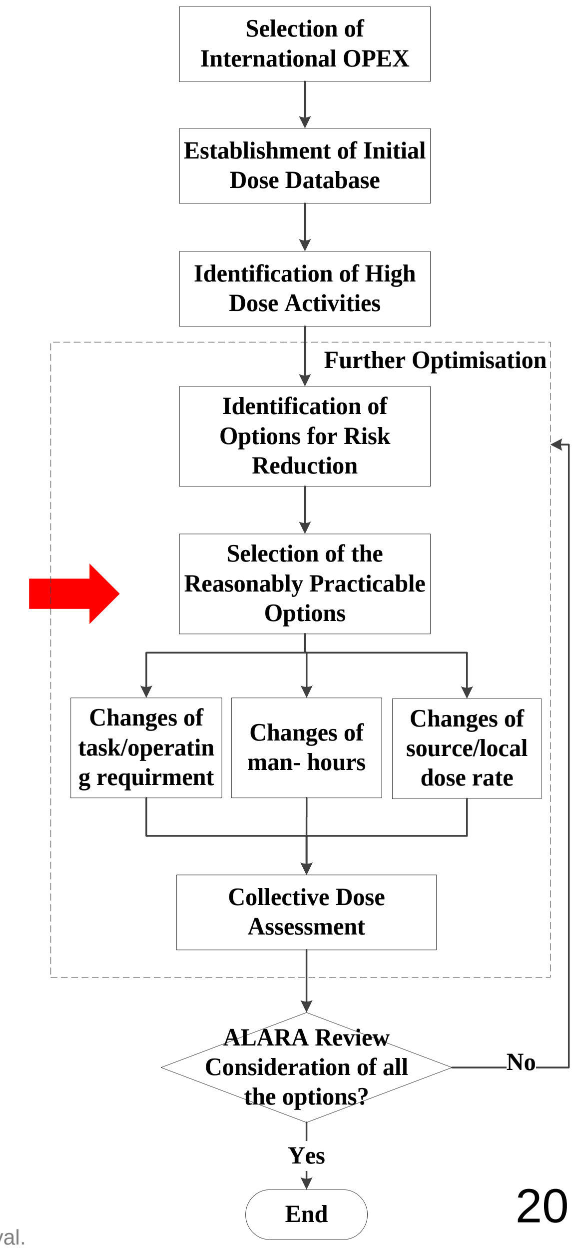
Use appropriate PPE for radiological protection.

/2/ Method *- Steps and Key Points*

Step5 Selection of the Reasonably Practicable Options

Objective： ***multi-disciplines analysis*** to help make good decision of reasonably practicable options.

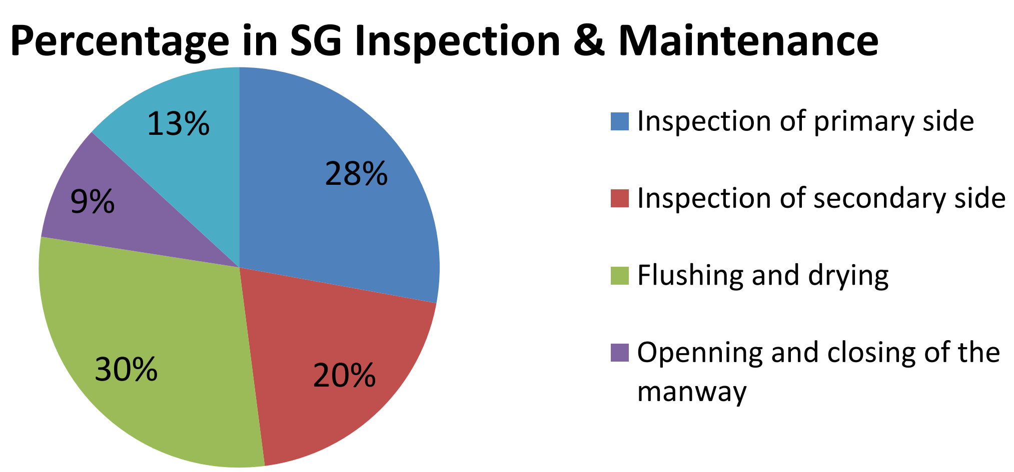
- Develop the assessment criteria and method for the potential options.
- Assess the performance of potential options against the criteria.
- Select the reasonably practicable option(s).



Example for optioneering

SG inspection and maintenance

Task	Activities	Collective Doses (man.mSv/yr/unit)	Percentages
Works involving steam generator (SG inspection and maintenance)	Inspection of primary side	10.60	28%
	Inspection of secondary side	7.65	20%
	Flushing and drying	11.22	30%
	Opening and closing of the manway	3.57	9%
	Opening and closing of the handhole and eye hole	5.01	13%



Example for optioneering

SG inspection and maintenance

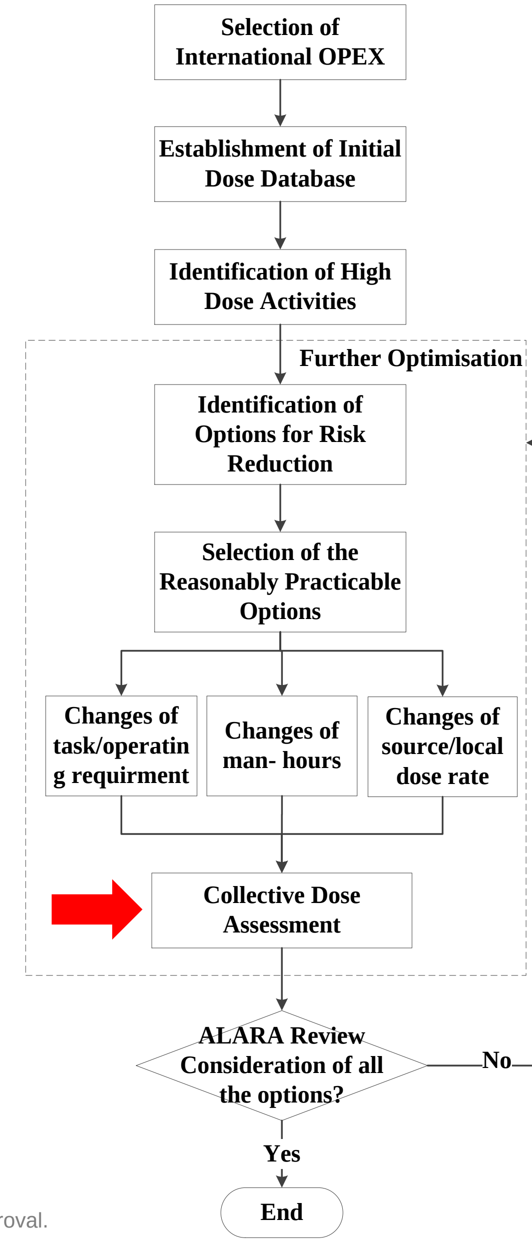
Hierarchy of control	thinking	options	Reasonable practicable options?
Elimination	-Eliminate the radioactive source?	Impossible to eliminate SG since SG is an essential equipment for PWR.	No
	-Eliminate the dose activity?	Impossible to eliminate the inspection and maintenance for SG because they are always necessary to guarantee that the SG works in expected performance.	No
Reduction	-Reduce the source term?	•Reactor chemistry Improvement on pH control and adoption of higher enriched boric acid maybe possible.	Yes
		•Material selection Reduction of the use of cobalt-based alloy, Use of the alloy with better resistance to corrosion	Yes
		•Decontamination Higher decontamination efficiency by RCV filters and demineraliser. Decontamination of SG before inspection and maintenance.	Yes
	-Reduce the duration?	•Use of sludge trap to reduce frequency of flushing and drying of SG •Use of fast assembly/disassembly tools •Use of Fast assembly/disassembly insulation •Improvement of inspection techniques •Installation of permanent platform for inspection and maintenance •More training on mock-up, etc.	Yes
Isolation	•Radiation zoning and contamination zoning •Radiation shielding		Yes
Control	•Access control to avoid unauthorized entrance •Contamination control to avoid entrance of extra radioactive contamination		Yes
Personal Protective Equipment (PPE)	•Use appropriate PPE if necessary		Yes

/2/ Method - *Steps and Key Points*

Step6 Collective dose assessment

the collective dose is assessed by :

1. Identify the improvements compared with baseline data
2. Analyse which activity are affected by the improvements
3. Evaluate the effects of specific improvement on dose (*reduce the local dose rate/ reduce the man-hours*)



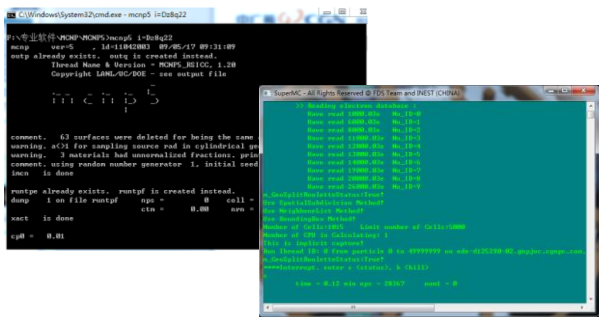
Example for dose assessment

SG inspection and maintenance

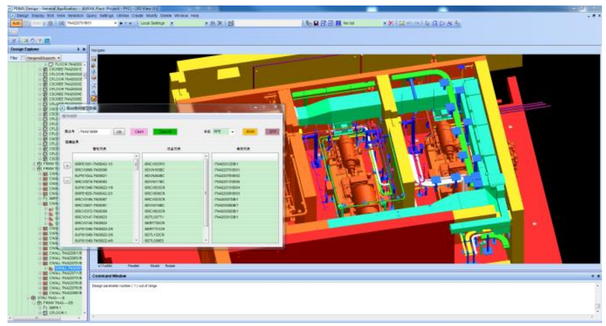
Based on optimization mentioned in the former slides, the collective dose for SG inspection and maintenance has been reduced.

Task	Activities	Collective Doses (man.mSv/yr/unit)	impacts	Optimised Collective Doses (man.mSv/yr/unit)
Works involving steam generator (SG inspection and maintenance)	Inspection of primary side	10.60	**-10.00%**	9.54
	Inspection of secondary side	7.65	**-10.07%**	6.88
	Flushing and drying	11.22	**-50.00%**	5.61
	Opening and closing of the manway	3.57	**-10.08%**	3.21
	Opening and closing of the handhole and eye hole	5.01	**-9.98%**	4.51

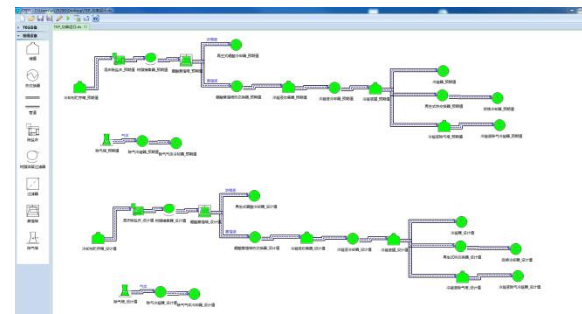
The use of radiation protection Optimization system



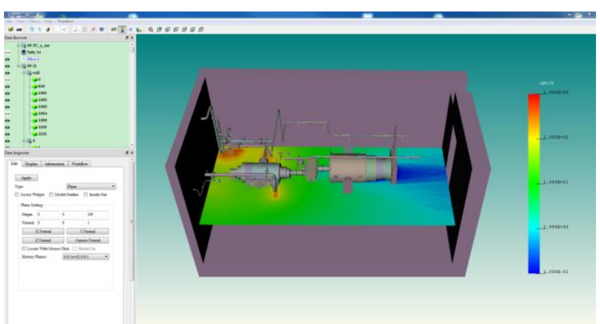
Core calculation model(MC method)



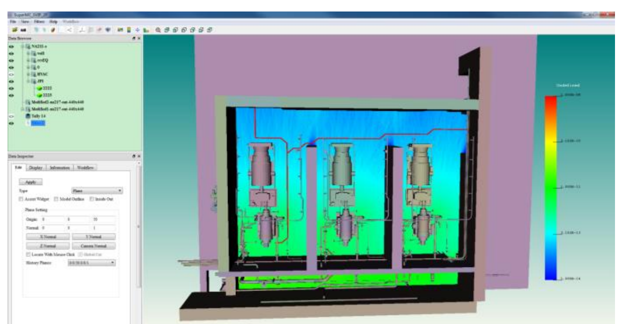
Geometry interface model



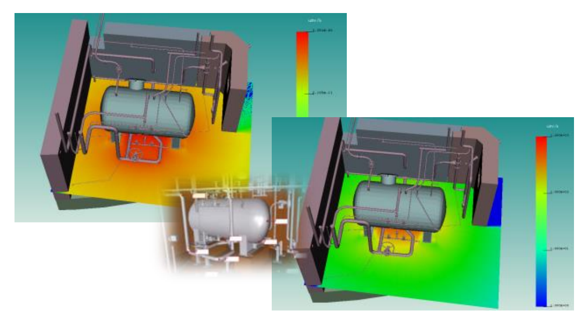
Source term interface model



Dose field Visualization model



Dose optimization model



Dose field modification model

/3/ Conclusions

/collective dose in HPR1000/

Improvement:

- source term reduction;
- Other Improvements (optimize equipment/layout/operation process design);
- ……..

Weakness:

- Valves increasing for safety design;
- ……….

In conclusion, optimized collective dose in HPR1000 ***is 565mSv/a (design value!)***;

Classification		Collective dose(man•mSv/yr)			
		Starting Point	Improvement impact for dose	Source Term Optimisation	Current Optimised Dose
Reactor operations & surveillance		103.88			
On-site Service	Scaffolding	12.97			
	Thermal insulation	43.45			
	Decontamination	13.72			
	Shielding	6.07			
	Working support	14.4			
	Others	19.46			
Operation & maintenance related to the reactor	Prepare For Refuelling Work	35.94			
	operation related to fuel assembly	15.32			
	maintenance related to the reactor	19.77			
RCP	Steam Generator(SG)	38.04			
	Reator coolant pump	8.1			
	Pressurizer(PZR)	0.47			
	Valves	27.34			
	Other equipment	3.3			
RCV	Pump	1.19			
	Valves	28.68			
	Other equipment	7.56			
RRA	Valves	15.48			
	Pump	7.24			
	Other equipment	1.95			
Other systems	Valves	44.76			
	Pump	4.81			
	Other equipment	10.4			
Electrical, instrumentation and control		13.11			
In-service inspection		16.47			
Waste treatment	Radwaste handling	6.63			
	Radwaste system adjustments/repairs	1.24			
others		72.24			
total		594			565.24

/3/ Conclusions

- *Based on the operating experience data of CGN units, this report establishes for HPR1000 and implements it to help optimize the design and reduce effectively occupational radiation exposure to workers.*
- *The preliminary evaluation of the collective dose has been completed based on the HPR1000 specific information; the high dose activities and potential options for risk reduction have also been identified.*
- *The evaluated collective dose and the identified high dose activities have been compared with the comparable stations across the world and OPEX data from CGN units proved that they are reasonable and credible.*
- *For the high dose activities, take efforts with each relevant discipline to make sure the exposure risk is ALARA.*

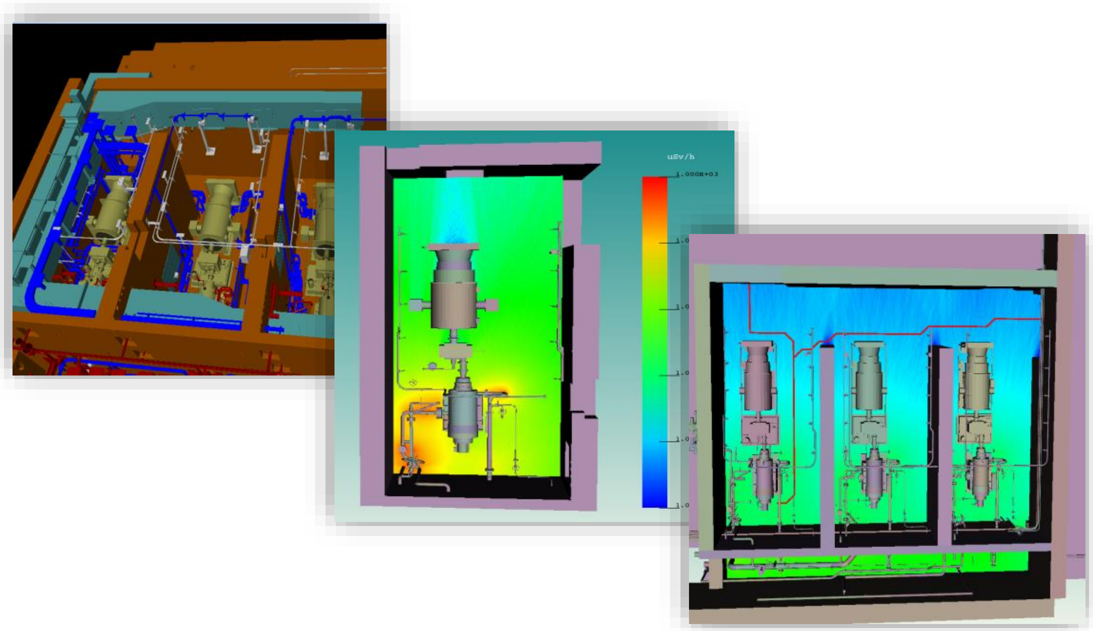
/4/ Future Works

- ***Strengthen the interaction with the utilities:***
  - Get more OPEX feedback(data, good practice, weakness….).
  - Establish standardized categories of activities with radiation risk and dose record method with the utilities(update RWP, more precise dose record…..).

- ***Better use of the model and data:***
  - ***Continuously optimize*** the categories and statistics method of the model;
  - **Auto match** the data towards the tasks/activities categorization between the model and RWP.
  - **Data mining** to find more valuable information for RP.

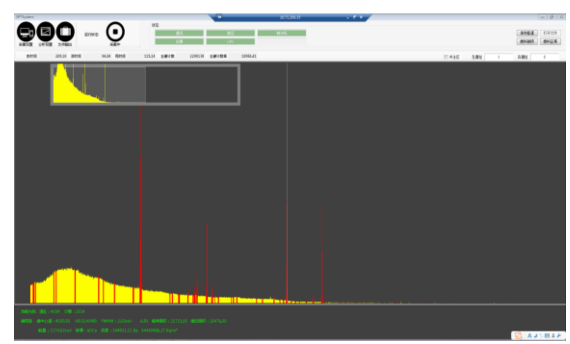
/4/ Future Works

- ***Application of new technology:***
  - Establish the link between 3-D dose field calculation and visualization system and dose management system;
  - apply the new monitoring system and device to get more information automatically.
  - ……



3-D dose field calculation and visualization system

Primary coolant real-time spectrum detector



Thanks for your attention