American Institute of Chemical Engineers

AIChE®

2006 National Student Design Competition

If there are any questions about the Design Competition,
student chapter advisors and design course instructors
are asked to contact:

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Please read the rules on the following pages carefully before submitting a solution to AIChE.

AIChE

November 2005

Dear Chemical Engineering Department Heads and Student Chapter Advisors,

I am pleased to send you the 2006 AIChE National Student Design Competition statement. Please forward it to those faculty teaching design courses. Following is this year's challenge:

"Crystallization of Uranyl Nitrate from Dissolved Spent Nuclear Fuel (SNF)."

As always, the names of the sponsoring organization and the authors are being withheld to ensure confidentiality. Both will be announced after the deadline, June 5, 2006.

An entry form – required for each participant -- is available as a separate attachment, and must be submitted along with the completed solution.

We welcome participation by individuals and teams of up to three students. Please indicate the names of all team members on each entry form, and be advised that each team member is required to submit a separate entry form.

Because the National Student Design Competition is a benefit of AIChE student membership, entrants must be AIChE national student members. Any non-member submissions will not be considered. To join, students can download a membership application form at http://www.aiche.org/students/.

Please take time to review the rules, found on the following pages. It is important that all solutions strictly adhere to the Final Report Format.

All submissions must be submitted in an electronic format. Submissions must be no more than two documents (totaling 100 or fewer pages) of the following format: PDF, HTM, or MS-Word. The requested format is a single PDF file—the Adobe Acrobat program can be used to combine pages from different sources into one document.

Student Chapter Advisors are asked to select the best solution or solutions, not to exceed two from each category (individual and team). Please email each entry separately to awards@aiche.org. In the event that the electronic file is too large to send via email, a link to the solution may be sent to this email address, where the link is expected to be active for no more than 2 days and AIChE will contact the advisor as to when the link has been copied by AIChE. The solution should then be removed from the University's system.

Solutions must be e-mailed/postmarked no later than Monday, June 5, 2006. Please maintain a copy for your files. To order additional copies of the Student Design Competition statement, email awards@aiche.org or call AIChE at 1-800-AIChemE (242-4363).

If I can be of assistance, please contact me at (212) 591-7107 or via email at awards@aiche.org. Questions relating to the substance of the design problem should be directed to Professor Richard L. Long, New Mexico State University, at (505) 646-2503 or rilong@nmsu.edu.

Thank you for your support of this important student competition.

Sincerely,

Gordon Ellis
AIChE Volunteer and Membership Activities

AIChE National Student Design Competition 2006

Rules of the Contest

Solutions will be graded on (a) substantial correctness of results and soundness of conclusions, (b) ingenuity and logic employed, (c) accuracy of computations, and (d) form of presentation. Accuracy of computations is intended to mean primarily freedom from mistakes; extreme precision is not necessary.

It is to be assumed that the statement of the problem contains all the pertinent data except for those available in handbooks and literature references. The use of textbooks, handbooks, journal articles, and lecture notes is permitted.

Students may use any available commercial or library computer programs in preparing their solutions. Students are warned, however, that physical property data built into such programs may differ from data given in the problem statement. In such cases, as with data from literature sources, values given in the problem statement are most applicable. Students using commercial or library computer programs or other solution aids should so state in their reports and include proper references and documentation. Judging, however, will be based on the overall suitability of the solutions, not on skills in manipulating computer programs.

The 2006 National Student Design Competition is designed to be solved either by an individual chemical engineering student working entirely alone, or a group of no more than three students working together. Solutions will be judged in two categories: individual and team. There are, however, other academically sound approaches to using the problem, and it is expected that some Advisors will use the problem as classroom material. The following confidentiality rules therefore apply:

1. *For individual students or teams whose solutions may be considered for the contest:* The problem may not be discussed with anyone (students, faculty, or others, in or out of class) before or during the period allowed for solutions. Discussion with faculty and students at that college or university is permitted only after complete final reports have been submitted to the Chapter Advisor.

2. *For students whose solutions are not intended for the contest:* Discussion with faculty and with other students at that college or university who are not participating in the contest is permitted.

3. *For all students:* The problem may not be discussed with students or faculty from other colleges and universities, or with individuals in the same institution who are still working on the problem for the contest, until after June 5, 2006. This is particularly important in cases where neighboring institutions may be using different schedules.

Submission of a solution for the competition implies strict adherence to the following conditions: **(Failure to comply will result in solutions being returned to the appropriate Faculty Advisor for revision. Revised submissions must meet the original deadline.)**

ELIGIBILITY

- ONLY AIChE NATIONAL STUDENT MEMBERS MAY SUBMIT A SOLUTION. Non-member entries will not be considered. If you would like to become a National Student member, we must receive your membership application prior to submitting your solution. Application forms are found at http://www.aiche.org/students/.
- Entries must be submitted either by individuals or by teams of no more than three students. Each team member must meet all eligibility requirements.
- Each Faculty Advisor should select the best solution or solutions, not to exceed two from each category (individual and team), from his or her chapter and submit them per the instructions below.

TIMELINE FOR COMPLETING THE SOLUTION

- A period of no more than thirty (30) days is allowed for completion of the solution. This period may be selected at the discretion of the individual advisor, but in order to be eligible for an award, a solution must be emailed/postmarked no later than midnight June 5, 2006.
- The finished report should be submitted to the faculty advisor within the 30-day period.

REPORT FORMAT

- The body of the report must be suitable for reproduction, that is, typewritten or computer-generated. Tables, supporting calculations and other appendix material may be handwritten.
- The solution itself must bear no reference to the students' names and institution by which it might be identified. Please expunge all such references to the degree possible.
- **Final submission of solutions to AIChE must be in electronic format (pdf, HTM, or MS-Word) and must be 100 pages or less. The final submission to AIChE must consist of 1 or 2 electronic files totaling 100 or fewer pages.**

SENDING THE SOLUTION TO AIChE

- There should not be any variation in form or content between the solution submitted to the Faculty Advisor and that sent to AIChE National. The Student Chapter Advisor, or Faculty Advisor, sponsoring the student(s), is asked to maintain the original manuscript(s).
- Email an electronic file of the solution accompanied by its corresponding entry form to awards@aiche.org.

- **DEADLINE: Entries must be emailed no later than midnight June 5, 2006.**

The American Institute of Chemical Engineers
2006 National Student Design Competition

Crystallization of Uranyl Nitrate from Dissolved Spent Nuclear Fuel (SNF)

1.0 Introduction and Scope

Spent fuel rods from nuclear reactors in power plants are initially stored under water for periods of 10 to 30 years. During this time, the fission products with short half-lives have the opportunity to decay. This reduces the radiation from the fuel and reduces radiation exposure during fuel separation. Uranium makes up about 95 weight % of the spent fuel. The first step in current separation processing is dissolution of the spent fuel using nitric acid. Uranium is then removed in the current process using liquid-liquid extraction with a hydrocarbon solvent. An alternative separation process removes crystallized uranyl nitrate hydrate from the spent fuel acid solution. Advantages are avoiding the extraction solvent recovery and solvent waste processing, and reducing the volume of the remaining stream of nitric acid, fission products and actinides. In addition, the size of the high radiation processing area is reduced. The scope of this problem is to design a process for uranium separation based on crystallization instead of liquid-liquid extraction.

2.0 Objective

There is a need for an improved separation process for removal of uranium (95% of the spent fuel mass) from SNF. The extraction process currently used is 50 years old and has been developed from a process originally designed for recovery of plutonium from spent reactor fuel. Process research into uranyl nitrate crystallization has been reported in Germany and Japan. The objective of this problem is to design a process consisting of unit operations to remove and purify uranyl nitrate crystals, produce a nitric acid stream that can be sent to a recovery/recycle unit, and to produce a concentrated nitric acid solution containing the 'fission product salts' for further separation of actinides and fission products. This process should include storage and equipment in sufficient detail to allow a cost comparison to the traditional UREX extraction process. However, such a comparison is outside the scope of this problem.

The following format should be used to prepare the proposal:

- Title Page
- Table of Contents
- Executive Summary: One page condensation of the report.
- Introduction: Restatement of the problem with background and objectives.
- Discussion: Present the alternative design options such as mixing devices, volume reduction techniques, crystal purification methods and assumptions and methods of minimizing radiation exposure. Provide all results and supporting calculations in SI units.
- Summary: Summarize the results of the analysis, conclusions and recommendations.
- Conclusions: Interpret your results and provide a structure that places the most important ones first.
- Recommendations: Clearly state the design specification and safety requirements for the process chosen.
- Project Assumptions: State the design or economic assumptions or any important fabrication or inspection requirements, i.e., ASME pressure vessel code stamps, nuclear service quality assurance requirements or inspection requirements.
- Process Flow Diagram (PFD): Show a flow scheme with all major process equipment, and with a stream number for each major process stream. Show the basic process control instrumentation including points of measurement for temperatures, pressures, flow rates, slurry densities, sample points, level measurements and other associated control elements.
- Mass and Energy balances: Provide a mass and energy balance summary associated with the Process Flow Diagram streams and equipment. Display the stream number, the component molar and mass flow rates, the temperature and pressure. Show phase details for each slurry. Show energy loads on heat exchangers. Show power loads on pumps and/or compressors. Summarize utility loads.
- Hazard and environmental analyses: Identify and discuss material, industrial and radiological hazards and the appropriate design or administrative controls.
- Equipment summary: Provide a list of all equipment used in the process, including equipment type and description, operating limits, sizes, duties, estimated purchase costs, important fabrication specifications and materials of construction.
- Economic analysis: Include a discussion of the economic analysis and cost estimate of the final design, including a COM.

Appendix

- Computer Simulators: While simulators may be used, as indicated in the Contest Rules, the data presented in the problem are most applicable and thus they take precedence over any simulator model calculations. Any software used should be adequately documented. For example, if a spreadsheet is used, the cell formulae must be shown
- Back up data and hand calculations
- Provide documentation in an attached appendix of any additional calculations or models used to set the final design. Also, provide nomenclature and a list of all references used.

Process Description and Design Basis

PROCESS DESCRIPTION:

In this process, the first separation will be to remove the uranium from the solution using a crystallizer. This separation process must take the dissolution effluent and perform unit operations that will remove the uranium to meet the specified recovery. The crystals will be uranyl nitrate hexahydrate. The crystals must then be cleaned to achieve the specified purity. There are several mechanisms for impurities – fission products and actinides – to contaminate the uranyl nitrate crystals. For this design, the basis for contaminants will be this: the weight of equilibrium liquid that remains on the filtered crystals will be 10.0 weight percent of the dry weight of uranyl nitrate hexahydrate.

So there will be no fission product contaminates within the crystals. The contaminants will be present in the remaining equilibrium liquid on the filtered crystals. There will be no partitioning of the fission products. They will be handled as a single component that is fully soluble in the liquid phase. The average molecular weight of the fission products, present in solution as their nitrate salts, is 319.1.

There can be only three effluent streams from the unit.

1) If water and nitric acid are removed by vaporization, they may be condensed to liquid phase and removed as an effluent stream. Actually, outside the scope of this design, such a stream can be distilled to produce concentrated nitric acid and recycled to dissolution.
2) A crystalline product stream of spec purity uranyl nitrate hexahydrate, with 10% filtrate liquid present
3) A liquid effluent stream that would be directed to additional unit operations to separate the fission products and actinides. This stream will contain everything that was in the feed and was not removed in streams #1 and #2 described above.

A supply of pure 15 Molar nitric acid will be available for use in the process.

DESIGN BASIS: The purpose of this process is to remove uranyl nitrate from spent reactor fuel dissolution effluent. The uranyl nitrate is to be removed by crystallization.
Flow rate is based on 500 MTPY Uranium, and is liquid effluent of the dissolution step. All fission products and actinides are grouped together and named ‘dissolved salts’.
Operating Time: 5000 hours per year.
Feed composition:

Uranyl Nitrate	50.37 wt.%
Dissolved salts	3.05 wt.%
Water	41.58 wt.%
Nitric Acid	5.00 wt.%

Specified recovery of Uranyl Nitrate as hexahydrate crystals: 91%
Specified purity of uranyl nitrate hexahydrate product crystals: Ratio of Fission Product Salts/ Uranyl Nitrate <1.5 e- 6.

NOTE: Chemical operations in a radioactive environment require the equipment to have few moving parts and be as simple as possible. For example, a stationary filter is better than a belt filter or a centrifuge. Gravity flow is better than a pump. However, with this guidance, it should be left to the designer to specify the equipment. It is important to recognize that if there are two well designed processes, the simpler design will have a strong advantage.

3.0 Technical Data

Physical property data, materials of construction information, cost information, capacity factors, and physical constraints on the process are required. They are given below.

Section 4.1

Phase Equilibria – UN solubility, wt% = f(Temp, acid wt%)

PHASE EQUILIBRIA:
AQUEOUS SOLUBILITY EQUILIBRIA:

Temp= +30.2 °C	
Wt.%	Wt.%
UO2(NO3)2	HNO3
61.00	0
60.73	0.14
50.03	7.1
49.88	7.3
46.70	12.5
44.56	18.1
43.40	23.0
42.00	25.4
41.30	25.7
40.38	27.6
39.08	30.6
38.50	31.3
38.44	31.5

Temp= minus 18 °C	
Wt.%	Wt.%
UO2(NO3)2	HNO3
45.14	0
44.93	0.14
41.70	2.3
24.14	15
17.25	21.2
4.06	40.1

Section 4.2
Physical & Transport Properties

Vapor Phase:

Specific heat= 0.4 BTU/#-°F for acid & water (composition changes don't matter enough to separate acid and water)

= 0.25 BTU/#-°F for air, if needed

Viscosity = 0.05 cp, all (unimportant)

Thermal conductivity – Use k of water for all liquid streams

Density: ideal gas, compressibility = 1.0 for all sensible flash conditions, comps.

Liquid Phase: Specific heat for acid/water mix = 0.96 BTU/#-°F., good for all compositions.

Specific heat for uranyl nitrate & other salts = 0.25 BTU/#-°F.

Liquid viscosity: Good data not available. Recommend using 10 to

15 times water viscosity.

Thermal conductivity: use 0.3 BTU/ft-hr-°F.

Liquid Density: Use published acid water density.

Data Point: Liquid Density for 5 wt% acid and 500 gm/L. U as uranyl

nitrate is about 1.8 gm/ml

Assume all crystals of uranyl nitrate are hexahydrate form.

Phase change latent heat of vaporization = 1200 BTU/#, all compositions used

Phase change heat of fusion for water to hydrate is 500 BTU/# and for UN is 300 BTU/#.

Section 4.3
Materials of construction will be ss316L

Section 4.4
Nitric Acid Vapor- Liquid Data at 1atm (wt %):

T(deg C)	x, nitric	y, nitric
100.000	0.000	0.000
104.000	0.067	0.003
104.500	0.072	0.003
106.500	0.102	0.010
107.000	0.110	0.012
108.500	0.135	0.020
109.500	0.141	0.023
110.500	0.162	0.035
111.500	0.181	0.042
112.5	0.181	0.042
114.5	0.217	0.082
115.5	0.233	0.096
117.5	0.282	0.165
119.200	0.348	0.297
119.400	0.341	0.297
120.000	0.383	0.375
119.900	0.374	0.375
118.5	0.450	0.564

Section 4.5

Table 4.5.1
Cost Summary

Item	Cost
Electricity	$0.10 kwatt-hr
Steam	$21.00 per 1000kg
Cooling water	$0.03 per 1000 liter
Engineering labor	$60.00 per hour
Operations labor	$85.70 per hour
Maintenance labor	$76.00 per hour
Solid waste	$50. per kg
Liquid waste	$0.10 per liter

Table 4.5.2
Capacity factors

Item	Factor
Operating schedule	5000 hrs per year
Feed storage	5 days
Product storage	5 days

Table 4.5.3
Spent Fuel Rod Composition

	Atomic wt	gms/kg
U		946
Pu	239	10.7
Am	241	0.6
Np	237	0.6
Cu	140	0.044
Xe/Xenon	131.3	6.56
Kr/Crypton	83.8	0.42
Rb	85.5	0.4
Sr	87.62	0.90
Y/Yttrium	88.9	.445
Zr	91.2	3.5
Mo	95.9	4.1
Ru	85.5	2.7
Rh	102.9	0.5
Pd	106.4	1.74
Cd	112.4	.11
Te	127.6	.48
Cs	132.9	3.0
Ba	137.3	2.1
La	139.9	1.2
Total		986.099

4.0 References

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3. E. Henrich, U. Bauder, R. Marquardt, W. G. Drickenbrodt, K. A., Wittmann, A Concept for product refining in the PUREX process, Atomkernenrgie Kerntechnik, 1986, 48 (4), 241-245.
4. A. Shibata, Y. Koma, T. Koyama, H. Funasaka, Study of Applicability of Crystallization to PUREX Process, Proceedings of the ATALANTE 200 Conference.
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7. DOE Standard, Guidelines for Preparing Criticality Safety Evaluations at DOE Non-Reactor Nuclear Facilities, DOE-STD-3007-93, November 1993, Change Notice No. 1, September 1998.
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9. DOE Standard, Critical Safety Self Assessment, DOE-STD-1158-2002, November 2002.

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