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Li_2O MICROSPHERE FABRICATION

Monthly Letter Progress Report #1 for
the Period Ending May 31, 1977

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TASK 1 RESULTS

1. OVERVIEW

1.1 The purpose of this task is to establish process parameters for the fabrication of lithium oxide (Li_2O) microspheres having properties which as closely as possible approximate those required for the design characteristics of the University of Wisconsin design for a TOKAMAK-type fusion reactor utilizing the moving bed of Li_2O microspheres as both reactor coolant and tritium breeder. At present, these requirements are roughly conceived as:

a. Ceramic microspheres of Li_2O approximately 100 μm in diameter

b. Approximately 85 percent theoretical density of the microsphere

c. Bed density aroung 1 g/cc

d. Average microsphere open pore-to-pore spacing of about 1 μm

e. Microsphere strength sufficient to withstand significant attrition rates in the proposed particle transport system.

1.2 The research being conducted at Babcock & Wilcox' Lynchburg Research Center concerning the lithium oxide microspheres can be broken down into the following general categories:

a. Investigation of experimental candidate fabrication processes for the production of lithium oxide microspheres

b. Production of experimental (small) quantities of microspheres by those fabrication methods which show promise as a basis for commercial production.

c. Analysis of the microspheres for density, porosity, pore morphology, and chemical purity characteristics

d. Rough estimation of costs for large-scale (TOKAMAK) production of microspheres

e. Identification of future R&D requirements for Li_2O microsphere production.

1.3 Since the experimental work was initiated early in April 1977, results have been obtained in each of the above categories excepting category d for some of the candidate fabrication processes. This interim report for TASK 1 is written to summarize the results thus far obtained and indicate the effect of these results on the future research effort.

2. CANDIDATE FABRICATION PROCESSES

2.1 FIGURE 1 shows the general flow chart for the type of process under consideration in this research contract. These processes have the advantages of mechanical, conceptual, and chemical simplicity. Possible alternative, i.e., more expensive and exotic approaches for future R&D work, will be discussed later in this report, but under the present contract, only the approaches presented below will be technically evaluated.

2.2 Step 1, involving preparation of the powder, has thus far consisted of simply receiving -325 Mesh lithium oxide powder from a supplier. This powder is presently available from only one known supplier at a cost of approximately $120/lb. Analysis in the as-received conditions reveals the powder to be only ∿95 percent pure, with the impurities mostly consisting of lithium hydroxide, lithium carbonate, and some magnetite. The high price for the material is felt to be primarily due to the lack of demand for it and consequent lack of supply. It is manufactured by the thermal decomposition of lithium carbonate which is in turn generated by decomposing certain naturally occurring lithium mineral salts. The primary supplier is Lithium Corporation of America, located in North Carolina.

The only instance, other than the recycle method which has not yet been analyzed, in which an actual powder preparation is required, concerns a proposed sol-gel extraction scheme which would require the prior conversion of the lithium oxide powder to lithium peroxide powder (discussed below). All other methods covered in this study simply utilize the as-received powder as input to the granulation step.

2.3 Step 2 involved the agglomeration of the powdered lithium oxide particles into granules roughly the size of microspheres ultimately desired. Two general methods are being studied to accomplish this agglomeration:

a. Mechanical agglomeration. This method consists chiefly of some method of tumbling the dry Li_2O powder with a binder material added. The two methods of mechanical granulating being investigated in this study are fluidized bed granulation and high intensity mixing. Samples of lithium oxide microspheres have been collected using a Glatt, Inc., fluidized bed with two different cellulose binders. The results will be discussed in more detail later in this report.

No samples have been obtained yet by means of the high intensity (LODIGE M-5G) mixer/granulator, but arrangements have been made for this work, which should be accomplished starting around early June 1977.

b. Sol-get extraction. It was initially thought that an aqueous Sol-gel extraction technique for a slurry of lithium oxide countercurrently extracted with hexanol or some other dessicating agent could be developed. This proved to be infeasible, primarily due to the fact that no aqueous sol-forming chemistry could be found for lithium oxide which did not completely convert the lithium oxide to lithium hydroxide monohydrate via the reaction:

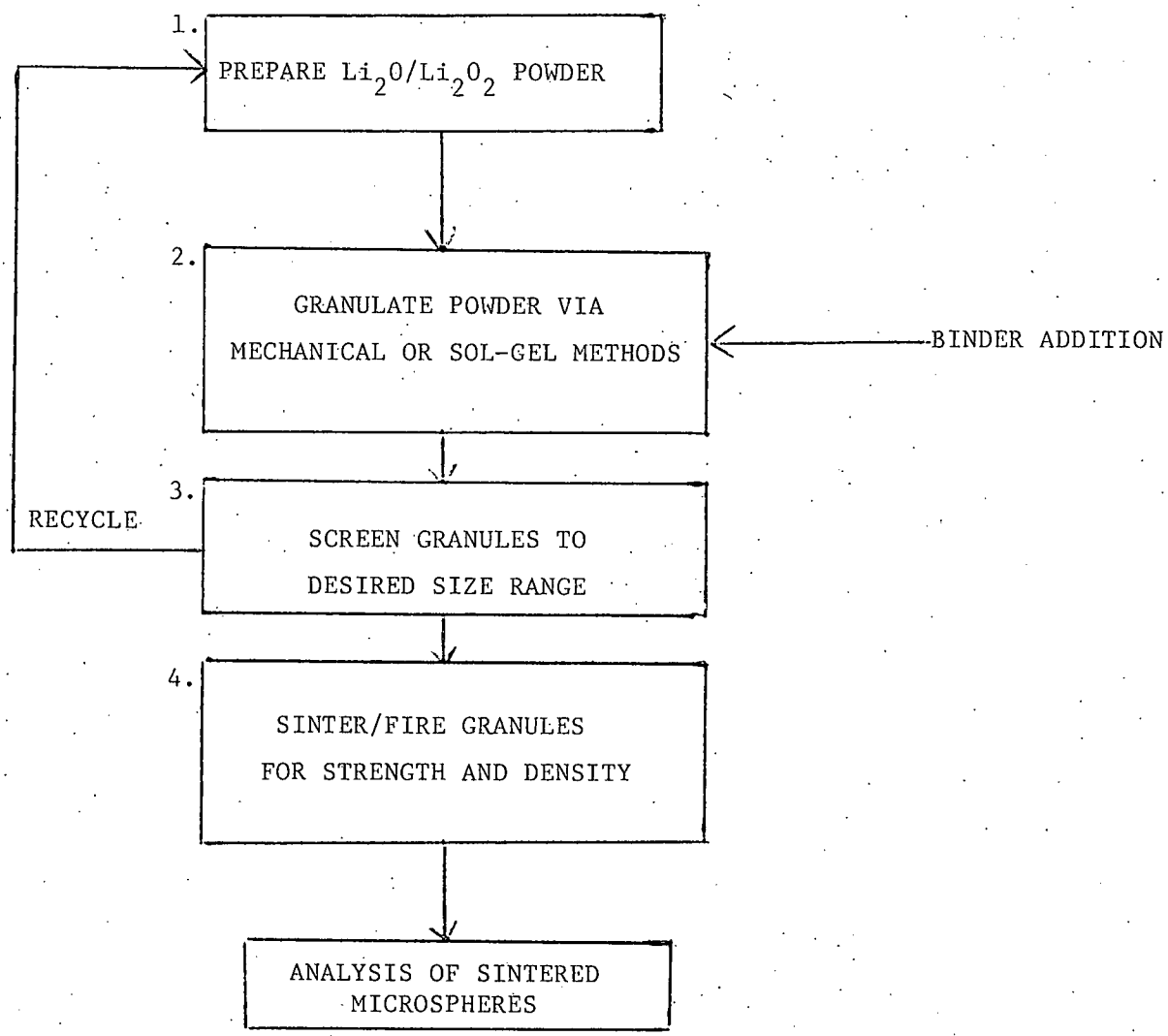

FIGURE 1. GENERAL FLOW CHART FOR Li_2O MICROSPHERE FABRICATION

$$Li_2O + 3H_2O \rightarrow 2LiOH \cdot H_2O + heat$$

It was originally hoped that this reaction could be impeded through the addition of strongly basic complexing agents, but this did not prove to be the case. The lithium hydroxide monohydrate contains too much water to be effectively flame decomposed while still maintaining its granular structure.

There is a possibility, however, based on some studies conducted at the University of Wisconsin (U.W.), that a stable aqueous sol of lithium peroxide (Li_2O_2) can be maintained sufficiently to permit a hexanol extraction of Li_2O_2 granules which then could be fired to form fairly pure Li_2O microspheres. The lithium peroxide can be formed by precipitation out of a solution of a soluble lithium salt (say, lithium nitrate) by hydrogen peroxide. This method was discussed at a meeting at U.W. with Dr. E. Larsen and J. Wrazel of the Analytical Chemistry group. It is hoped that time and funds will permit at least a rough evaluation of this proposed fabrication method as an alternate to purely mechanical granulation methods.

2.4 Step 3 is straightforward and simply involves sieving the granulates produced in Step 2 to separate the desired size ranges. In the cases of mechanical granulation used above, the granulates can be transferred directly from the granulating unit to the sieve trays. In the case of sol extraction, the granulates may require drying followed by a mild milling technique to break up any 'soft' agglomerates prior to sieving.

2.5 Step 4 involves the sintering/firing of the granulated lithium oxide/binder agglomerates. It has been found that on the granulates so far produced (in the fluidized-bed agglomeration) that this step cannot be done in a furnace, but that rather each particle must be fired separately by flowing the particles through a combustion flame. If a furnace is used, the binder causes the powder bed to sinter together, forming a cake. When fired by flow through a flame, very free flowing, spherical particles are produced (see FIGURE 2b). However, in the initial fluidized bed experimental agglomerations, 5-7 percent by weight of cellulose binder was added to the bed. Upon firing of the granulates, a large part of the lithium oxide was converted to lithium carbonate, either through reaction with the binder combustion products or by reaction with the constituents of the combustion flame. It is felt now that the large part of this carbonate formation could be eliminated by cutting the binder to 1-2 percent of the lithium oxide by weight, but this requires verification.

The granulates formed by the high intensity mixer/granulator and the sol extraction techniques will be initially fired by the same method.

2.6 Analysis. (See paragraph 4.)

3. PRODUCTION OF EXPERIMENTAL QUANTITIES OF Li_2O MICROSPHERES

3.1 Based on the results presented in Section 2 above, three methods are expected to yield experimental quantities of lithium oxide microspheres; fluidized bed granulation, high intensity mixing/granulation, and sol extraction of lithium peroxide. Some microspheres have been produced by fluidized bed granulation and have been partially analyzed. It is confidently expected that the high intensity mixing method will produce some quantity of microspheres within the next few weeks. The final method, sol extraction of Li_2O_2, still contains considerable uncertainty and depends on how much time and funding remain after the other two methods are evaluated.

Parameters to be varied within each method include type and amount of binder material, sintering flame temperature and residence time, and particle size distribution acceptability.

TABLE 1 presents a summary of the lithium oxide microsphere fabrication thus far accomplished using the fluidized bed granulation technique along with the type of data and fabrication methods yet to be accomplished. The remainder of the fluidized bed agglomeration work will be accomplished on June 1-3, 1977, at Glatt Air Techniques in Norwood, New Jersey. Appendix A also includes the processing sheets concerning fluidized bed operating parameters used to produce the existing microsphere samples.

3.2 Figures 2a and 2b show photo-micrographs of, respectively, a typical fluidized bed granulation of -325 mesh lithium oxide powder with ethylcellulose binder and the resultant fired microspheres; in this case, screened to 200 mesh particles. Figure 2c is a photomicrograph of the original -325 mesh Li_2O powder.

The fluidized bed granulation process produces a fairly wide range of agglomerate sizes and, therefore, an equally wide range of fired microspheres. Experience in firing the microspheres shows that, in general, the smaller the agglomerate particle, the more easily the binder material is "fired off". In the laboratory firing apparatus used thus far, the granules from the fluidized bed were slowly flowed into a series of burner flames. These particles were then propelled by the gas flame into a staggered series of collector trays, the smaller particles tending to collect in the trays furthest from the flame. It is these smaller particles which tended to be most free of binder material and which are shown in FIGURE 2b. Samples exist, however, in a series of mesh sizes, with the larger particles progressively less "sintered" and spheroidized. An example of these particles, which would require much longer flame retention times than is presently feasible in our laboratory set up, is shown in FIGURE 3.

TABLE 1. LITHIUM OXIDE MICROSPHERES FABRICATION TECHNIQUES

No.	Granulation Technique	Binder Material/ Amount	Granulation Analysis	Sintering/Firing Method	Microsphere Analysis: Chemical	Microsphere Analysis: Porosity	Microsphere Analysis: Size Distribution	Comments
1	Dry-air fluidized bed granulation (-325 mesh powder)	2.5% Ethylcellulose in acetone Total 7% Ethylcellulose to Li_2O added	- See Fig. 2a - Formation of generally spherical granules - Approximate size distr: d >100 mesh 50% 100 mesh > d >200 mesh 40% 200 mesh > d >325 mesh 10% 325 mesh > Trace	Combustion Flame Approx. 850°C Avg.	Approx. 31.5 wt% Li	See Fig. 26	d>65 mesh 20% 65>d>100 50% 100>d>200 25% d<200 5%	Chemical (titration) analysis reveals presence of Li_2CO_3, $LiHCO_3$ and LiOH formation, probably from oxidation of binder material. Question whether decreasing binder amount will eliminate or decrease carbonate and hydroxide formation circumstances of setting fluidization parameters required addition of more binder than normally necessary.
2	Dry-air fluidized bed granulation (-325 mesh powder)	3.7% KLUCEL-L in acetone Total 5% KLUCEL to Li_2O added	- See Fig. 3a - Formation of generally spherical granules - approximate size distr: d >100 mesh 10% 100 > d > 200 40% 200 > d > 325 40% 325 > d 10%	Combustion Flame Approx. 850°C Avg.	- - -	- - -		Generally same characteristics as No. 1 above. Binder seems to be slightly more difficult to burn off. Again, a high percentage of binder was used.
3*	Dry-air fluidized bed granulation (-325 mesh powder)	2.5% Ethylcellulose in acetone Total 2% Ethylcellulose to Li_2O added		Combustion Flame				Reduction in amount of binder should reduce carbonate, hydroxide formation.
4*	Dry-air fluidized bed granulation (-325 mesh powder)	∿3% Ethyl silicate in acetone Total 5% by weight to Li_2O		Combustion Flame				High melting (∿1100°C) lithium silicate could form rather than carbonate/ hydroxide. Due to high melting point, presence of silicate is less objectionable than carbonate/hydroxide formation.
5*	Dry-air fluidized bed granulation (-325 mesh powder)	∿3% Ethyl silicate in acetone Total 1% by height to Li_2O		Combustion Flame				Same as above
6*	High intensity mixing (LODIGE M-5G)	2.5% Ethylcellulose in acetone Total 7% by weight to Li_2O		Combustion Flame				Compare microspheres obtained to No. 1
7*	High intensity mixing (LODIGE M-5G)	2.5% Ethylcellulose in acetone Total 2%		Combustion Flame				Compare microspheres obtained to No. 3.
8*	High intensity mixing (LODIGE M-5G)	∿3% Ethyl silicate in acetone Total 2% by weight		Combustion Flame				Compare microspheres obtained to No. 5.
9*	High intensity mixing (LODIGE M-5G)	∿3% Ethyl silicate in acetone Total 5% by weight		Combustion Flame				Compare microsphere obtained to No. 4.
10**	Sol extraction of Li_2O_2 Sol	Unknown as yet						Li_2O_2 prepared as precipitate from lithium nitrate solution. Aqueous Li_2O_2 sol stability will need to be determined.

* Planned samples not yet generated.

** Possible sources of microsphere samples

FIGURE 2a. FLUIDIZED BED GRANULATED LITHIUM OXIDE POWDER (-325 MESH) WITH 5 PERCENT ETHYLCELLULOSE BINDER. NO SIEVE SEPARATION.

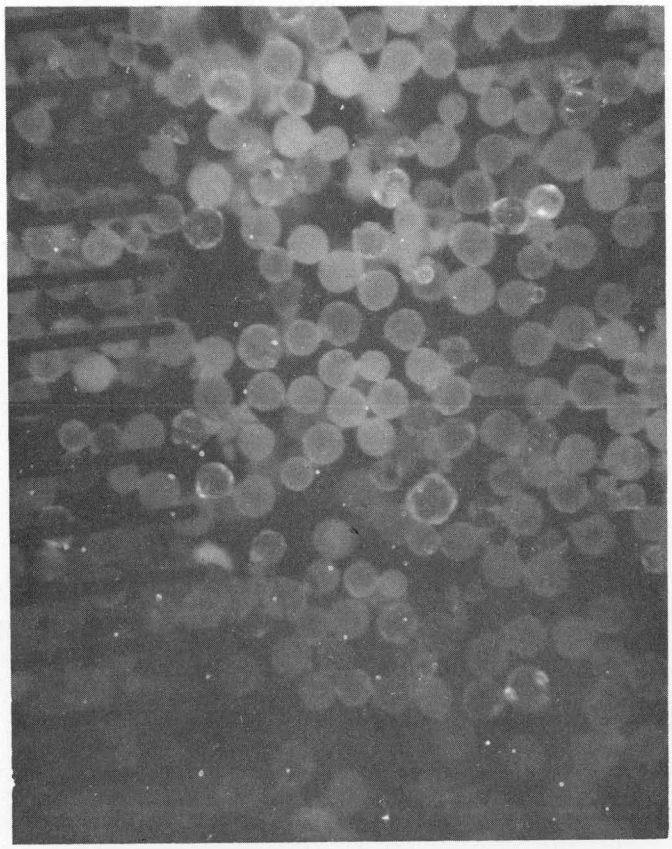

FIGURE 2b. FIRED LITHIUM OXIDE/ETHYCEL BINDER MICROSPHERES THRU 200 MESH SIEVE.

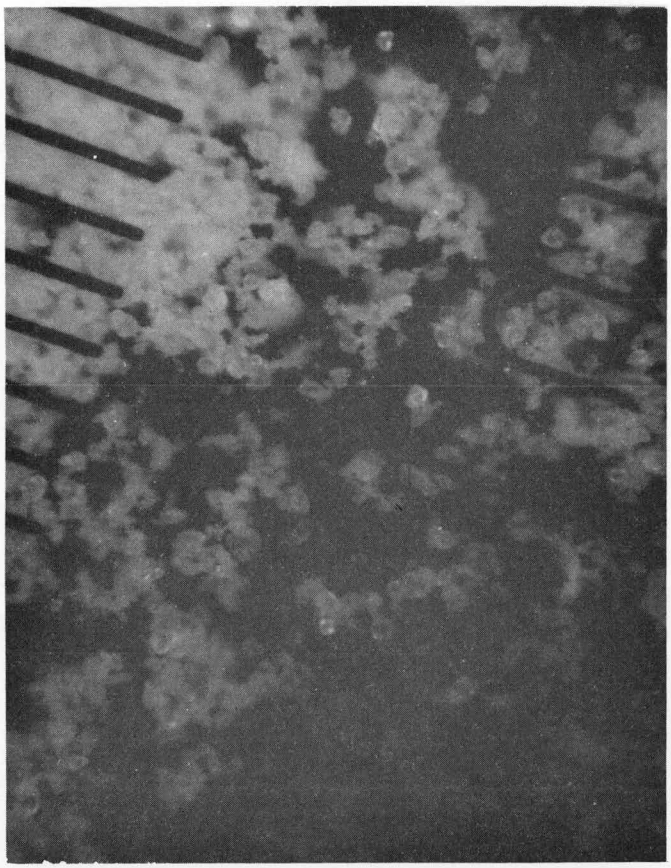

FIGURE 2c. -325 MESH LITHIUM OXIDE POWDER

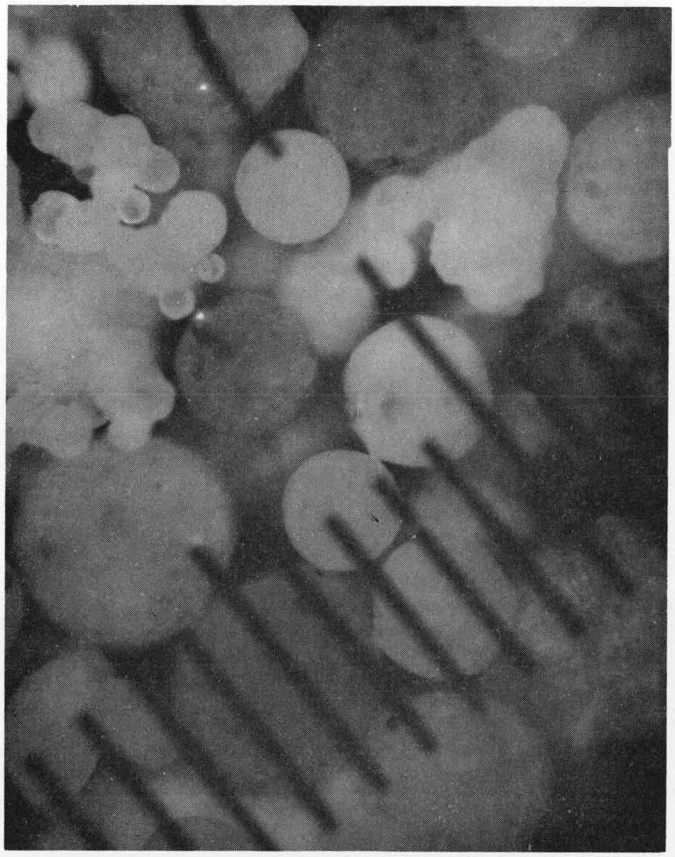

FIGURE 3. ON 65 MESH SCREENED LITHIUM OXIDE/ETHYCEL BINDER AFTER FIRING

3.3 As was mentioned earlier, the microspheres here developed consist of extensive amounts of lithium carbonate and possibly lithium hydroxide. This carbonate and hydroxide most likely were generated as the carbonaceous (cellulose-type) binder materials were decomposed and oxidized in the burner flame during firing. It is presently thought unlikely that much carbonate or hydroxide is formed as a result of the flame combustion products upon the lithium, although it is not impossible. For the samples thus far generated, far more binder was used (5-7percent) than is generally thought necessary for sintering purposes (1-2 percent). It is hoped that by reducing the amount of binder in future samples and by changing the nature of the binder (to ethyl silicate), the amount of carbonate and hydroxide in the microsphere could be effectively minimized. This effect will be evaluated in subsequent microsphere batches.

3.4 An as-yet unexplained phenomenon concerning the granulated Li_2O powder occurred during the fluidized bed processing. After the granulation of the Li_2O/binder mixture had been accomplished in the Glatt fluidized bed equipment, the two approximately one-kilogram batches (one with Klucel-1 binder, one with ethyl cellulose) of granulated powder were packaged and set aside. After about one-and-a-half hours, both powders were found to be generating a great deal (∿300°F) of self-heat. Both batches were then quickly recooled in the fluidized bed and the phenomenon did not repeat. It should be noted that the powders remained at ambient temperature for better than an hour before heating up. Various theories explaining this effect have been proposed, such as a delayed air-binder combustion reaction or a delayed hydration of the lithium oxide with air moisture, etc. No certain explanation has yet been accepted; however, any future processing procedure will be observed for a possible repeat of the phenomenon.

4. ANALYSIS OF MICROSPHERES

As yet, the only analyses performed on the generated microspheres have been photo-micrograph visual analyses, total lithium content analysis titration curves, and sieve analyses for particle size distributions. Porosity and pore morphology studies of the particles are yet to be accomplished.

5. ESTIMATION OF MICROSPHERE PRODUCTION COSTS

Microsphere production costs for commercial quantities will be estimated after all processing methods under study have been evaluated.

6. COMMENTS AND EXPECTED FUTURE RESULTS

6.1 As has been indicated previously, the primary thrust of the mechanical granulation methods still to be done is to try to decrease the amount of lithium carbonate and lithium hydroxide generated in the microspheres. It is also hoped to establish processing parameters which result in a narrower microsphere size distribution than has thus far been indicated.

6.1 (Continued)

The sol-extraction technique proposed, utilizing an aqueous lithium peroxide sol, even if successfully initiated, would produce only gram quantities of Li_2O microspheres.

Porosity and pore morphology studies of the microspheres thus far produced will shortly be initiated.

6.2 In line with the stated objectives of TASK 4 of the research, consultations were held May 12-13 at Madison, Wisconsin, with members of the U.W. Fusion Study group concerning the integration of the results of this research with the ongoing U.W. fusion effort.

Concern was expressed at this meeting in relation to the early experimental results indicating that the simple microsphere fabrication processes under study would involve at least a small presence ($\sim$10 percent) of lithium carbonate in the microsphere. Alternate means for creating microspheres were discussed such as flame spraying of melted Li_2O to form microspheres and other processes akin to this. It was pointed out that these processes would likely involve the formation of a non-porous microsphere and that this could complicate the tritium buildup and recovery parameters of the reactor. It was agreed that present research effort in this area should concentrate on decreasing the carbonate content resulting from the simple fabrication methods.

A possible alternate wet chemistry for the formation of porous Li_2O microspheres, involving the creation of a stable sol of lithium peroxide which could be countercurrently extracted with n-hexanol to form lithium peroxide gel microspheres as an intermediate species, might provide an alternate means of creating more pure lithium oxide microspheres. It was agreed that a rough experimental study of this method would fall within the workscope of the present contract and would be carried out if funding permitted.

2.0 Task II Nuclear Steam Supply System Components

2.1 Objectives of Task II

The objectives of this task are as follows:

- o Develop preliminary conceptual design of steam generator
- o Develop preliminary conceptual design of reheater
- o Specify major components required to incorporate heat storage capability needed to provide continuous steam generation at full load
- o Identify required R&D

2.2 Task II Work Scope

This work consists of the following three phases:

<u>PHASE I</u>. Establish Reference Ground Rules and Parameters

This phase has three sub-phases. The first sub-phase will involve an initial listing of design parameters, ground rules and assumptions based on work performed on this concept prior to submittal of this proposal. In the second sub-phase this information will be reviewed by experienced Babcock & Wilcox Company people and others, as required for comments and recommendations. The third sub-phase will incorporate the resulting comments and recommendations into a final set of design parameters and ground rules. This will be the basis of work to develop reference component designs (Phase II) from design concepts begun prior to submittal of this proposal.

<u>PHASE II</u>. Complete Preliminary Design of Steam Generator, Reheater and Heat Storage Components

In this phase, component conceptual designs will be adjusted and completed in accordance with the ground rules and parameters developed by Phase I above. These designs will be reviewed by experienced B&W people and others as required. This work will generate information in the following areas:

1. Thermal, hydraulic design
2. Steam cycle selection
3. Materials selection
4. Component containment (casing design)
5. Tritium diffusion to steam

6. Steam leak monitoring and isolation
7. Design parameters and ground rules
8. Applicability of current technology
9. Inspection and maintenance considerations
10. Heat storage features to allow continuous steam generation at full load between reactor "burn" periods.

PHASE III. Identify Required Research and Development Work

This phase will scope the research and development work considered necessary to complete development of the component designs covered by this task.

2.3 Work Performed During Period Ending May 31, 1977

Part-time work on this task began in April, 1977 prior to completion of contract negotiations in May 1977 with the Chicago Operations Office of ERDA. Phase I is virtually completed and Phase II is well underway. This is described in the following sub-sections.

2.3.1 Work performed under Phase I of Task II

Original ground rules and parameters as presented in Germantown last summer have been revised to be compatible with revised steam generator and reheater design requirements and the current 1500 MWt University of Wisconsin Tokamak reactor design. This work involved a trip to U of W in Madison and a number of discussions within B&W.

The following general tokamak plant parameters were selected for sizing heat exchange and particle transport equipment:

Total MWt	1500
MWt in 1st wall	300
MWt in blanket	1200
Li_2O temp. ent. blanket ^oC	350
Li_2O temp Lv. blanket ^oC	550
Steam press from 1st wall reboiler psia	400
Steam press from blanket SG psia	1500
Steam press to HP turbine psig	1450
Steam Temp. to HP turbine ^oF	900
Press Ent RH psia	375
RH temp/press ^oF, psig	900/325
Feed Temp ^oF	450
Blanket gas	Helium

It was also agreed that all particle lifting would take place at 350°C after Ll_2O had passed through the steam generators and reheaters. Total lift is assumed to be 75 ft.

The first wall steam generator was assumed to be isolated from the main steam system by a reboiler to avoid contamination of this system by N-16, tritium or other radioactive materials.

The above parameters do not take into account reactor down line between operating power periods. Heat storage requirements remain undefined except that added Ll_2O inventory for this purpose is ruled out to reduce total Ll_2O requirement and improve system characteristics from the standpoint of tritium management.

The reboiler mentioned above is assumed to produce saturated steam at 400 psia and is considered to be of conventional design.

The steam cycle has been tentatively selected to be compatible with the Ll_2O temperatures shown above; and to provide a reheat steam pressure under 400 psia so that reboiler saturated steam flow could be combined with high pressure turbine exhaust. This would permit the combined flow at 375 psia and approx. 560°F to be heated in the reheater to 900°F at 325 psig for further expansion in the turbine cycle.

Operating temperatures are also designed to avoid use of stainless or high alloy steels in steam generator, reheater, Li_2O ducts, etc.

Tubing in steam generators and reheaters will be sized and used in configurations permitting in-service inspection by non-destructive methods (eddy current or ultrasonic) so that tube defects, tube erosion, tube corrosion, etc. can be detected at an early stage such as to prelude tube failure from these causes.

2.3.2 Work Performed Under Phase II of Task II

Work under this task consisted of the following:

- Evolving a suitable design configuration for steam generator and reheater

- Evolving a fin tube design suitable for Li_2O flow and heat transfer requirements and considered capable of satisfactory in-service inspection provided a special system is developed for this purpose.

- Sizing of steam generator and reheater for application to U of W 1500 MWt Tokamak reactor using six (6) Li_2O heat transfer loops. Details of the above are described in the following sub-sections.

2.3.2.1 Design configuration for steam generator and reheater

The basic design configuration for both the steam generator and reheater is shown in Fig. 2.3-1. Li_2O flows vertically downward past vertical finned tubes shown in Figs. 2.3-2 or 2.3-3. For the steam generator these tubes are an 1.09 triangular spaing provided by 1" wide spacer rings on about 12" vertical spacing. Circumferential bands combine with tube flexibility to hold each tube in contact with its neighbor at spacer ring locations. Spacer rings are furnished in halves and welded in place. Weld shrinkage produces a tight fit. Welding to fin tips is avoided to preclude the presence of heat affected zones in fin tips which would complicate eddy current inspection.

Each steam generator (or reheater) tube has upper and lower 90° bends and a horizontal portion which connects to upper and lower tube sheets as shown. Fins are machined off above and below the vertical heat transfer section or as an alternate, unfinned tubes are welded to each end of the 20.5' finned section shown (Fig 2.3-1).

The C shaped tube configuration can easily be adjusted to avoid excessive tube and shell stresses due to differential expansion.

Access openings (manways) in upper and lower steam side plena are provided for easy access to tube ends for inspection and repair. The steam generator configuration is ideal for once through operation to produce 1500 psi steam at 900°F. It could also be used to produce saturated steam in either once thru or recirculated operating modes.

Li_2O enters the top shell opening as shown, flows downward over the finned tubes and exits from the bottom shell connection. Baffle plates are used to avoid flow of the moving bed into upper and lower horizontal tube portions of the unit.

This steam generator configuration permits use of a shell with circular cross sections welded to tube sheets and connecting Li_2O piping. No expansion joints are required.

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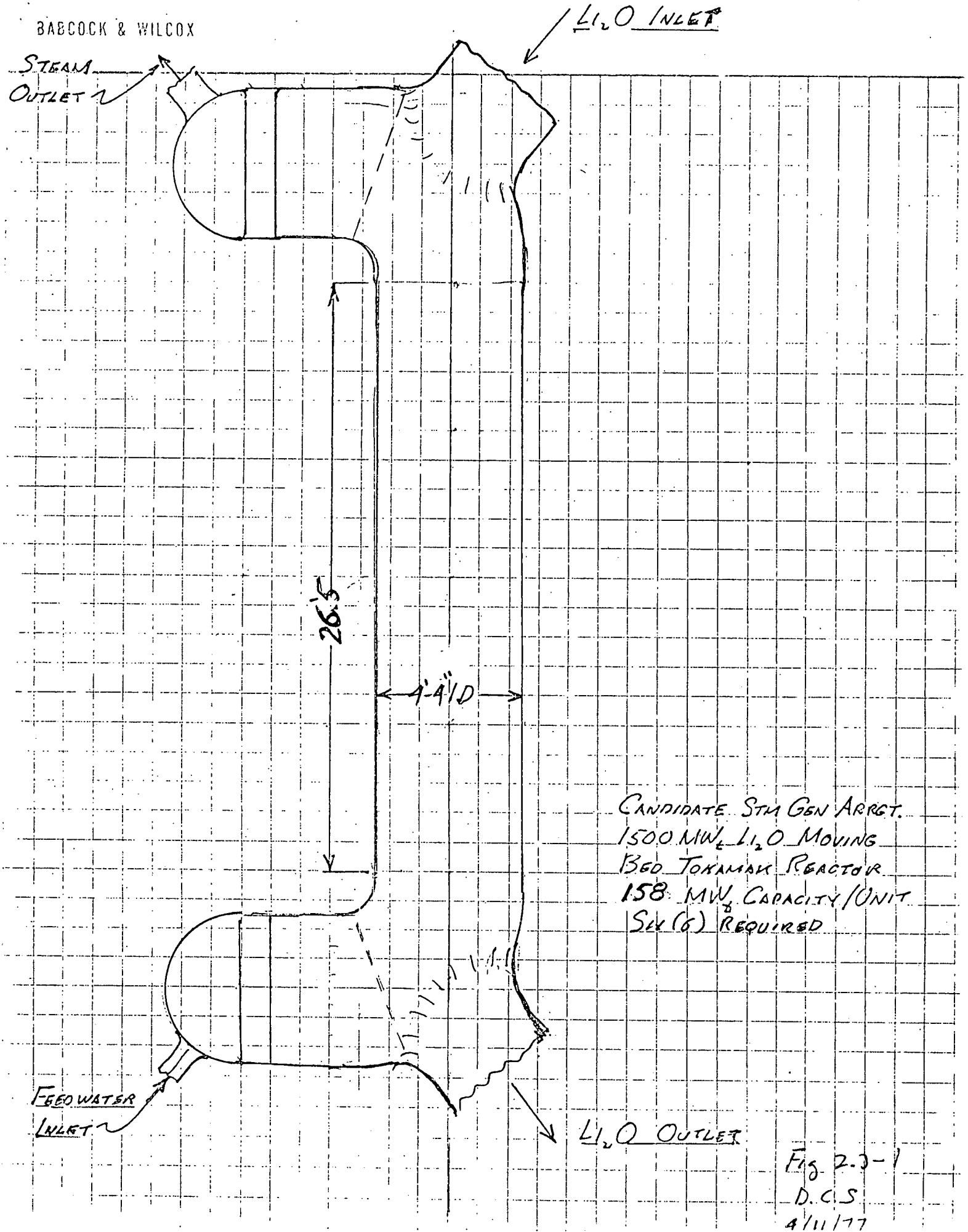

CANDIDATE STM GEN ARRGT.
1500 MW_t Li_2O MOVING
BED TOKAMAK REACTOR
158 MW_e CAPACITY/UNIT
SIX (6) REQUIRED

Fig 2.3-1
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D.C. Schluderberg
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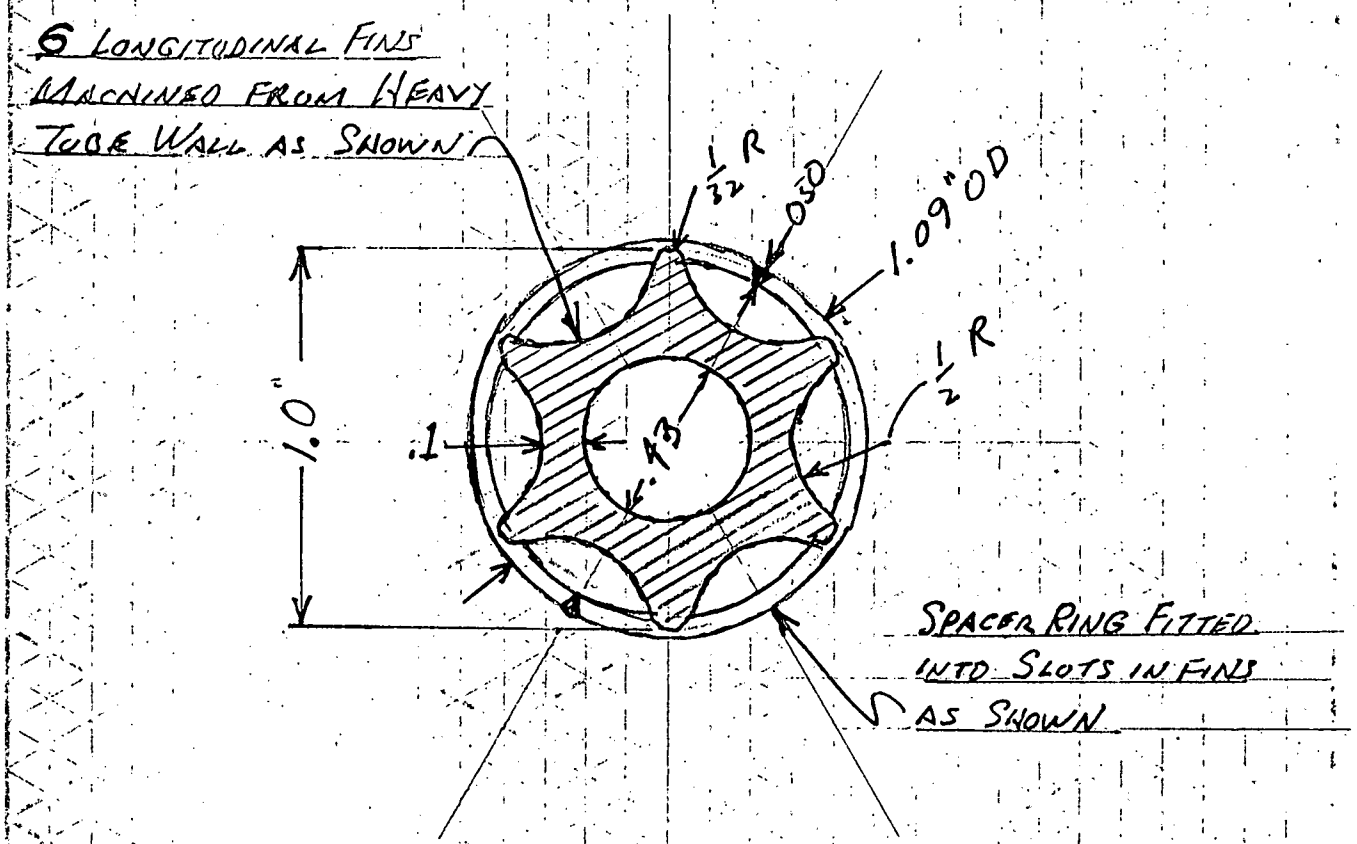

FIG 2.3-2
CANDIDATE TUBE DESIGN
Li_2O MOVING BED STM GEN.
SCALE - DOUBLE SIZE

D. C. Schnuderberg
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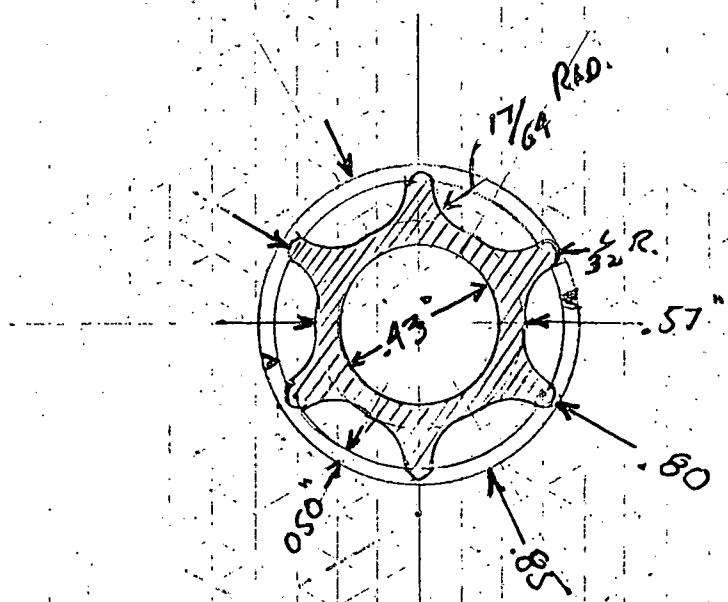

FIG. 2.3-3
CANDIDATE TUBE DESIGN
Li_2O MOVING BED REHEATER
SCALE - DOUBLE SIZE

2.3.2.2 Finned Tube Design

The finned tube designs Figs. 2.3-2 and 2.3-3 provide extended surface to improve Li_2O to tube heat transfer in a configuration considered suitable for eddy current or UT inspection. The smallest practical ID (.430") was selected on the basis of inspection probe design limitations. This in turn reduced shell side hydraulic diameter to improve Li_2O heat transfer. A minimum tube diameter also provides the highest practical amount of heat transfer surface per ft^3 of heat exchanger and therefore the lowest possible Li_2O inventory requirement (an important requirement for good tritium management).

If necessary, the flow area restriction produced by spacer rings can be relieved at such locations by removing an equivalent amount of material from every other fin.

2.3.2.3 Steam Generator and Reheater Sizing

Preliminary sizing of these components has been accomplished using a Li_2O to tube heat transfer coefficient of 450. This number will be checked next month by data provided by Dr. F. A. Zenz and which is expected to predict a similar value. Important design parameters are listed below.

	Steam Generator	Reheater
Number req'd	6	6
MWt - each unit	157.63	42.37
Li_2O Flow, each unit Lb/Hr	3,458,464	928,802
Steam Flow - Lb/Hr	564,274	689,242
Finned Tube Lenghth - Ft	26.5	26.5
No Tubes/Unit	2038	1420
Shell ID in	54	36

3.0 Task III Particle Transport System Design

3.1 Objectives of Task III

The objectives of this task are as follows:

- o Identify preliminary conceptual design of particle transport system
- o Identify required research and development work.

This work will consist of the following three phases:

PHASE I. Establish Reference Ground Rules and Parameters

This phase, which parallels the work performed in Phase I of Task II, will consist of an initial listing of design parameters, ground rules and assumptions based on work performed on the concept prior to this contract proposal. In the second subphase, this material will be reviewed by experienced Babcock & Wilcox Company people and others, as required, for comments and recommendations. The third sub-phase of this phase will incorporate the resulting comments and recommendations into an approved set of design parameters and ground rules, including a reference method of particle transport.

The descriptive matter generated will include information on the following subjects:

1. Applicability of current technology
2. Particle attrition
3. Pumping power
4. System component wear
5. Component design

6. Provision for continuous steam generation.

PHASE II. Identify Required Research and Development Work

This phase will scope the research and development work considered necessary to complete development of the particle transport system and components.

3.3 Work Performed During Period Ending May 31, 1977

Work on this Task remained at a relatively low level until Chicago Operations Office approval was obtained on May 16, 1977 to enlist the consulting services of Dr. Fred A. Zenz.

Dr. Zenz spent Thursday evening, May 26th and Friday, May 27th in Lynchburg in discussions with the writer, D. C. Schluderberg, and Dr. T. A. Thornton of B&W.

The discussions proved to be very productive. Current particle transport, fluid catalyst, and other related technologies tend to show the reference moving bed Nuclear Steam Supply System to be entirely feasible with the major problem being engineering research and development to establish this application of particle transport and heat transfer technology. This is summarized in the following sub-sections.

3.4 Reference Ground Rules and Parameters

The initial concept assumed the Li_2O moving bed would consist of 75-150 micron spheres (microspheres) having intercommunicating pores suitable for tritium removal in a sidestream by an unspecified method. It was further assumed that fines produced by particle attrition would have to be kept to a low level to retain the desired free flowing properties.

Our discussions with Dr. Zenz indicated that these restrictions may possibly be relaxed to some degree. Continuous circulation of irregular shaped particles will tend to knock off their sharp edges and produce an equilibrium bed condition having adequate free flowing characteristics, a relatively stable particle size spectrum and little or no further particle attrition.

This tends to materially reduce the possibility that particle attrition rate and fines production will be troublesome from the standpoint of maintaining free flowing characteristics, particle structural strength limits due to required pore structure or permissible rate of particle reconstruction.

An interface meeting held at the University of Wisconsin in Madison on May 12th and 13th (See Task IV) led to our conclusion that fines production will be helpful in tritium management. Bed particles reduced to fines of a given size spectrum will tend to be those having the longest bed residence time and therefore a tritium content roughly twice the bed average. Thus, for any method of tritium recovery, the production of fines will tend to halve the bed tritium inventory. This will improve licensability and reduce reactor tritium requirement for initial operation.

In view of the above, it will be necessary to characterize particle size, shape and free flowing properties on the basis of both initial and equilibrium conditions by suitable experiment. This work can also be used to determine surface wear and flow friction characteristics.

A simple experimental set up may be suitable for this work. It would consist of a number of torus shaped tubes each partially filled with a candidate Li_2O particle type. These tori would be mounted in a vertical plane and rotated so that the contained material flowed downward relative to the tube wall to balance lift produced by drag on said wall.

Results of these tests would provide a candidate material for use in a larger engineering prototype loop containing candidate heat transfer configurations, particle transport (lift) system, fines removal bypass, etc.

3.5 Methods of Particle Transport

The methods of particle transport which may be considered for this application are listed below:

a. Light phase gas transport
b. Screw elevators, mechanical
c. Bucket elevators, mechanical
d. Mass lift
e. Other

Suitability of each of these methods for the reference application was discussed with Dr. Zenz. The obvious choice appears to be mass lift which has found acceptance in circulation of catalyst particle beds under similar conditions.

Light phase gas transport is used in particle transport applications not involving continuous circulation. Particle attrition, system wear and high power requirement tend to preclude this method.

Screw elevators are also useful in applications not involving circulation. Attrition is higher than bucket elevators and mass lift. In addition, solids flow rate in the reference application would require considerable extrapolation of current screw sizes with problems possibly arising therefrom.

Bucket elevators have the desired low attrition characteristics for continuous circulation and have been used to circulate catalyst beds. High maintenance caused their replacement by the mass lift method. Since such maintenance would be even more difficult in this application due to the presence of tritium and activated corrosion products, it appears that there is even greater reason to discard bucket elevators for the mass lift system.

A search for other possible methods suggests that the Archimedes spiral lift such as used in ancient times for irrigation pumping may have application here especially where small continuous flows are required. Its advantage over the mass lift method is continuous flow and elimination of charging tanks, receiving tanks, compressors or gas filters.

Future work will therefore be directed toward evaluation of the mass lift and Archimedes spiral methods of particle lift.

4.0 Task IV Interface Information for University of Wisconsin

4.1 Objectives of Task IV

This task has the purpose of supplying and interchanging information developed from this independent research effort to the University of Wisconsin as required to maintain a well coordinated joint effort in developing the Li_2O moving bed Tokamak Fusion Power Reactor Concept. Information interchange will be necessary in the following areas:

1. General NSS parameters
2. NSS arrangement
3. Microsphere information
4. Steam leak monitoring and isolation
5. Inspection and maintenance

4.2 Work Performed During Period Ending May 31, 1977

As noted previously in Section 1.0, 2.0 and 3.0 above Dr. T. A. Thornton of the B&W Lynchburg Research Center and D. C. Schluderberg of B&W's Nuclear Power Generating Division visited Madison on May 12th and 13th to help establish plant

parameters and steam cycle and discuss work on Li_2O microsphere production. The information developed is covered in the above sections.

5.0 Task V Reporting

This letter report is the first of five monthly letter reports required to fulfill reporting requirements of this contract.

D. C. Schluderberg