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GUIDELINES FOR INTERPRETING POST-ACCIDENT SAMPLING RESULTS TO ESTIMATE REACTOR CORE DAMAGE

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PC-25.4

GUIDELINES FOR INTERPRETING POST-ACCIDENT SAMPLING RESULTS TO ESTIMATE REACTOR CORE DAMAGE

1.Ø **PURPOSE:**

1.1 This procedure provides guidelines for the preliminary assessment of reactor core damage based upon post-accident sampling results or other radiological indications.

1.2 Certain reactor transients could result in fuel cladding damage, fuel overheating or potential fuel melting. One or more of these conditions would involve the release of radionuclides into the primary coolant, followed by possible transfer to auxiliary systems and the containment atmosphere.

1.3 By examining the magnitude of radioactivity increases in a post-accident condition, as well as confirming the presence or absence of certain groups of radionuclides, an early assessment of core damage can be performed.

2.Ø **REFERENCES:**

2.1 Procedure PC-23.1, PC-23.2, PC-25.2, PC-4, PC-5

2.2 Procedure P-9

2.3 Procedure S-14.2, S-14.3

2.4 Procedure SC-1ØØ

2.5 NUREG-Ø737, II.B.3

2.6 Westinghouse Mitigating Core Damage Training Manual

2.7 Rogovin Report, Part 2, Volume II, pp 524 - 527

2.8 WASH-14ØØ Appendix VII

3.Ø **PRINCIPLE:**

3.1 Gross indicators of radioactivity concentration (letdown monitor, containment area and airborne monitors) will provide early information on the severity of core damage following a transient. When later primary coolant and containment samples are collected and analyzed, measured concentrations of radionuclides can be examined to determine the extent of total available activity that has been released to the RCS Auxiliary systems. Certain radionuclides will tend not to be released unless fuel overheating or melting occurs. Thus the absence of these species will bound the maximum extent of core damage. The determination of certain isotope ratios may also help distinguish whether released activity originated in the gap or from overheated fuel.

4.Ø **PREREQUISITES AND NEEDED EQUIPMENT:**

4.1 Isotopic analysis of primary liquids.

4.2 Data from plant radiation monitors.

4.3 Plant operational status including pertinent core data.

4.4 Isotopic analysis of containment atmosphere.

5.Ø **PRECAUTIONS AND LIMIT VALUES:**

5.1 Care should be taken to avoid defining too precisely the extent of core damage based upon initial sampling results. Other plant indicators will also be available (such as incore temperature indication, containment hydrogen monitors, etc.) which should also be considered in arriving at a more refined estimate.

5.2 The time of sampling relative to the suspected transient or core degradation sequence must be considered. The effects of isotope decay, sampling equilibrium and progressing core degradation may tend to confound sample interpretation.

5.3 Reactor power history is to be considered in determining whether certain key radionuclides have reached equilibrium.

5.4 Measured concentration of radioactivity may need to be adjusted to account for system dilution (e.g. accumulators, safety injection water) prior to estimating fuel damage.

6.Ø **INSTRUCTIONS:**

6.1 Indication of RCS Abnormal Conditions

6.1.1 There are various instruments which will indicate to the plant operator if abnormal conditions exist in the RCS which could contribute to fuel failure. This instrumentation would include indication of coolant temperature, pressure; subcooling and water inventory (if available). Plant operating and emergency procedures provide detailed instruction on how the instrumentation is to be used.

6.1.2 Post-accident analysis of these parameters should determine whether voiding of the RCS occurred, or more specifically, whether any part of the core was uncovered at any time. Special attention should be paid to core exit thermocouple temperatures and core water level indications. If the core remained covered, fuel damage should be limited to gap releases from cladding defects. However, if the core was uncovered, it becomes more probable that extensive cladding oxidation could have occurred leading to cladding and fuel pellet fragmentation.

6.2 Gross Radioactivity Indications

6.2.1 Letdown Monitor R-9

6.2.1.1 If letdown has not been isolated, monitor R-9 will provide a gross indication of current primary coolant activity. Refer to procedures P-9 and SC-100. A reading of 2000 mR/hr on monitor R-9 will correspond to approximately 1% fuel rod cladding defects. The monitor's upper range, 10,000 mR/hr, may therefore be assumed to correspond to about 5% cladding defects.

6.2.1.2 Containment Airborne Monitors R-11, R-12

6.2.1.2.1 Primary coolant system leakage results in the release of noble gas and radioactive particulates into the containment atmosphere. An increase in primary coolant activity and/or system leakage will be indicated on containment monitors R-11 and R-12. Refer to procedures P-9 and S-14.2.

6.2.2 Containment Area Monitors R-2, R-29 and R-30

6.2.2.1 An increase in the direct radiation readings of the containment area monitors will also indicate abnormal primary coolant activity and/or leakage conditions in the containment building. Refer to procedures P-9 and S-14.3. Procedure S-14.3 provides a series of curves showing monitor dose rate versus time

6.2.2.1 (Cont'd)

after shutdown. The curves have been calculated for various accident categories including postulated gap activity release, coolant release, and fuel inventory release. The procedure also provides tables of estimated isotopic activities which correspond to the accident categories considered.

6.2.3 Primary Coolant and Containment Atmosphere Samples

6.2.3.1 The previous indications may show that a substantial release of radioactivity has occurred from an accident condition. Undiluted samples may read several orders of magnitude higher than under normal conditions. Extreme precautions are required in sample collection, handling and analysis to minimize potentially severe radiological hazards that may exist.

6.3 Release of Fuel Rod Gap Activity

6.3.1 Table 1 provides escape fractions (EF) for various categories of radionuclides which may be assumed in determining the degree of ruptured fuel rod damage. The table also indicates the associated uncertainties for each radionuclide category.

6.3.2 Table 2 gives the calculated reactor core inventories (NI) of various radionuclides based upon 1520 MWT.

6.3.3 The following equation is used to estimate the failed fuel rod fraction based upon the measured sample concentration of a given category of radionuclide:

$$FF = \frac{(CA)\ (V)}{(NI)\ (EF)}$$

Where: CA = coolant activity (uCi/g)
V = coolant mass (1.18×10^8 g)
NI = nuclide inventory (Table 2)
EF = escape fraction (Table 1)

6.3.4 Analytical results indicating only noble gas, iodines and cesium isotopes will suggest that only a release of gap activity has occurred. Radionuclides such as strontium, barium and tellerium would not be significant contributors to coolant activity in this situation because of much lower escape fractions.

6.3.5 For a given fraction of failed fuel (e.g. 10%), the initial degassed activity will be mainly comprised of radioiodines (at T=0 hr). The initial activity contribution due to cesium may be small compared to the iodine activity.

6.3.6 For perspective, assuming 10% failed fuel defects, the initial gas and degassed activities are calculated to be approximately 10^4 times higher than normal activity levels. Activity levels will drop substantially (factor of 2 to 3) during the first day due to the decay of short-lived noble gas and iodine isotopes.

6.4 Evidence of Fuel Overheating

6.4.1 Potential fuel overheating may be suggested if the actual primary coolant activity cannot be accounted for by assuming 100% release of gap activity; or, if certain radionuclides are detected which are indicators of fuel pellet overheating.

6.4.2 Under conditions of fuel overheating, radionuclides such as strontium, barium and tellerium would be released from the fuel to a greater extent than predicted from the escape fractions given in Table 1.

6.5 Evidence of Fuel Melting

6.5.1 Post-accident samples which display extremely high activity or a greater presence of normally less volatile radionuclides, may indicate that partial fuel melting has occurred in addition to clad damage.

6.5.2 Table 3 provides estimated escape fraction for various radionuclide categories, assuming fuel melting conditions. The percent of fuel melted can then be estimated using the same equation given in step 6.2.3.

6.5.3 For a given fraction of melted fuel (e.g. 10%) the initial degassed activity will be largely due to radioiodine. However, the presence of strontium activity is likely to be detected following radioiodine decay, and is calculated to be more predominant than cesium activity under fuel melt conditions.

6.5.4 For perspective, assuming 10% melted fuel, the initial gross gas is calculated to increase approximately a factor of 10^6 over normal levels. The gross degassed activity may increase as much as 10^5 to 10^6.

6.5.5 Detailed sample isotopic analysis may also indicate the presence of noble metals (Ru, Rh, Pd, Mo, Tc), rare earths and actinides (U, Pu) and other refractory materials which would also confirm extensive fuel damage.

TABLE 1

GAP RELEASE COMPONENT VALUES

Fission Product Species	Gap Release Fraction	Gap Escape Fraction	Total Gap Release/Escape Value
Xe, Kr	Ø.Ø3[a]	1	Ø.Ø3
I-Br	Ø.Ø5[a]	1/3[c]	Ø.Ø17
Cs, Rb	Ø.15[b]	1/3[c]	Ø.Ø5
Sr, Ba	Ø.Ø1[a]	$1Ø^{-4}$[d]	Ø.ØØØØØ1
Te, Se, Sb	Ø.1Ø[a]	$1Ø^{-3}$[d]	Ø.ØØØ1
Others			Negligible[e]

(a) Values can be higher or lower by a factor of 4
(b) Values can be higher by a factor of 2 or lower by a factor of 4
(c) Values can be higher or lower by a factor of 3
(d) Values can be higher or lower by a factor of 1ØØ
(e) While no numerical value was developed for these various species, the number should not exceed that used for strontium-barium.

Reference: WASH-14ØØ, Appendix VII

TABLE 2

TOTAL INVENTORY OF SELECTED RADIONUCLIDES IN THE NUCLEAR REACTOR CORE AT THE TIME OF THE HYPOTHETICAL ACCIDENT

RADIONUCLIDE	RADIOACTIVE INVENTORY SOURCE (curies)	HALF-LIFE (days)
Cobalt-58	3.7×10^{5}	71.0
Cobalt-60	1.4×10^{5}	1,920
Krypton-85*	2.7×10^{5}	3,950
Krypton-85m	1.2×10^{7}	0.183
Krypton-87	2.3×10^{7}	0.0528
Krypton-88	3.2×10^{7}	0.117
Rubidium-86	1.3×10^{4}	18.7
Strontium-89	4.5×10^{7}	52.1
Strontium-90*	1.8×10^{6}	11,030
Strontium-91	5.2×10^{7}	0.403
Yttrium-90	1.8×10^{6}	2.67
Yttrium-91	5.8×10^{7}	59.0
Zirconium-95	7.3×10^{7}	65.2
Nobium-95	7.3×10^{7}	35.0
Molybdenum-99*	7.9×10^{7}	2.8
Technetium-99m	6.8×10^{7}	0.25
Ruthenium-103	5.2×10^{7}	39.5
Ruthenium-106	1.2×10^{7}	366
Tellurium-127	2.8×10^{6}	0.391
Tellurium-127m	5.2×10^{5}	109
Tellurium-129	1.5×10^{7}	0.048
Tellurium-129m	2.5×10^{6}	0.340
Tellurium-131m	6.3×10^{6}	1.25
Tellurium-132	5.8×10^{7}	3.25
Iodine-131*	4.0×10^{7}	8.05
Iodine-132	5.8×10^{7}	0.0958
Iodine-133*	7.9×10^{7}	0.875
Iodine-134	8.9×10^{7}	0.0366
Iodine-135	7.3×10^{7}	0.280
Xenon-133*	7.9×10^{7}	5.28
Xenon-135	1.6×10^{7}	0.384
Cesium-134*	3.6×10^{6}	750
Cesium-136	1.4×10^{6}	13.0
Cesium-137*	2.3×10^{6}	11,000
Barium-140	7.9×10^{7}	12.8
Lanthanum-140	7.9×10^{7}	1.67
Cerium-141	7.3×10^{7}	32.3
Cerium-143	6.3×10^{7}	1.38
Cerium-144	4.0×10^{7}	284
Praseodymium-143	6.3×10^{7}	13.7

* These are the most significant nuclides.

TABLE 3

MELTDOWN ESCAPE FRACTION VALUES

ELEMENTS	RELEASE RANGE (percent)	BEST ESTIMATE (percent)
Xe, Kr	50-100	90
I, Br	50-100	90
Cs, Rb	40-90	80
Te[a]	5-25	15
Ba, Sr	2-20	10
Noble Metals[b]	1-10	3
Rare Earths[c]	.01-1	0.3
Zr, Nb	.01-1	0.3

Reference: WASH-1400, Appendix VII