ANALYSIS AND DISSCUSSION OF OCCUPATIONAL INTERNAL EXPOSURE CAUSED BY RADON AT NPP

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I INTRODUCTION

Ling'ao nuclear power plant consists of 2 units 1000MW PWR type in China; while was commissioned in 2002 and designed by FAMATOME Company. It is completely sameness with adjacent Daya bay nuclear power plant in aspects of capacity, design, and so on in which commissioned in 1994.

At Ling'ao and Daya bay nuclear power plant, the case of internal exposure has always been as far as possible to avoid, which all administers regard it very important; so vast fund has been put into for the individual protection, to give worker enough training and good control. Since nuclear power plants commissioned, no one has been detected internal contamination that measured internal dose exceeding 0.25mSv caused by artificial radionuclides. But internal exposure caused by natural radionuclides which radon progeny always has been ignored. The internal exposure caused by radon progeny has been excluded occupational exposure all through. In recently, the internal exposure from radon progeny has been investigated at Ling'ao nuclear power plant. The result shows the internal exposure from radon progeny should be focused and valuably taken intervention. The effective dose by radon should be recorded in the individual dose document, which dose contribution for collective dose is not very slighting during outage.

II RADON SOURCE AND EXPOSURE TRAIT AT PWR

PWR as the type of Ling'ao nuclear power plant, the reactor containment is airproof building and close to no air exchange with outer air during one refueling cycle. Containment was built by concrete, the thickness of wall about 80-100cm, so the radon has been separated out from architectural materials constantly. During normal operation, no fresh air hardly has been supplied, just a closed circuit ventilation inside containment to take away heat by equipments produced. During period of normal operation, work staff seldom enters into containment, except for emergent maintenance. The mostly observing phase in the beginning of outage, the system EBA (containment sweeping ventilation) fail to start, but a great deal work have been carried inside containment in advance. In the phase, the end of refueling cycle, the activity of radon and radon progeny in air of containment hardly get to balance that radon release and radon progeny decay by passed 12 months. Commonly, the phase last more than two days, and total man-hour work about 500-700man-hours. Measurement result proves activity of radon keep about the scope of 4500Bq/m^3-5500Bq/m^3 inside containment atmosphere during this phase in Ling'ao nuclear power plant.

Compare with activity of artificial radio nuclides aerosol inside containment, the average activity of aerosol caused by Co-60, Co-58, and other artificial nuclides often keep less than 1Bq/m^3 in normal condition, but radon progeny always has been deducted as ambient by radiated monitor in nuclear power plant. In fact, effective internal dose from radon progeny takes major contribution more than artificial nuclides aerosol, while the following context give analysis of internal exposure caused by radon progeny.

III INTERNAL EXPOSURE ANALYSIS FROM RADON PROGENY

Radon diffuses air as form of noble gas with stable chemical quality. It decays with 3.82days half time and produces a series of progeny. Figure 1 shows these radon progeny decay with different radioactive ray including α, β, γ ray and different half time. The radionuclide ^{210}Pb in 22 years half time always has been regard final stable nuclide, other nuclide after ^{210}Pb have been considered unimportant. Currently, the research of internal exposure caused by radon progeny just has been taken care of ^{218}Po(RaA), ^{214}Pb(RaB), ^{214}Bi(RaC) and ^{214}Po(RaC'), compared with half time of radon, the activity in air of these four radionuclides easily get to balance with activity concentration of radon, and these four radio nuclides nearly deposit high concentration until same activity concentration with radon in air because of very short half time less than radon.

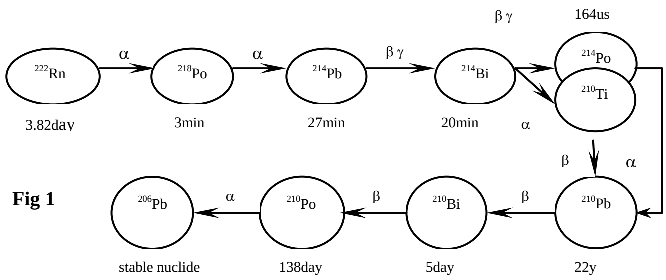


Fig 1

Research that internal exposure mostly causes by α ray from radon progeny, β and γ ray to internal exposure may be ignored. Worker often intakes radon progeny in containment, while radon progeny continuously expose in body until stable nuclide. That means radon progeny release all energy by alpha decay, which is so called alpha potential energy.

Figure 2: radon progeny alpha potential energy value

Nuclide	Sign	Radioactive type	α Energy E_j(MeV)	Half time	Atom quantity per Bq	Alpha potential energy per atom (MeV)	Alpha potential energy per Bq (MeV)
^{222}Rn	Rn	α	5.48	3.82d	4.7×10^{5}	19.2	9.1×10^{6}
^{218}Po	RaA	α	6.0	3.05min	263	13.7	3610
^{214}Pb	RaB	β, γ	/	26.8min	2315	7.7	17779
^{214}Bi	RaC	β, γ	/	19.7min	1703	7.7	13084
^{214}Po	RaC'	α	7.68	164μs	2.4×10^{-4}	7.7	1.8×10^{-3}

Figure 2, the list shows alpha potential value is different in varies radon progeny. RaA, RaB and RaC take major internal exposure contribution, so the total alpha potential energy is given by following formulas:

$$E_p = \sum_j E_p(j) N_j = \sum_j E_p(j) \frac{A_j}{\lambda_j} \qquad (3.1)$$

E_p is total alpha potential value of all radon progeny; λ_j is decay constant of nuclide j; total alpha potential value of all atom is $N_j E_p(j) = E_P(j)\, Aj/\lambda_j$.

The alpha potential energy concentration per cube meter in air is:

$$C_p = E_p / V = \sum_j C_j E_p(j) / \lambda_j \qquad (3.2)$$

C_p is alpha potential energy concentration (J/m^3); V is air volume; C_j is activity concentration of radon progeny.

To take potential energy value of RaA, RaB and RaC into formula 3.2; and change 1MeV= 1.63×10^{-13}J;

$$C_P = (0.59C_A + 2.90C_B + 2.13C_C) \times 10^{-9} \text{J/m}^3 \qquad (3.3)$$

C_A, C_B, C_C are each other part of RaA, RaB, and RaC activity concentration.

The measurement of radon at Ling'ao nuclear power plant had been carried in twice, in which on April 22. 2003 (first outage) and on May 12.2002 (mini outage that reactor operated only two months). Figure 3: radon concentration in containment building (from at 11am Apr 22.2003 to at 2pm Apr 23.2003) The red means reactor shutdown just now; the blue means reactor shutdown after 8 hours; the yellow means system EBA (containment sweeping ventilation) start that radon concentration rapidly decreases.

Figure 3

No.	Time	Humidity	Radon ambient	Count	Radon concentration (Bq/m^3)
1	9:30/Apr.22	65	2	4651	5241
2	10:00	64	2	4313	4860
3	14:30	60	8	4221	5079
4	14:50	61	8	4357	5213
5	7:20/Apr.23	60	10	2609	3038
6	7:48	59	23	2917	2917
7	10:23	58	9	884	976
8	10:40	58	9	912	1025
9	11:00	56	9	806	997
10	11:23	56	9	702	862
11	11:52	57	9	573	678
12	13:40	56	9	395	458
13	13:57	56	9	392	463

Figure 4: radon concentration in RX at mini outage at 12am May 12.2002)

Measurement point	Measurement site	Radon count	Radon concentration (Bq/m^3)
1	Annulus minus 3.4meter	7678	3378
2	Annulus 0 meter	6930	3049
3	Beside personal airlock 8 meter	10761	3946
4	Annulus 16 meter	7621	3353
5	Annulus 20 meter	6470	2847
6	Average	7174	3157

According to statistics, from reactor shutdown to system EBA in line, 482man.hours has been performed at this outage.

Radon in the airproof building follow this formula dN/dt + KST-N λ t=0 to balance.

In the dN/dt + KST-N λ t=0; N is radon activity concentration, Bq/m^3; K is release constant, Bq/cm^{2}s; S is building area, m^2; λ is decay constant; t is time change. Resolve the equation getting result: $N = KS/\lambda\ (1-e^{-\lambda t})$ (3.4)

Coefficient K relate to building materials and ventilation condition in room, and it always is given K=1.83×10^{-2} Bq/cm^{2}s without any protection measurement for radon.

Chinese national standard regulates when radon concentration get to 500Bq/m^3 at workshop, some intervention measurement should be adopted; and when radon concentration get to 1000Bq/m^3 at workshop, some intervention measurement must be adopted, even worker in this work condition is occasionally.

The measurement in figure 3 shows the average radon concentration at beginning of outage is 4385Bq/m^3. According to balance theory, radon and radon progeny have been considered getting concentration balance when air inside containment building get enough time to decay. The total alpha potential energy of radon progeny that RaA, RaB, and RaC should be calculated:

To consider radon progeny concentration $C_A=C_B=C_C$=4385 Bq/m^3 and take them into 3.3:

Alpha potential energy concentration of radon progeny in observing phase:

C_P = （0. 59C_A+2. 90C_B+2. 13C_C）×10^{-9}（J/m^3）= 2. 46×10^{-2}（mJ/m^3）(3. 5)

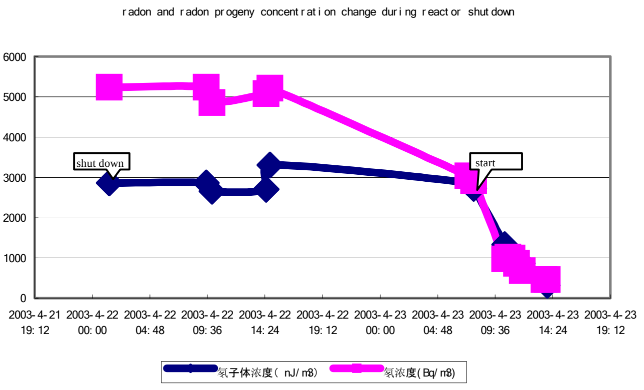
Based on the international BSS recommendation standard: change coefficient between dose rate and alpha potential energy concentration is 1.4 mSv $(mJhm^{-3})^{-1}$.

The internal exposure dose rate inside containment building in this phase:

H_E =2. 46×10^{-2}（mJ/m^3）×1. 4mSv/(mJ. h. m^{-3})=34. 4uSv/h (3. 6)

According to the result, internal dose rate caused by radon progeny is about 34.4uSv/h at this phase. Considering the scope of 500man.hour - 700man.hour under this atmosphere condition at every outage, the collective dose caused by radon is about 20man.mSv per outage. If four outages have been performed in Daya bay area, the collective dose caused by radon is about 80man.mSv.

Figure 5: radon concentration change after ventilation in containment



As mentioned analysis, internal exposure level has been determined ventilation condition. Figures 3 also show the radon concentration after ventilation, system EBA (containment sweeping ventilation) put into operation that radon concentration rapidly decreases.

Workers do maintenance work during outage under good ventilation condition, except for maintenance of containment ventilation system. The total man.hours have been recorded more than 4000man.hours during period of ventilation system maintenance at first outage in Ling'ao NPP. When the ventilation stopped; radon quickly increases to more than 500Bq/m^3 in one day. Supposed radon and radon progeny getting concentration balance (in fact, radon progeny is less than radon in few day, and balance coefficient F nearly from 0.4 to 0.8), conservatively, follow formula 3.5 and 3.6:

The collective dose reaches 16man.mSv caused by radon in one outage during ventilation system maintenance. The average internal dose rate keeps about 4uSv/h in containment without ventilation.

As above assessment, collective internal exposure caused by radon progeny is more than 36man.mSv in every outage. It takes dose contribution about 20man.mSv at beginning of reactor shutdown that EBA fail to start, and takes dose contribution more than 16man.mSv during the period ventilation system maintenance.

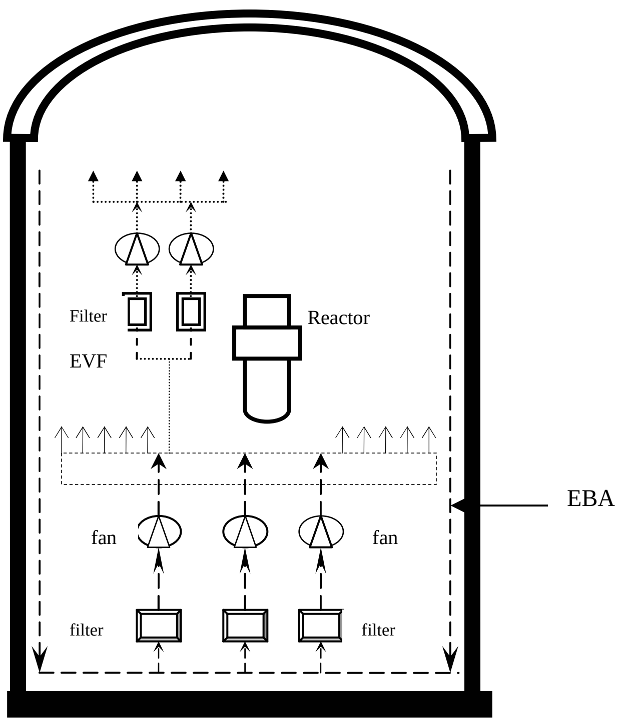
Compare the level with collective dose of common outage; Internal exposure caused by radon just takes about 5 per cent of collective dose in one outage.

According to the ALARA principle, the purpose of radiated protection that takes as low as reasonable attainable measurement to decrease personal exposure. If the intervene measurements accord with radiated protection principle, and easily realization, and cheap cost, the measurements should be adopted. The next section introduces some intervene measurement for reducing internal exposure of radon and radon progeny.

IV INTERVENTION MEASUREMENT FOR REDUCING RADON INTERNAL EXPOSURE AT NPP

As figure 6 shows, the mode of ventilation is forced to continuously close circuit ventilated during normal operation. The design original purpose that cooled air takes away heat in containment. As limit of nuclear safety and environment requirement, it is difficult to sweep ventilation for reactor during normal operation frequently, so it is difficult to reduce radon inside containment. In fact, radon progeny has mostly caused internal exposure, and radon progeny exists in air as aerosol, so some measurements for

Figure 6: ventilation condition in containment building



purifying air to decease aerosol in air are attainable.

The flow of closed circuit design 185000m^3/h by fan (figure 6) inside containment, and the volume of containment are about 50000m^3/h. That means ventilation cycle more than 3.7 times per hour inside containment building. A bulk of air can be purified by filter at front of fan about 16 minutes.

The simple filter in front of fan filtrate particle, and the original design purpose is to protect fan. This design may be good utilized for reducing radon progeny, to replace simple filter with absolutely filter or effective filter. The massive radon progeny would be constantly adsorbed by filter at the form of internal closed circuit, and radon progeny concentration quickly decrease to quite low level, though the radon concentration has no any change.

The above way is very simple and attainable to reducing radon progeny, but maintenance of absolutely filter more trouble that use time is short and periodic test must be performed and filter change only be arranged in outage. So effective filter has been widely recommended to install.

Figure 7: radon progeny alpha potential energy value concentration after intervention action

Measurement point	Measurement site	Radon progeny count	Radon concentration (nJ/m^3)
1	Annulus minus 3.4meter	1473	2860
2	Annulus 0 meter	1368	2656
3	Beside personal airlock 8 meter	1302	2702
4	Annulus 16 meter	1590	3303
5	Annulus 20 meter	1384	2869
6	Average	1423	**2878***

The measurement had been performed after intervention action in Ling'ao nuclear power plant.

Compare the value (figure 7) with 3.5, the alpha potential energy value of radon progeny decrease from $2.46\times10^{-2}mJ/m^3$ to $2.88\times10^{-3}mJ/m^3$ and internal exposure dose rate from 34.4uSv/h to 4.03uSv/h after adopted intervention action. The radon progeny exposure is less about 10 times than before.

The discussion above, the intervention had been adopted when ventilation system operate. The internal closed circuit can be utilized to adsorb radon progeny. If ventilation system is out of service, which means this measurement cannot be utilized. The paragraph mentioned before, maintenance of ventilation systems only has been arranged at outage. In the condition, to reasonable arrange ventilation maintenance and shorten maintenance time is effective way to avoid deposit of radon progeny. And design system EVF may be utilized to reducing radon progeny.

System EVF (figure 6) is designed to purify air inside containment. EVF is made up of fans, absolute filter and iodine filter, and original design purpose that filtrate artificial radionuclide aerosol and iodine while high activity in containment air. According to this function of absolute filter, to start EVF during other ventilation systems in maintenance can avoid deposit of radon progeny.

In fact, the continuous monitoring detector for radon may be set in containment during outage. The reasonable alarm threshold can be set. If monitor shows radon progeny reach the level that should be considered to intervene, EVF would be operated to adsorb radon progeny and to reduce radon exposure.

V CONCLUSION

The assessment of radon exposure indicates internal exposure level caused by natural radionuclide at NPP. Investigation result shows radon has valuable been monitored and focused during outage and some special condition. Compare radon concentration at NPP with international standard, 500-1000Bq/m^3 often should be considered to adopt intervention action in workshop. Though dose contribution takes few than collective dose in nuclear power plant, it yet is most one of source of internal exposure.

Because external exposure takes most contribution in nuclear power plant, excessive protection and devotion has not been suggested to measure for reducing radon exposure. The simple measurement and system design function should be best utilized as possible as recommended in paragraph 4 to avoid radon exposure. The concept accords with ALARA principle.

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