MOCK-UP FUEL FOR USE IN TESTING CONSOLIDATION EQUIPMENT[a]

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ABSTRACT

Via its Prototypical Consolidation Demonstration Program (PCDP), the Department of Energy is developing fuel consolidation equipment to reduce the storage volume required in national storage facilities, e.g., the Geologic Repositories (1). In 1989 the equipment will be ready for testing at the Idaho National Engineering Laboratory, using "hot" spent commercial fuel assemblies obtained from utilities. Before the hot testing, however, the equipment must undergo extensive cold tests to prove its readiness. This paper explores some of the goals foreseen for the equipment cold test, and focuses on the necessary features for the mock-up fuel to assure that cold test objectives are met. The better the mock-up fuel simulates actual spent fuel, the more accurate the equipment assessment will be.

INTRODUCTION

Specification of mock-up fuel seems a relatively simple task until some of the implications are considered. For example, if the mock-up fuel doesn't adequately represent actual spent fuel behavior during consolidation cold tests, the equipment evaluation and selection may be distorted. During the Hot Demonstration, expensive and difficult problems could develop which were not predicted by the cold tests. It is therefore important that the mock-up fuel represent actual spent fuel characteristics, including normal amounts of crud deposits, irradiated material properties, and rod bowing, collapsing, and length increase. Off-normal spent fuel characteristics such as torn spacer grids and rods with swollen or ruptured clad, or loose end caps, must be simulated to allow evaluation of equipment recovery capabilities, and to prepare for possible off-normal events during the Hot Demonstration. Mock-up fuel specifications are currently being written, with procurement packages (RFPs) anticipated for release in June of 1987.

CONSOLIDATION EQUIPMENT COLD TESTS

The primary role of the mock-up fuel will be to allow cold testing of consolidation equipment. To select mock-up fuel features, it is therefore necessary to understand the objectives of the cold tests. These objectives are presently defined to be:

a. To prove feasibility of the general consolidation concept, i.e., dry environment, horizontal position, remote operation, rod consolidation ratios, and canister sizes.

b. To allow evaluation of the PCDP consolidation equipment, i.e., ease and speed of operation, flexibility in handling different types of fuel with various fuel defects, adequate recovery from off-normal events, data acquisition capabilities, and consolidation ratio attained. To meet this objective, aspects of the equipment will be tested which won't be tested at any other stage, i.e., off-normal recovery, and flexibility regarding fuel types.

c. To prepare for the Hot Demonstration, i.e., to verify that all equipment components work well together and function efficiently as a system, to allow equipment adjustment or minor redesign, and to confirm adequate utility interfaces and fixtures are available for fuel and equipment handling.

The cold test objectives do not include proof of equipment long-run reliability, or non-fuel bearing component (NFBC) volume reduction demonstrations. Therefore mock-up fuel requirements need not address these aspects.

PCDP plans include up to two competing firms that will design and build consolidation equipment and perform cold tests for equipment evaluation. These cold tests will be conducted separately, during the same time frame, at the two contractors' facilities. Enough mock-up fuel must be obtained to support this double cold test concept. Based on these cold tests, one of the contractors will be selected to continue on with Hot Demonstration at the INEL.

The mock-up fuel must also serve to confirm adequacy of INEL interfacing equipment and to provide a "system checkout" of the consolidation equipment after it has been dismantled, shipped to the INEL, and reassembled in preparation for the Hot Demonstration. Also, training on the consolidation equipment will be performed with the mock-up fuel prior to going hot.

TYPES OF FUEL

One of the biggest challenges facing the PCDP consolidation equipment designers will be to produce equipment which can accommodate all major U.S. commercial LWR fuel types. However, only a few common types of nondefective PWR and BWR spent fuel will be used to test the equipment in the Hot Demonstration. It is therefore desirable that the mock-up fuel represent not only those fuel types which will be used in the Hot Demonstration, but also other common fuel types which will be undergoing consolidation in the future and which have unique features which may challenge the consolidation equipment. Based on these

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reasons, it is anticipated that mock-up assemblies will represent the following fuels for PCDP cold tests:

PWR

WE 15 x 15 (Westinghouse)
WE 17 x 17
BW 15 x 15 (Babcock & Wilcox)
CE 14 x 14 (Combustion Engineering)

BWR

GE 8 x 8 (General Electric)

The WE 15 x 15, BW 15 x 15, and GE 8 x 8 fuels are proposed for the Hot Demonstration (2), and hence must be mocked up for the cold tests. Mock-ups of the WE 17 x 17 and CE 14 x 14 are also anticipated for the cold tests for the following reasons:

Table I (3) provides estimated amounts of fuel assemblies for U.S. operating and planned commercial reactors to the year 2020. The WE 17 x 17 is not planned for Hot Demonstration but is a good choice for cold testing, as it will be by far the most dominant PWR fuel type of the future. CE type fuel will also comprise a significant share of the PWR spent fuel inventory, holding about 17% through the year 2020. Of the CE fuels, the CE 14 x 14 is currently the most predominant.

Predominance in the spent fuel inventories is not the only reason for proposing to mock-up the WE 17 x 17 and CE 14 x 14. These fuel types also display many dimensional extremes which could impact consolidation equipment performance. For sake of comparison, Table II (4) shows dimensions and materials of the most common PWR fuels, including the planned Hot Demonstration fuels, plus several other popular fuel types. Note that the WE 17 x 17 and the CE 14 x 14 have many of the extremes from among the fuel dimensions, including parameters that will likely impact the consolidation process (e.g., maximum and minimum numbers of fuel rods, rod pitches, rod diameters, minimum space between rods, numbers of guide tubes, and tube thicknesses).

No BWR type fuel other than the GE 8 x 8 is planned for mock-up. The GE 8 x 8 will sufficiently represent all current BWR fuel due to its large predominance and because most other types are similar to it. The next most popular BWR type is the GE 7 x 7, not recommended for mock-up because it is so similar to the 8 x 8 that it would be redundant. It is shown in Table III (4) along with the GE 8 x 8 to allow comparison.

NORMAL SPENT FUEL SIMULATION

Mock-up fuel procurement must proceed even though the specific consolidation equipment design (and its inherent sensitivities to fuel parameters) is unknown at this point. Therefore the mock-up fuel should include all possible features that might impact the consolidation process. Dimensions of actual, unirradiated fuel assemblies are listed in Tables II and III, and for the most part these dimensions must be duplicated. But during irradiation many of the dimensions are changed. Therefore some of the mock-up fuel must represent not only the envelope, dimensions, and weight of a fuel assembly, but also various characteristics of spent fuel, e.g., bowed and lengthened rods, crud deposits, twisted or bowed assemblies, and material properties of irradiated metals. Modified features to allow repeated insertion of rods into skeletons for rod extraction testing and to allow replacement of components destroyed during repeated destructive cold tests will also require dimensional inconsistencies from the manufacturer's norm. On the other hand, a few of the mock-up assemblies will exhibit no differences at all from a manufacturer's new assembly, so that the consolidation equipment performance can be judged in regard to sensitivity to the various spent fuel characteristics.

Bowed Rods (5)

Rod bowing occurs to some extent in most spent fuel assemblies. The amount of bow may not show up until the rod is removed from the assembly; otherwise the spacer grids restrain the rod so the bow may not be visible. The amount of rod bow usually varies across the core, with those fuel assemblies which have experienced higher burnup yielding rods with greater amount of bow. Because fuel rods are long and slender, speculation is that they are flexible enough so that rod bowing will not be a serious problem for consolidation. However, since many fuel assemblies have bowed rods and the equipment must be able to extract and pack them, the mock-up fuel must also represent this phenomenon.

Lengthened Rods (5)

Fuel rods often grow in length during irradiation. The amount of length increase varies from rod to rod, and a single fuel assembly may contain rods representing the whole spectrum of length increase, from none to about 4 cm (1.5 in.). Since the increase in rod length is a common phenomenon which could easily impact the consolidation process (i.e., end box removal and rod gripping procedures), it must be represented by the mock-up fuel.

Collapsed Rods (6)

Some older fuels (without prepressurized rods) have experienced collapsed rods, which caused problems for certain previous consolidation experiments. In such a fuel assembly, rod collapse generally occurs in a few rods located around the guide tubes. Because the phenomenon occurs on inside rods without breaching the clad, it is often not detectable until the fuel is disassembled. For PCDP, extra rods with collapse dimensions will be obtained. These extra rods can be inserted into mock-up assemblies to test the impact of this phenomenon on the fuel consolidation equipment performance.

Assembly Twist and Bow

Spent fuel assemblies occasionally exhibit twists and/or bows across the entire assembly. Since the assemblies are flexible enough so that they can usually be easily straightened out, the PCDP mock-up fuel need not demonstrate this phenomenon.

Replaceable Components

During cold tests, the consolidation equipment will probably require several cycles to "work out the bugs." Cost savings can be achieved in that mock-up rods can be reassembled into their skeletons so that

TABLE I
Total Fuel Assemblies by Manufacturer and Type (3)
U.S. Operating and Planned Reactors

		Year 1985	% Total	Year 2000	% Total	Year 2020	% Total
PWR	BW 14 X 14	2	negl	2	negl	2	negl
	BW 15 X 15	3579	19.8	10698	15.4	19628	14.7
	BW 17 X 17	51	0.3	759	1.1	1613	1.2
	BW Total	3632	20.1	11459	16.5	21243	15.9
	CE 14 X 14	2393	13.3	5048	7.3	7541	5.7
	CE 15 X 15	299	1.7	922	1.3	2275	1.7
	CE 16 X 16	355	2.0	5960	8.6	13580	10.2
	CE Total	3047	17.0	11930	17.2	23396	17.6
	EX 14 X 14 (CE)	449	2.5	2261	3.3	3678	2.8
	EX 15 X 15 (WE)	798	4.3	2673	3.8	4146	3.1
	EX 17 X 17 (WE)	182	1.0	528	0.8	528	0.4
	EX Total*	1429	7.8	5462	7.9	8352	6.3
	GU	76	0.4	76	0.1	76	0.0
	WE 13 X 13	160	0.8	160	0.2	160	0.1
	WE 14 X 14	2793	15.5	5341	7.7	7386	5.5
	WE 15 X 15	3815	21.1	8520	12.3	12342	9.3
	WE 17 X 17	3122	17.3	26486	38.1	60425	45.3
	WE Total	9890	54.7	40507	58.3	80313	60.2
PWR	TOTAL	18074	100	69434	100	133380	100
BWR	AC 10 X 10	155	0.5	155	0.2	155	0.1
	EX 6 X 6 (GE)	66	0.2	66	0.1	66	0.0
	EX 8 X 8 (GE)	655	2.3	3687	3.7	7770	4.1
	EX 9 X 9 (GE)	4	0.0	4	0.0	4	0.0
	EX 10 X 10 (GE)	100	0.4	424	0.4	562	0.3
	EX 11 X 11 (GE)	102	0.4	420	0.4	420	0.2
	EX Total*	927	3.3	4601	4.6	8822	4.6
	GE 6 X 6	656	2.3	656	0.7	656	0.4
	GE 7 X 7	9925	35.3	14819	15.0	19306	10.3
	GE 8 X 8	15829	56.3	78195	79.0	158079	84.2
	GE 9 X 9	157	0.6	157	0.1	157	0.1
	GE 11 X 11	4	0.0	4	0.0	4	0.0
	GE Total	26571	94.5	93831	94.8	178202	95.0
	NF 9 X 9	4	0.0	4	0.0	4	0.0
	UN 6 X 6	448	1.7	448	0.4	448	0.3
BWR	TOTAL	28105	100.0	99039	100.0	187631	100.0

* Exxon fuel assemblies provide reload batches to replace other manuracturer's fuel assemblies. Exxon fuel is therefore similar to fuel by other manufacturers.

TABLE II
PWR Fuel Assembly Pre-Irradiated Parameters (4)
- Six Most Predominant PWR Fuel Types -

Top Most Plentiful PWR Types:	WE 17 X 17	BW 15 X 15	WE 15 X 15	CE 16 X 16	CE 14 X 14	WE 14 X 14
	(mock-up)	(hot demo & mock-up)	(hot demo & mock-up)		(mock-up)	
PERCENT OF PWR INVENTORY						
Year 1985	17.3%	19.8%	21.1%	2.0%	13.3%	15.5%
Year 2000	38.1%	15.4%	12.3%	8.6%	7.3%	7.7%
ASSEMBLY						
Transverse dim, in.	8.426	8.536 MX	8.426	8.23	8.12	7.763 mn
Assembly wt, lb.	1467	1515 MX	1440	1435	1204 mn	1274
Overall length, in.	159.8	165.6	159.8	177 MX	157 mn	159.7
FUEL RODS						
Fuel length, in.	144	142	144	150 MX	137 mn	144
Total fuel wt/rod, lb.	4.37 mn	5.58	5.52	4.5	5.4	5.63 Mx
Number/assembly	264 MX	208	204	236	176 mn	179
Length, in.	151.6	153.7	151.8	161 MX	146 mn	151.8
Rod pitch, in.	0.496 mn	0.568	0.563	0.506	0.58 MX	0.556
OD, in.	0.374 mn	0.43	0.422	0.382	0.44 MX	0.422
Space between rods, in.	0.122 mn	0.138	0.141 MX	0.124	0.14	0.134
Clad thickness, in.	0.0225 mn	0.0265	0.0243	0.025	0.028 MX	0.0243
Clad Material	Zr-4	Zr-4	Zr-4 (pre-1968 have SST clad)	Zr-4	Zr-4	Zr-4

TABLE II (Continued)
PWR Fuel Assembly Pre-Irradiated Parameters (4)
- Six Most Predominant PWR Fuel Types -

Top Most Plentiful PWR Types:	WE 17 X 17 (mock-up)	BW 15 X 15 (hot demo & mock-up)	WE 15 X 15 (hot demo & mock-up)	CE 16 X 16	CE 14 X 14 (mock-up)	WE 14 X 14
GRIDS						
Number/assembly	8	10 *	7 mn	12 MX	10 *	7
Material	Inc 718	Zr-4	Inc 718	Inc, bot	Inc, bot *	Inc 718
GUIDE TUBES						
Number/assembly	24 MX	16	20	4	4 mn	16
OD, in.	0.474 mn	0.53	0.546	0.98	1.115 MX	0.539
Wall thickness, in.	0.016 mn	0.016	0.017	0.04	0.04 MX	0.017
Material	Zr-4	Zr-4	Zr-4 (pre-1970 were SST)	Zr-4	Zr-4 *	Zr-4
INSTRUMENT TUBE						
OD, in.	0.48 mn	0.493	0.546	0.98	1.115 MX	0.422
Material	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4 *	Zr-4
TOP AND BOTTOM END FITTING MATERIAL	SST	SST *	SST	SST	SST *	SST

* Estimated value, based on other parameters or on information on other fuel assemblies by the same manufacturer.

MX or mn = Maximum or minimum dimensional value among those shown in this table.

TABLE III

BWR Fuel Assembly Pre-Irradiated Parameters (4)

	GE 8 x 8 (hot demo and mock-up)	GE 7 x 7
PERCENT OF BWR INVENTORY		
Year 1985	56.3%	35.3%
Year 2000	79.0%	15.0%
ASSEMBLY (including channel)		
Transverse dim, in.	5.518	5.518
Assembly weight, lb.	600	600
Overall length, in.	179	171
FUEL RODS		
Number per Assembly (including 8 tie rods)	62 - 63	49
Rod pitch, in.	0.64	0.738
OD, in.	.483 - .493	.563 - .57
Space between rods, in.	.147 - .157	.168 - .175
Length, in.	161	161
Fuel length, in.	144 - 146	144 - 146
Clad thickness, in.	.032 - .034	.032 - .034
Clad material	Zr-2	Zr-2
COMPRESSION SPRINGS		
Working length, in.	0.84	0.94
Material	Inconel	Inconel
CHANNELS		
Transverse inner dim, in.	5.215	5.278
Length	167.4	166.9
Wall thickness, in.	.08 - .12	.08 - .12
SPACER GRIDS		
Number/assembly	7	7 *
Material	Zr-4 w/Inc springs	Zr-4 * w/Inc springs
WATER ROD		
Number/assembly	1 - 2	0
TIE PLATES Material	SST	SST
TIE NUT Material	SST	SST
TIE WASHER Material	SST	SST

* Estimated value, based on other parameters or on information on other fuel assemblies by the same manufacturer.

several adjustment cycles of the rod extraction and canister loading process can occur. Normal mock-up rods and deliberately defective rods will be recombined within the skeletons to test the consolidation equipment with various defect combinations. Mock-up assembly design must be such that this is possible. Any resulting deviations from actual fuel design should be minimized.

Some steps of the consolidation process will be destructive, e.g., removal of end fittings via cutting or clipping the skirts, guide tubes, or tie rods, or drilling out the tie nuts. To cold test these destructive procedures, several replaceable components are needed for the mock-up fuel. Other than those few destructive steps, the cold tests will be primarily nondestructive.

Simulated Fuel Rod Materials

Accountability requirements for special materials (7) mean that use of either natural or depleted UO_2 in the mock-up fuel rods would be expensive and perhaps a source of delay in procuring, and later in handling. The use of lead may cause later disposal problems for the potentially mixed hazardous/radio-active contaminated waste. Better options include aluminum oxide, brass, or steel, as long as the total mock-up assembly weight is within an arbitrarily chosen range of 10% of that of an actual fuel assembly. (The mock-up assemblies will not be used to load test and/or certify the consolidation handling equipment, therefore the slightly lower weight is acceptable if necessary. It is not, however, desirable.) The procurement specifications for mock-up fuel will specify the acceptable weight range, and let the bidders propose a mock-up fuel material of their choice, subject to review by the purchaser.

Actual spent fuel is fragmented due to irradiation. Fuel rod stiffness would therefore not be well simulated by solid mock-up rods; a better choice would be material in pellet or granular form, within the constraints of weight. The BW 15 x 15 mock-up rods, where canister packing is expected to be the tightest and therefore most sensitive to rod stiffness, should have this material characteristic even if the weight limits are not met.

Irradiated Materials

Material properties such as hardness, ductility, and strength are altered by irradiation (8). For some components, this could significantly impact the consolidation process. The mock-up fuel will therefore simulate irradiated material properties for components where this is expected to make a difference during consolidation. Vendors will propose a method of simulation of the special material properties, subject to review and approval by the purchaser.

For example, irradiation of zircaloy produces a considerably stronger, harder and more brittle material. These different zircaloy material properties could distort the fuel behavior during consolidation so that adequate simulation would not be performed. For PWR mock-up assemblies used to test end box removal, these special zircaloy material properties are required for guide tubes (and perhaps material properties of irradiated stainless steel for end boxes and irradiated Inconel for skirts, depending on the consolidation method chosen). BWR components planned for use to cold test tie rod end cap cutting or clipping must also exhibit these properties. Note that zircaloy pyrophoricity could be important to the test, and therefore zircaloy must be retained as the mock-up fuel material in at least some of these special assemblies.

Crud Deposits (9)

All zircaloy spent fuel components have "crud" deposits to some degree. "Crud" is comprised of oxidized zircaloy and a film of cooling system corrosion products that deposit on the zircaloy surfaces. The color, thickness, texture, and uniformity of crud varies considerably, the largest factor being the chemical composition of the cooling water. There are two basic types of crud: a loosely adherent, friable substance which brushes off easily, and a tightly adherent gray-black film which is difficult to remove. Both types are highly radioactive due to activation. The first type can be simulated separately from the mock-up fuel (perhaps by scattering a powder) and so is not addressed by the mock-up fuel design.

The second type of crud is of varying thickness, usually not more than .002 in. thick. It ranges in texture from shiny to a rough matte, and is unevenly distributed over a zircaloy surface. The impact of this crud type on the consolidation process (other than generation of radioactive fines) is unknown, though expected to be minimal. At most, it might increase the pulling force required for rod extraction. Because of this uncertainty, the crud deposits must be simulated. Mock-up procurement specifications will delineate requirements for crud simulation and call for the vendor to propose a technique, subject to the purchaser's review and approval.

Crud simulation need not be applied to all the mock-up rods. At a minimum however, the crud should be simulated on some of the BW 15 x 15 fuel rods, to learn of any impact on rod packing, and on WE 17 x 17 mock-up fuel rods to increase the required pulling force to a reasonable maximum.

OFF-NORMAL EVENT SIMULATION

The consolidation equipment is intended for use at an MRS or repository with "normal," i.e., undamaged, spent fuel. Such fuel may have considerable crud deposits, bowed, lengthened, and/or collapsed (but unbreached) rods. The equipment must routinely handle such defects, and the mock-up fuel is required to demonstrate these normal spent fuel phenomena as explained above. However, if a failed fuel assembly (e.g., one containing a rod with breached clad) is inadvertently put through the an "off-normal" event might occur, as described in the following paragraphs. This "off-normal" damage is not expected on a routine basis, but the consolidation equipment must be capable of dealing with it as well as the "normal" spent fuel flaws. Such defects will be simulated in portions of the mock-up fuel so that equipment operation can be judged and training can be performed in this regard during the cold tests. The Hot Demonstration will not intentionally include any damaged fuel.

Off-normal fuel conditions discussed in the following sections and planned for simulation in the mock-up fuel include swollen and ruptured rods, which could be stuck or even broken during consolidation; rod end caps which pull off during rod extraction; and torn spacer grids which might interfere with assembly and NFBC handling, clamping, and storage.

Possible off-normal events that could occur during consolidation can be simulated by designing mock-up fuel that will intentionally fail in the same way that spent fuel might. Note that the mock-up fuel will not simulate development of the fuel defect, but rather the defect's impact on consolidation. For example, the mock-up fuel rods will not be pressurized or hydrided to cause swelling or rupture. Instead, they will be mechanically modified as necessary to simulate this defect's impact on the consolidation function (i.e., stuck rods or fuel spillage).

A potential off-normal occurrence which is not part of the mock-up fuel requirements is that of a zircaloy fire. Planning for the cold test (not yet complete) will consider whether simulation is desired and, if so, the best means of providing it. Even if simulation is not desired, cold tests with the mock-up fuel could create burnable zircaloy fines, and the Cold Test Plan must therefore address the possibility of an inadvertent zircaloy fire. Meantime, simulation of this obviously destructive event is not a requirement for the mock-up fuel.

Swollen and Ruptured Rods

Ruptured or swollen rods may not be visually detected if they are internal in the fuel assembly, hidden from view during visual inspection. Sip testing can be unreliable and may not indicate any problem with a damaged rod (10). Ultrasonic tests are usually not performed unless there is some other indication of trouble with the fuel assembly. So, although fuel with these off-normal conditions is not intended for consolidation, it may inadvertently be sent through the routine consolidation process at the MRS or repository. Estimates indicate that a broken rod may occur during consolidation about once per 25 MTU (Metric Tons Uranium) (11).

The mock-up fuel needn't simulate the full scope of swelling or rupture mechanism, but it must simulate the impact on the consolidation process. A swollen or ruptured rod could get stuck in a spacer grid during rod extraction, possibly requiring the grid to be cut to allow rod removal. Ruptured rods will pose consolidation problems beyond those caused by swollen rods: besides getting stuck in spacer grids, they might also spill spent fuel out from the open clad (in pellet, fragment, and powder form). Recovery will probably include removing the stuck rod, either by cutting the grid and/or by clipping and crimping the rod into two halves. The spilled fuel must be cleaned up remotely.

To test the impact of a stuck rod on the rod extraction equipment (i.e., to test and adjust the rod gripper release mechanism), some spare rods will be furnished which can be inserted into a mock-up assembly, then modified to "stick" during the rod extraction process. Fuel spillage, however, may be simulated separately from the mock-up fuel by scattering material in the vicinity of the rupture.

Spare mock-up grids (with material properties of irradiated Inconel) will be provided to allow the proposed recovery procedure to be tested. So that performance of this destructive procedure does not render an entire mock-up skeleton unusable, these spare grids can be loose and need not be incorporated into an assembly; the cutting can be performed on one individual grid at a time. When the cutting procedure has been proven and adjusted as necessary on the individual grids, then it can be practiced on an assembly.

Two BW 15 X 15 swollen rods will also be mocked up, not to test the stuck rod extraction process, but to test the impact on canister packing procedures and space (the BW 15 X 15 has the smallest margin for packing volume). These rods will more closely represent actual dimensions of swollen rods than those rods discussed above; material properties, however, are not important.

Damaged Rod End Caps

One of the points most vulnerable to hydriding on a fuel rod is the end caps; badly hydrided caps have been known to actually fall off a rod (12). Rods with undetected end cap damage might inadvertently in the future go through the consolidation process. The result could be an end cap that pulls off altogether during rod extraction. The mock-up fuel will allow simulation of this off-normal event by including several extra mock-up rods with end caps that will pull off during consolidation.

Torn Spacer Grids

Spacer grids are often torn during handling, e.g., as the fuel assemblies slide up or down during removal or installation in a reactor or storage rack, their grids can catch and tear (usually at the corners). This phenomenon may impact the consolidation storage, handling, and clamping steps for fuel assemblies and for NFBC. Mock-up fuel need not be procured to represent the torn grids. Instead, the grids can easily be torn during the cold tests, using hand tools. Provision to simulate this fuel assembly defect will be part of the Cold Test Plans.

QUANTITIES OF MOCK-UP ASSEMBLIES

The rod consolidation ratio sought by the PCDP is 2:1 for PWR fuel and 4:1 for BWR fuel. In other words, all the rods from two PWR fuel assemblies or from four BWR fuel assemblies must fit together within one consolidated fuel canister. It is assumed that the equipment will perform consolidation on the multiple assemblies at any one time, i.e., two PWR assemblies of the same type or four BWR assemblies of the same type at a time. A reasonable alternate assumption is that individual assemblies will undergo staggered consolidation, overlapping in time. For either case, a sufficient number of mock-up fuel assemblies must be available to prove that the consolidation equipment can indeed attain the desired consolidation ratio while handling multiple assemblies. Therefore at least two of each PWR type and four of the BWR type are desired to cold test each set of equipment. This indicates that a total of four each of the WE 17 x 17, WE 15 x 15, BW 15 x 15, and CE 14 x 14, and eight of the GE 8 x 8 full-length mock-up assemblies are desired for the cold tests at contractors' facilities. If these mock-ups cannot be rebuilt for reuse at the INEL to prepare for the Hot Demonstration, then an additional two each of the WE 17 x 17, WE 15 x 15, BW 15 x 15, and CE 14 x 14, and four of the GE 8 x 8 will be necessary. Exact quantities to be procured will not be decided until vendor bids are received this summer.

During the cold test, the consolidation process must be performed several times to allow equipment adjustments, or simply to prove adequate equipment operation. It is expected that some steps of the consolidation process will be destructive, e.g., removal of an end fitting via cutting the guide tubes. To allow repeated cold test of these destructive procedures, several extra replaceable components are planned for each mock-up assembly. In particular, it is anticipated that the CE 14 x 14 will be represented only by specially designed and built mock-up assemblies which will allow repeated end box removal testing, and not necessarily rod extraction tests. This is because the primary purpose for including the CE 14 x 14 as a mock-up fuel type is because of its unique features which will challenge the end box removal step. Rod extraction from the CE 14 x 14 is expected to be similar to that of the other fuel types, and therefore not required to be cold tested.

The mock-up fuel rods themselves (both "normal" and "off-normal") will be inserted back into their skeletons several times to allow repeated testing of the rod extraction and canister packing processes. It is expected that clamps (and perhaps some training) must be obtained from some of the mock-up fuel vendors to enable the cold test personnel to easily reconstitute the assemblies. Features such as lead-in chamfers on the rod ends may be desirable to facilitate the re-assembly, and vendors will be asked to propose such features. However, simulation of the consolidation process must not be distorted.

CONCLUSIONS

PCDP plans for mock-up fuel procurement are summarized as follows:

a. Cold test objectives are the drivers for mock-up fuel requirements.

b. Mock-up of fuel types proposed for Hot Demonstration is mandatory. These types include PWR fuel WE 15 x 15 and BW 15 x 15, and BWR type GE 8 x 8. In addition, PWR types CE 14 x 14 and WE 17 x 17 are anticipated for mock-up due to their unique features and predominance in spent fuel inventories.

c. The mock-up assemblies will simulate normal spent fuel conditions such as bowed, lengthened, and collapsed rods, "crud" deposits, and irradiated materials.

d. Mock-up material for spent UO_2 will be as recommended by the mock-up fuel vendors and approved by the purchaser. Use of lead or of special nuclear materials, e.g., depleted uranium, is not acceptable.

e. To test equipment recovery capability in off-normal conditions, mock-up fuel rods are required to simulate stuck, swollen, ruptured, and/or broken rods. Rods with loose end caps must also be supplied, as well as assemblies with torn spacer grids.

f. Replaceable components are needed to allow several cycles of cold test processes which are expected to be destructive.

g. Additional materials, not part of the mock-up fuel procurement, will be needed to simulate crud particulate and spent fuel spillage. Such materials will be identified as part of the Cold Test Plan. The Cold Test Plan will also address the possibility of a zircaloy fire.

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