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Some Logistical Considerations in Designing a System of Deep Boreholes for Disposal of High-Level Radioactive Waste

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Abstract

Deep boreholes could be a relatively inexpensive, safe, and rapidly deployable strategy for disposing Americaś nuclear waste. To study this approach, Sandia invested in a three year LDRD project entitled "Radionuclide Transport from Deep Boreholes." In the first two years, the borehole reference design and backfill analysis were completed and the supporting modeling of borehole temperature and fluid transport profiles were done. In the third year, some of the logistics of implementing a deep borehole waste disposal system were considered. This report describes what was learned in the third year of the study and draws some conclusions about the potential bottlenecks of system implementation.

Acknowledgment

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1 Introduction

To dispose of the radioactive waste produced as a byproduct of the operation of nuclear power plants, the United States was considering a mined geologic repository at Yucca Mountain, NV. However, this project was terminated in 2011. Thus, alternative solutions have been proposed and are being studied. One of the most promising alternatives is the placement of the spent fuel assemblies into the lower 1-2 *km* portion of vertical boreholes. Preliminary evaluation of this deep borehole disposal of high-level radioactive waste and spent nuclear fuel indicates the potential for excellent long-term safety performance at costs competitive with mined repositories as described in SAND2009-4401. Therefore, additional studies have been undertaken to complete reference designs for deep borehole disposal. Technical report SAND2011-6749 is a comprehensive summary of the requirements and objectives for one such design. This report describes some of the details that are a consideration in designing a system of deep boreholes for the disposal of nuclear waste. Specifically, it summarizes some of the activities of year three of the LDRD project "Radionuclide Transport from Deep Boreholes."

In years one and two, this LDRD completed the borehole reference design and backfill analysis, and performed the supporting high resolution THM modeling of borehole temperature and fluid transport profiles. In year three, the LDRD project was carried out in conjunction with a complimentary Department of Energy study funded to identify and develop a borehole demonstration site. While the DOE project focused on the basic feasibility and demonstration of a deep borehole, the LDRD work focused on the logistics of a deep borehole waste disposal *system*. To this end, the following three problems were posed:

- What is the optimal number of deep borehole waste disposal sites?
- What is the best procedure for rod consolidation and transportation?
- What is the best drilling and coordination strategy for constructing the deep borehole system?

In the next paragraphs, each of these questions is examined in more detail.

The problem of determining the optimal number of deep borehole sites must take both location and geology into consideration. Geological considerations such as depth to the crystalline basement and seismic hazards must be taken into account. In addition, location must be considered with respect to transportation costs. It may be the case that a proposed site is too isolated so that the financial requirements of transporting waste to the location make the site undesirable. Since each site will have construction and operation costs, site capacity should also be a consideration. In other words, if a proposed site is centrally located but capacity limited, then it may be cost prohibitive. The questions of location, geography and capacity can certainly be studied and associated uncertainties can be computed. However, the political implications of disposal site location present a set of complicated and challenging questions. The uncertainties associated with the public reaction to nuclear waste disposal are significant. Mathematically, the optimal number and location of sites is dependent on political constraints, and these constraints will be difficult to determine. Moreover, such constraints may change over time, with additional public education, or as a result

of changes in leadership. Therefore, although the number of disposal sites in the system is an interesting and important issue, the LDRD team did not feel that useful results could be obtained at this time, and this problem was not studied in any detail.

Determining whether or not the spent fuel rod assemblies should be consolidated for waste disposal is not marred by political considerations. The related issues are far more objective. Namely, the cost of consolidating the fuel rod assemblies must be weighed against the costs of drilling the boreholes. It may be the case that disassembled packages will allow for boreholes of smaller diameter or a reduced number of boreholes and thus save on installation costs. Furthermore, smaller waste packages may reduce transportation costs. At first glance and without any additional information, it appears that disassembly would be the preferred method. On closer examination, it was learned that the disassembly process may be prohibitive to the system design. This is due to the fact that the disassembly work must be done by highly trained individuals and overseen by safety regulators. At this time in the project, it is unclear whether or not disassembly is even allowed as a possibility in the system design. Therefore, the LDRD team opted not to study this problem at this time.

This project focused on problem three, the drilling and coordination strategy. The remainder of this report covers the information gathered regarding this problem. Section 2 proposes a mathematical formulation of the problem and describes the relevant variables. Section 3 describes a simplification and how it was used to determine some initial answers to questions of construction time. Finally, Section 4 discusses what was learned and sets the stage for future work in this area.

2 The Staging Problem

The staging of the drilling of the system boreholes and the related transport of the waste to these boreholes can be posed in a few different ways. Both the time and the cost of the project should be considered, but different problem formulations may weight their importances differently. Consider the following formulations. Let $c(\mathbf{x})$ be the total project cost and $t(\mathbf{x})$ be the total time required to completed the project where $\mathbf{x}$ is a vector of the variables that describe the system design. Assume that the project must be completed in T years (or less) and for a budget of at most C dollars. Then, one optimization formulation would be

$$\begin{aligned} \min \quad & c(\mathbf{x}) \\ \text{s.t.} \quad & t(\mathbf{x}) \leq T \end{aligned} \tag{1}$$

where the cost is minimized subject to the constraint of time. Alternatively, the time could be optimized subject to the cost constraint as follows

$$\begin{aligned} \min \quad & t(\mathbf{x}) \\ \text{s.t.} \quad & c(\mathbf{x}) \leq C \end{aligned} \tag{2}$$

In a multi-objective format, minimizing both the cost and the time could be the goal. Such a formulation would give a curve of possible outcomes in which the decision maker could see the trade-offs between cost and time.

One way of reducing the multi-objective problem to a single objective is to use the function

$$f(\mathbf{x}) = \alpha c(\mathbf{x}) + \beta t(\mathbf{x}) \tag{3}$$

where α and β are constants that represent the importance of one objective with respect to the other. In general, it can be difficult to determine reasonable values for α and β. For the specific staging problem, determining these values seems particularly difficult. Given the politics of the (government) system implementation, determining these values is a problem in itself. In fact, the α and β would have to be included in any subsequent uncertainty study. Also, note that for the specific staging problem studied here, the complete relationship between time and cost is complex and not clearly understood. For example, because of lack of resources and equipment, it does not seem logical that the project could be completed in half the time if the budget is doubled.

The drilling and coordination objective input $\mathbf{x}$ has several variables that will determine the cost and time frame of the project. The first is the number of locations, N. As previously discussed, because of geological features, it is unlikely that each nuclear power plant will be able to dispose of its own waste at a borehole located within 5 miles of the plant. Moreover, there are complex political considerations associated with the location(s) of the boreholes. To avoid these, in this study, the number of locations will be considered only with respect to geological aspects. Using

the assumption that 600 boreholes, 6 for each of the 100 nuclear power plants, are required in the system, solutions are considered over a range of 1 to 100. This eliminates the need to include any political constraints in this study or to identify any specific borehole sites.

Other variables to consider are related to the resources available for the drilling activities. These include both rigs and personnel. Discussions with experts revealed that conventional rigs can and will be used for drilling. Moreover, it is estimated that there are approximately 6 rigs in the US and 10 rigs internationally that could complete the job required. Although these rigs will likely be unavailable for the deep borehole project envisioned by this project, it is known that machinery with the required specs can be made and purchased. The same may not be true for the waste emplacement process. Special rigs or special modifications to existing rigs may be required. Experts also agree that specialists will not be required to complete the drilling. More investigation is needed to better understand the costs associated with paying the personnel. In addition, the cost of moving rigs must be determined so that questions about the economics of number of sites versus cost of equipment can be answered. Many of these unknowns can be estimated at this stage in the project and specified more exactly at the bidding stage of the construction when specialists can consider and price these activities.

Time is another important constraint to consider. There are three basic tasks that contribute to the system staging time. They are: borehole construction, waste emplacement, and borehole sealing. As for borehole construction, it is known that at the drilling phase, ground penetration can be as slow as 1m per hour and that the total required depth is 5000 m. It may be cost effective to use different rigs for the drilling, emplacement, and sealing. But, as with the rig transport costs, this will remain uncertain until specialists can bid on these activities. Much has been done to estimate the cost of drilling and using a borehole, and specific values are given in SAND2011-6749. These numbers were used in the studies completed in this project. The uncertainties associated with these values will come into play in subsequent studies.

Finally, we note that this study will utilize the cost constraint identified in SAND 2011-6749, that the entire project be completed for no more than 40 million dollars. More specific cost breakdowns are given and can be applied in the problem formulations included in this study. It should also be noted that it is assumed that revenues are earned at a rate of 400 dollars per kilogram of waste.

Given the information collected during the time frame of this LDRD, it was decided that it is more informative to consider the problem of minimizing the time subject to the cost constraints, equation (2). In this case, the objective function will be to minimize the total time objective

$$t(\mathbf{x}) = \sum_{i=1}^{N} t_i(\mathbf{x}) \tag{4}$$

where t_i is equal to either the time required to transport and emplace the waste from plant i to a borehole site or the time to drill and emplace the waste at plant i at a site within five miles of the plant. In this study, the time required to seal the borehole was considered negligible and thus was ignored. The variabilities associated with transporting the waste include the number of plants at

which drilling within a 5 mile radius is infeasible due to geological features, the transportation costs, and the availability of transport casks. Some of the uncertainty issues associated with the drilling include the number of boreholes drilled assuming that a certain percentage are found to be geologically unsuitable (i.e. the drilling process fails), availability of rigs, availability of materials for the borehole (i.e. steel), and the time required to place the waste. In both cases, the time and resources available for waste emplacement can also add uncertainty.

There is much information available regarding the transport of nuclear materials. One of the primary sources for this information is the NEPA (National Environmental Policy Act) website which contains publicly available reports describing the environmental impact of proposed DOE activities. Specifically, report EIS-250 relates to using Yucca Mountain as a mined geologic repository for nuclear waste. Part of the report describes the potential impacts of transporting spent nuclear fuel materials nationally and in the State of Nevada. This information can also be used to describe the transportation issues related to a deep borehole system. Moreover, a cost calculation package was designed to estimate transportation costs, and this can be included as part of the cost objective function.

3 Initial Estimates

The general question of how long the entire borehole disposal system project might take was examined. To do this, some simplifications of the total time equation (4) were made. First, it was assumed that there are $N = 100$ power plants and that each plant requires 6 boreholes to store its nuclear waste. Moreover, the assumption was made that the waste transportation tasks and drilling work can be carried out simultaneously. Thus, transportation does not add to the total time of the project, only to the total cost.

Then, let $n < N$ be the number of plants at which drilling is possible within a 5 mile radius. In this study, n will be varied between 1 and 100. Realistically, deep boreholes can only be drilled near approximately half of the sites, but for completeness, all scenarios are considered. Given the n sites, assume that the drilling is spaced as evenly as possible. For example, if drilling is to be done at 80 sites, then there will be 7 boreholes drilled at 40 plants and 8 drilled at the other 40. The time needed to complete each borehole is 186 hours as estimated in the SAND2011-6749.

Next, consider that there will be some rate of drilling failure. For this exercise, the failure rate percentages considered were 0, 10, 20, 30, 40, and 50. According to drilling experts, a realistic failure rate will be around 20%, but this exercise looked at a broader range of scenarios. From SAND2011-6749, the worst case scenario is that it takes 140 hours to determine that the geology is unsuitable for a borehole which is the total time required to construct the borehole minus the emplacement and sealing costs. In addition, assume that a rig can work 24 hours a day, 7 days a week. This is unrealistic as no rig can operate continuously work without some regular maintenance downtime. The time required to move a rig from one site to another should be included in the total time calculation. In this study, it is assumed that the time to drill an unsuitable hole is overestimated, but this is canceled out by the exclusion of rig transportation time and overestimation of rig working hours.

The complete results are given in a table in the appendix. Table 1 summarizes the results. Note that not unexpectedly, the number of drilling hours increases with the percentage of failure. The range of required drilling hours varies with the number of disposal sites in the system. It is interesting to note that the relationship between the number of drilling hours required and the number of sites is not linear. This is due to the constraint that boreholes be evenly distributed between sites.

Drilling Failure Percentage	Min Number of Drilling Hrs	Max Number of Drilling Hours
0	113280	195600
10	126720	279600
20	148560	363600
30	178800	447600
40	218000	531600
50	265460	615600

Table 1. The percentage of drilling failures has a drastic effect on the number of drilling hours required to complete the borehole waste disposal system.

4 Discussion

The results obtained allow us to make some conclusions about implementing the borehole disposal system. They are:

- If only one or two rigs are used to create the system and the borehole drilling failure rate is around 50 percent, this project could take 70 (or more) years to complete.
- The number of rigs (less than 8) needed to complete the system in a 10 year time frame is reasonable given the number of appropriate rigs currently in existence.
- The biggest time saver appears to be limiting the drilling failures or the amount of time it takes to declare the geology unsuitable for a borehole and move on to a new attempt. Thus, further study of these issues is important.
- After additional information is obtained about the acquisition and operation of the rigs, optimization techniques can be used to help minimize the total time. For example, knowing how long it takes to move a rig or knowing that the drilling failure rate at one location is much lower than at another can guide the placement of the boreholes so that time is minimized.

The mathematical tools of optimization and uncertainty quantification can play an important role in the planning phase of the borehole waste disposal system. With additional information, the functions described in Section 2 can be modified to include more information. For example, the time equation (4) can be reformulated so that

$$t(\mathbf{x}) = \sum_{i=1}^{N} t_i(\mathbf{x}) = \sum_{i=1}^{N} m_i(\mathbf{x}) + \sum_{j=1}^{D} d_j(\mathbf{x}) \tag{5}$$

where m_i describes the time it takes to move the waste from plant i to the disposal borehole, D is the total number of borehole sites and d_j is the time it takes to drill the boreholes at site j. This formulation separates the borehole sites from the power plant sites. As discussed in this paper, currently, enough information exists to make good estimates for the transport costs m_i. More information is needed to make good estimates of the drilling costs d_j.

References

[1] B. W. Arnold, P. V. Brady, S. J. Bauer, et al. Reference design and operations for deep borehole disposal of high-level radioactive waste. Technical report SAND2011-6749, Sandia National Laboratories, Albuquerque, New Mexico 87185, 2011.

[2] P. V. Brady, B. W. Arnold, et al. Deep borehole disposal of high-level radioactive waste. Technical report SAND2009-4401, Sandia National Laboratories, Albuquerque, New Mexico 87185, 2009.

Results Table

This table present a the results of a numerical study designed to respond to concerns about whether or not the borehole waste disposal system implementation could be completed in 10 years. The first column varies the number of plants which have a disposal location within a 5 miles radius. The second column is a percentage rate for drilling failure. The third column gives the number of drilling hours required to complete the entire system given the simplifying assumptions described in this report, and the final column gives the number of rigs needed to complete the borehole disposal system within the 10 year time frame. Note that it is estimated that there are 6 rigs in the US and 10 additional rigs international that could complete the drilling required. Thus, even the requirement that 8 rigs be used is not unrealistic.

Number of Sites	Drilling Failure Percentage	Number of Drilling Hrs	Minimum Number of Rigs Needed
1	0	195600	3
1	10	279600	4
1	20	363600	5
1	30	447600	6
1	40	531600	7
1	50	615600	8
2	0	195600	3
2	10	279600	4
2	20	363600	5
2	30	447600	6
2	40	531600	7
2	50	615600	8
3	0	195600	3
3	10	279600	4
3	20	363600	5
3	30	447600	6
3	40	531600	7
3	50	615600	8
4	0	195600	3
4	10	279600	4
4	20	363600	5
4	30	447600	6
4	40	531600	7
4	50	615600	8
5	0	195600	3
5	10	279600	4
5	20	363600	5
5	30	447600	6
5	40	531600	7
5	50	615600	8

6	0	195600	3
6	10	279600	4
6	20	363600	5
6	30	447600	6
6	40	531600	7
6	50	615600	8
7	0	135400	2
7	10	165500	2
7	20	201900	3
7	30	243900	3
7	40	292200	4
7	50	346100	4
8	0	195600	3
8	10	279600	4
8	20	363600	5
8	30	447600	6
8	40	531600	7
8	50	615600	8
9	0	139320	2
9	10	172920	2
9	20	212400	3
9	30	257760	3
9	40	308160	4
9	50	364440	5
10	0	195600	3
10	10	279600	4
10	20	363600	5
10	30	447600	6
10	40	531600	7
10	50	615600	8
11	0	149400	2
11	10	192240	3
11	20	239280	3
11	30	291360	4
11	40	347640	4
11	50	408960	5
12	0	195600	3
12	10	279600	4
12	20	363600	5
12	30	447600	6
12	40	531600	7
12	50	615600	8
13	0	182440	3
13	10	254680	3
13	20	328320	4

13	30	403360	5
13	40	479520	6
13	50	557080	7
14	0	123360	2
14	10	143520	2
14	20	170400	2
14	30	204000	3
14	40	246000	3
14	50	294720	4
15	0	195600	3
15	10	279600	4
15	20	363600	5
15	30	447600	6
15	40	531600	7
15	50	615600	8
16	0	153040	2
16	10	198960	3
16	20	249360	3
16	30	304240	4
16	40	363600	5
16	50	426320	5
17	0	170400	2
17	10	232000	3
17	20	296400	4
17	30	362900	5
17	40	432200	5
17	50	503600	6
18	0	167040	2
18	10	225840	3
18	20	287160	4
18	30	351840	5
18	40	419040	5
18	50	488760	6
19	0	146320	2
19	10	187200	3
19	20	232700	3
19	30	282820	4
19	40	337560	4
19	50	396920	5
20	0	195600	3
20	10	279600	4
20	20	363600	5
20	30	447600	6
20	40	531600	7
20	50	615600	8

21	0	146880	2
21	10	187200	3
21	20	232560	3
21	30	282960	4
21	40	338400	4
21	50	398880	5
22	0	172080	2
22	10	235080	3
22	20	300600	4
22	30	368640	5
22	40	439200	6
22	50	511440	6
23	0	188040	3
23	10	265320	4
23	20	343440	4
23	30	422400	5
23	40	501920	6
23	50	582280	7
24	0	195600	3
24	10	279600	4
24	20	363600	5
24	30	447600	6
24	40	531600	7
24	50	615600	8
25	0	195600	3
25	10	279600	4
25	20	363600	5
25	30	447600	6
25	40	531600	7
25	50	615600	8
26	0	188880	3
26	10	267000	4
26	20	345680	4
26	30	425200	5
26	40	505280	6
26	50	585920	7
27	0	176280	3
27	10	243480	3
27	20	312360	4
27	30	382920	5
27	40	456000	6
27	50	530760	7
28	0	158640	2
28	10	210720	3
28	20	266160	4

28	30	324960	4
28	40	387120	5
28	50	452640	6
29	0	136800	2
29	10	170400	2
29	20	209600	3
29	30	254400	3
29	40	304800	4
29	50	360800	5
30	0	195600	3
30	10	279600	4
30	20	363600	5
30	30	447600	6
30	40	531600	7
30	50	615600	8
31	0	164800	2
31	10	221080	3
31	20	280440	4
31	30	344420	4
31	40	409940	5
31	50	478540	6
32	0	131760	2
32	10	158640	2
32	20	192240	3
32	30	232560	3
32	40	279600	4
32	50	333360	4
33	0	179640	3
33	10	249360	3
33	20	320760	4
33	30	393840	5
33	40	468600	6
33	50	545040	7
34	0	140160	2
34	10	174880	2
34	20	215760	3
34	30	262800	3
34	40	316000	4
34	50	372280	5
35	0	183000	3
35	10	255800	3
35	20	330000	4
35	30	405600	5
35	40	482600	6
35	50	560300	7

36	0	138480	2
36	10	172080	2
36	20	212400	3
36	30	259440	3
36	40	309840	4
36	50	366960	5
37	0	176560	3
37	10	243760	3
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41	0	141000	2
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42	10	232560	3
42	20	296400	4
42	30	363600	5
42	40	432480	5
42	50	504720	6
43	0	115240	2
43	10	130360	2
43	20	151220	2

43	30	183560	3
43	40	221640	3
43	50	265460	4
44	0	140720	2
44	10	177680	3
44	20	218560	3
44	30	267280	4
44	40	319920	4
44	50	376480	5
45	0	166200	2
45	10	225000	3
45	20	285900	4
45	30	351000	5
45	40	418200	5
45	50	487500	6
46	0	191680	3
46	10	272320	4
46	20	353240	5
46	30	434720	5
46	40	516480	6
46	50	598520	7
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50	10	279600	4
50	20	363600	5
50	30	447600	6
50	40	531600	7
50	50	615600	8

51	0	130080	2
51	10	159480	2
51	20	194340	3
51	30	234660	3
51	40	280440	4
51	50	331680	4
52	0	148560	2
52	10	193360	3
52	20	242080	3
52	30	294720	4
52	40	351280	5
52	50	411760	5
53	0	167040	2
53	10	227240	3
53	20	289820	4
53	30	354780	5
53	40	422120	5
53	50	491840	6
54	0	185520	3
54	10	261120	3
54	20	337560	4
54	30	414840	5
54	40	492960	6
54	50	571920	7
55	0	118600	2
55	10	139600	2
55	20	167600	2
55	30	202600	3
55	40	244600	3
55	50	293600	4
56	0	134000	2
56	10	167600	2
56	20	206800	3
56	30	251600	3
56	40	302000	4
56	50	358000	5
57	0	149400	2
57	10	195600	3
57	20	246000	3
57	30	300600	4
57	40	359400	5
57	50	422400	5
58	0	164800	2
58	10	223600	3
58	20	285200	4

58	30	349600	4
58	40	416800	5
58	50	486800	6
59	0	180200	3
59	10	251600	3
59	20	324400	4
59	30	398600	5
59	40	474200	6
59	50	551200	7
60	0	195600	3
60	10	279600	4
60	20	363600	5
60	30	447600	6
60	40	531600	7
60	50	615600	8
61	0	124200	2
61	10	143940	2
61	20	170820	2
61	30	211980	3
61	40	253140	3
61	50	301440	4
62	0	136800	2
62	10	167880	2
62	20	204840	3
62	30	253560	3
62	40	302280	4
62	50	356880	5
63	0	149400	2
63	10	191820	3
63	20	238860	3
63	30	295140	4
63	40	351420	5
63	50	412320	5
64	0	162000	2
64	10	215760	3
64	20	272880	4
64	30	336720	4
64	40	400560	5
64	50	467760	6
65	0	174600	2
65	10	239700	3
65	20	306900	4
65	30	378300	5
65	40	449700	6
65	50	523200	6

66	0	187200	3
66	10	263640	4
66	20	340920	4
66	30	419880	5
66	40	498840	6
66	50	578640	7
67	0	114960	2
67	10	127280	2
67	20	148560	2
67	30	178800	3
67	40	218000	3
67	50	266160	4
68	0	125040	2
68	10	146320	2
68	20	175440	3
68	30	212400	3
68	40	257200	3
68	50	309840	4
69	0	135120	2
69	10	165360	2
69	20	202320	3
69	30	246000	3
69	40	296400	4
69	50	353520	5
70	0	145200	2
70	10	184400	3
70	20	229200	3
70	30	279600	4
70	40	335600	4
70	50	397200	5
71	0	155280	2
71	10	203440	3
71	20	256080	3
71	30	313200	4
71	40	374800	5
71	50	440880	6
72	0	165360	2
72	10	222480	3
72	20	282960	4
72	30	346800	4
72	40	414000	5
72	50	484560	6
73	0	175440	3
73	10	241520	3
73	20	309840	4

73	30	380400	5
73	40	453200	6
73	50	528240	7
74	0	185520	3
74	10	260560	3
74	20	336720	4
74	30	414000	5
74	40	492400	6
74	50	571920	7
75	0	195600	3
75	10	279600	4
75	20	363600	5
75	30	447600	6
75	40	531600	7
75	50	615600	8
76	0	119440	2
76	10	136800	2
76	20	163680	2
76	30	200080	3
76	40	246000	3
76	50	291920	4
77	0	127280	2
77	10	151500	2
77	20	184260	3
77	30	225560	3
77	40	275400	4
77	50	325240	4
78	0	135120	2
78	10	166200	2
78	20	204840	3
78	30	251040	3
78	40	304800	4
78	50	358560	5
79	0	142960	2
79	10	180900	3
79	20	225420	3
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79	40	334200	4
79	50	391880	5
80	0	150800	2
80	10	195600	3
80	20	246000	3
80	30	302000	4
80	40	363600	5
80	50	425200	5

81	0	158640	2
81	10	210300	3
81	20	266580	4
81	30	327480	4
81	40	393000	5
81	50	458520	6
82	0	166480	2
82	10	225000	3
82	20	287160	4
82	30	352960	5
82	40	422400	5
82	50	491840	6
83	0	174320	2
83	10	239700	3
83	20	307740	4
83	30	378440	5
83	40	451800	6
83	50	525160	6
84	0	182160	3
84	10	254400	3
84	20	328320	4
84	30	403920	5
84	40	481200	6
84	50	558480	7
85	0	190000	3
85	10	269100	4
85	20	348900	4
85	30	429400	5
85	40	510600	6
85	50	591800	7
86	0	113280	2
86	10	126720	2
86	20	151920	2
86	30	188880	3
86	40	225840	3
86	50	274560	4
87	0	119160	2
87	10	137640	2
87	20	167040	2
87	30	207360	3
87	40	247680	3
87	50	298920	4
88	0	125040	2
88	10	148560	2
88	20	182160	3

88	30	225840	3
88	40	269520	4
88	50	323280	4
89	0	130920	2
89	10	159480	2
89	20	197280	3
89	30	244320	3
89	40	291360	4
89	50	347640	4
90	0	136800	2
90	10	170400	2
90	20	212400	3
90	30	262800	3
90	40	313200	4
90	50	372000	5
91	0	142680	2
91	10	181320	3
91	20	227520	3
91	30	281280	4
91	40	335040	4
91	50	396360	5
92	0	148560	2
92	10	192240	3
92	20	242640	3
92	30	299760	4
92	40	356880	5
92	50	420720	5
93	0	154440	2
93	10	203160	3
93	20	257760	3
93	30	318240	4
93	40	378720	5
93	50	445080	6
94	0	160320	2
94	10	214080	3
94	20	272880	4
94	30	336720	4
94	40	400560	5
94	50	469440	6
95	0	166200	2
95	10	225000	3
95	20	288000	4
95	30	355200	5
95	40	422400	5
95	50	493800	6

96	0	172080	2
96	10	235920	3
96	20	303120	4
96	30	373680	5
96	40	444240	6
96	50	518160	6
97	0	177960	3
97	10	246840	3
97	20	318240	4
97	30	392160	5
97	40	466080	6
97	50	542520	7
98	0	183840	3
98	10	257760	3
98	20	333360	4
98	30	410640	5
98	40	487920	6
98	50	566880	7
99	0	189720	3
99	10	268680	4
99	20	348480	4
99	30	429120	5
99	40	509760	6
99	50	591240	7
100	0	195600	3
100	10	279600	4
100	20	363600	5
100	30	447600	6
100	40	531600	7
100	50	615600	8

Table .1: In order to completely implement the borehole disposal system in 10 years, the number of rigs in column 4 are needed to drill boreholes at the number of sites in the first column given a drilling failure percentage in the second column.

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