DOE/ER/60578--T1

RADON:

**GAS TRANSPORT IN SOILS AND ITS RELATION
TO RADON AVAILABILITY:**

**HOT SPOT IDENTIFICATION AND FLOW
CHARACTERISTICS NEAR STRUCTURES**

Progress Report and Request for Third Year Incremental Funding

Project Number DE-AI05-87-ER60578

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Renewal Request

This request seeks incremental funding for the third year of the project "Gas transport in soils and its relation to radon availability: Hot spot identification and flow characteristics near structures," project number DE-AI05-87-ER60578. The project is in accordance with Task 1 of the Radon Program the guideline overseen by Dr. Curtis Olsen, DOE technical representative for the Task.

Overview of Objectives

There are 3 major objectives being addressed in this research.

The first is to participate, by providing ground truth quality assurance, in the DOE/LBL/EPA cooperative study to determine a methodology to predict the areas where indoor radon concentrations have the highest probability of exceeding 20 pCi/L (750 Bq/m³). The second is to examine 2 common types of homes (basement and non-basement) for radon entry by monitoring specific parameters under normal living conditions. The third task is to participate with other researchers in their studies using the techniques and experience developed by this principal investigator during previously funded times. Those researchers seek assistance in measuring soil permeability, determining the effect of meteorological parameters on radon entry, determining the diffusion characteristics of standard basement wall materials, developing a GIS (Geographic Information System) data base for predicting regional radon potential, and examining the contribution of regional solution-developed permeability in limestone to the radon potential of an area.

Detailed Objectives

The first objective is to be accomplished as part of the directed DOE/EPA cooperative project to develop a methodology to predict the areas of the US where homes are located that have the potential for the highest indoor radon concentrations. The DOE/EPA cooperative proposal addresses the issue of model development and testing but does not provide funding for ground-truth acquisition. The specific effort for which this project seeks funding is to provide ground truth for both soil-gas radon and transport-related parameters (diffusion, mass transport, permeability) and indoor radon levels for the first study area (6 counties in Minnesota). This will provide a quality assurance measure of the predictive power of the model developed by the DOE/EPA cooperative project. It should be noted that the DOE/EPA project has several phases of testing and, as an evolving project, subsequent ground-truth studies are intended to be evaluated by a project principal investigator, Linda Gundersen of the USGS.

The second objective is to acquire data base information on the transport of radon into 2 types of common-style homes, that is, one with a basement and one without. Studies will be conducted to measure the radon migration within the critical zone of migration influence of a specific structure or house. One limitation of tests being conducted at the artificial structures designed to develop information on entry rate, is that

they may not be representative of the actual nature of the infiltration. Basically, this test is designed to provide information on an "average house" with average living conditions. It is not to be conducted with worst case scenarios that may be interpreted as standard conditions. Rather, it is the observations that are controlled, not the structure or the living style. In addition to making measurements of standard meteorological and soil parameters, two novel aspects of measurement will be included in this study. One is that the periodic air infiltration rate will be measured by having a continuous controlled leak of a tracer gas (helium) within one house. Periodic measurements throughout various rooms, or zones, of the house will indicate the transport characteristics of the house. Dilution toward ambient concentrations will give information on both steady state and abrupt exchange (as when a window is opened or the forced air furnace is running). The other unique concern will focus on the transition zone of transport and soil flow within the backfill zone.

The third objective involves numerous cooperatives with other projects and will be conducted over the extent of the proposal. The formal cooperation will be with Dr. Donald Thomas of the Hawaii Institute of Geophysics, to characterize a site both before and after a structure has been built. Another formal cooperative is to provide expertise and gain information on the effects of solution enlargement of fissures and cracks in limestone terrain. This study is in cooperation with Dr. P.A. Colgan of the Radiological Protection Institute of Ireland. This study will permit results of tracer injection studies, a technology developed by earlier funding of this project, to be correlated to the subsurface structure. In addition, an effort will be initiated in this cooperative segment of the project to estimate from regional soil-gas surveys the extent of the radon distribution. There have been attempts to provide the estimation but there is very little known about the errors involved in establishing predictive power. This part of the study will examine the issue so that realistic constraints will be presented to define the applicability.

Additional cooperation will be with Dr. Thomas Borak of Colorado State University, (CSU) and Dr. Richard Sextro of Lawrence Berkeley Laboratory (LBL), on performing tracer studies at the locations of their helium test structures. At the CSU site, the permeability of the concrete wall will be determined as well as the influence, if any, on transport of radon by the network of monitoring pipes and cables surrounding the structures. At the LBL site, cross calibration of determining soil anisotropy will be performed between the pressure technique being developed by LBL and the injection technique developed by this project.

General Work Plan

The work approach of this proposal will be to perform a multi-task study to address the present and future needs of the DOE Radon Program and will incorporate extensive cooperation with other researchers.

Third-Year Work Plan

The primary third-year goal is to complete the study of gas infiltration and migration in 2 homes. This objective will be accomplished by using helium as a tracer gas and providing a controlled leak of helium into the house from a point source. Numerous analyses will be made during the course of the year from different locations the houses. The samples will be analyzed using a helium mass spectrometer modified to provide helium concentrations with a sensitivity of 10 parts per billion. Assuming air exchange rates of 2 to 10 times an hour, this will require a helium release rate of about 30 liters per day. In addition to the tracer study, multiple analyses of radon will be made to correlate long-term and short-term measurements through a complete change of seasons. This is a very important study because it will be conducted under normal living conditions rather than a setting that mandates worse-case conditions. In addition, a very detailed survey of inhouse radon on different levels related to the soil gas variations will be completed. Because of the unusual winter conditions in the Denver area where this study is planned, there was a delay until spring as before initiating this study. Monthly average temperatures for December through February averaged 10° to 15° F higher than average.

Time Frame of Study

Studies conducted by DOE-funded researchers during the past few years have indicated that the question of radon availability cannot be answered with a single set of assumptions. There are significant variations in radon concentration and transport, both of which are critical input parameters used for developing models needed to predict radon availability. These variations are reflected in the fundamental sample measurements and elementary gamma-ray signatures used to identify potential source materials for radon, as well as the secondary parameters (e.g. permeability modified by soil moisture content) used to determine radon availability.

Because of the multi-task nature, and dependency on cooperatives, the project requests funding for 3 years. This request addresses the third year of funding. However, each task is established as a discrete subunit so that it can be essentially completed with individual year funding in case there is a major need to modify funding because of the federal budget vagaries.

First Year Accomplishments

By evaluating the radon potential of a building site before, during, and after construction, information will be gained for predictive model validation for identifying areas with high radon potential. Work was initiated in Jefferson County, Colorado, where the county school district is building 16 new schools within the next few years. Several school sites at various stages of construction are being examined to determine the effect of construction activity on predictive radon parameters such as surface gamma ray intensity, radon availability of soils, and physical parameters of soils. These changes are brought about typically because of the common construction practice of cut-and-fill.

The common building technique for the Jefferson county schools is to modify grade and use a slab foundation with either footers or pylons set to bedrock. Pipes and electricity run within or under the slab. Top soil is removed and stored for redistribution around the finished structure. The slab is set on recompacted soil or soil brought from a borrow pit. Rarely is crushed gravel placed under the slab for leveling purposes.

Tests at 2 school sites revealed that the soil gas radon concentration, one of the major parameters of site predictive model, was significantly modified by the construction activities. Compared to native soil in its undisturbed setting, the recompacted soil used under the slab and around the footers had lower available radon concentrations. This was caused because the compaction of the soil was greater than in the native state. At another school site, soil for compaction was brought in from another site and had a higher radon concentration and availability than the native soil from the construction site.

Because site materials are redistributed or even new ones brought in, there can be a substantial change in radon potential from initial estimates to what is available after construction. These observations are not a limitation in predictive capability but point out that alterations to the natural setting of the site should be part of the evaluation and predictive process.

Field gamma-ray measurements of soils indicate that the mobile fraction of radon can be discerned by measuring under "static" conditions and "dynamic" conditions whereby air is blown into the soil to dilute or remove from soil-pore spaces the emanated fraction of radon. In all cases, the differential of radon, as measured from Bi-214, was less than the measured or predicted emanation of radon. What is measured, therefore, is more related to the radon availability, because not all radon emanated to pore spaces is available for transport because of permeability limitations.

Cooperation with CEC partners in a study of the radon transport through limestones in Ireland is continuing. A field sampling program in and around the town of Claremorris revealed that there is a very pronounced control on radon transport direction caused by the dominant jointing direction in the limestone. Where dissolution of the limestone has occurred to a large extent, a much larger volume of bedrock (and soil) from which radon can be drawn is available.

Second Year Accomplishments

Two homes selected for tracer studies to determine the radon ingress and distribution have undergone preliminary evaluation of the radon concentration. Both homes are "typical" in that their radon concentrations are around the national average as determined by the EPA National Residential Radon Study. Materials have been ordered to begin the helium tracer tests which will study distribution and flow patterns for a complete year. This will mark the first time a study will have been done over all seasons and their variation and influence in home heating and cooling demands.

A very effective method of decreasing radon in a home with a forced air, gas combustion furnace in the basement was to provide outside air for combustion, not directly to the burners, but rather to the basement. This added a quantity of dilution to the basement air as well as providing a pressure balancing port for the home house to decrease the inside negative pressure that draws soil gas into the structure. See the following figure. For the brief period of time the air vent was open, the indoor radon concentration dropped by nearly a factor of 2. This would be a very advantageous mitigation method for reducing radon concentration near the current action level established by the US EPA.

The cooperative study with the CEC has been completed and a preliminary report is attached. Briefly, the study revealed the utility of soil-gas radon measurements in a limestone terrain to provide an adjunct measurements to predicting radon potential in a limestone terrain as a function of scale of the measurement. The study revealed that reconnaissance sampling, defined as on 0.3 to 0.5 km centers or more, indicated the general magnitude of the radon potential, but did not help in delineating specific sites where the radon potential may be higher than the average for the study area. Detailed sample spacing, on the scale of 100 m or less, did accurately locate individual home sites where the indoor radon was higher than average for the study area.

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ATTACHMENT

Radon and helium mapping in limestone terrain of western Ireland: Limited utility in estimating radon potential from reconnaissance soil-gas radon measurements in the absence of complementary data bases.

Introduction

Radon and helium mapping were conducted in western Ireland as part of a cooperative study involving the European Union, the U.S. Department of Energy and the U.S. Geological Survey. The Radiological Protection Institute of Ireland and the Geological Survey of Ireland conducted indoor radon analyses and geological studies, Enmotec GmbH collected and analyzed soil gases for radon, and the U.S. Geological Survey conducted the helium analyses.

This study provides information on the precision of estimating radon potential from a reconnaissance scale (200-300 m sample spacing) and to evaluate the use of soil-gas radon concentrations as an assessment technique to identify areas of differing radon potential or to estimate the portion of an area that may be classified as providing elevated radon potential. Radon potential in this paper refers to source-controlled (soil) radon potential as opposed to entry or house-controlled radon potential, the latter being established by many other factors, such as indoor ventilation rates, attached and unattached fractions of radon and radon progeny, and lifestyle. Reference to radon potential estimates in this section of Ireland is based exclusively on the radon concentration measurements of soil-gas samples that were collected in the reconnaissance study area.

Radon potential estimation is an important component of any national program seeking to develop a plan to provide the public with prioritized radon risk information. In many areas of the world, thorough complementary data bases, such as wide-area gamma-ray spectrometer surveys, soil characterization, and even detailed geologic mapping, are lacking and would be prohibitively expensive to acquire. Therefore, techniques that estimate the regional indoor radon potential in the absence of previously mentioned detailed information are needed. Also, in view of the finite resources that some governments can devote to the issue of radon and public health, these techniques need to be affordable.

Technical Background

The radon (Rn) concentration in any soil or rock is dependent upon the concentration of its progenitor, radium. Weathering (climate), mineralogy (composition and form), and natural distribution of forces (local tectonic stresses) control the physical and chemical distribution of radium and help establish the emanation and transport pathways for Rn. Geologic information allows estimations of the Rn potential from particular rock types or soils (Åkerblom, 1987; Reimer and Gundersen, 1989; Kunz, 1988; Gates and Gundersen, 1989; Sutherland, 1991; Ball and others, 1991). Climate is a strong factor controlling soil development and properties as well as the chemical

distribution of elements throughout the various soil horizons (Asher-Bolinder and others, 1990).

Using rock classification as a general guide, higher Rn concentrations might be expected from rock types that typically have higher uranium and thorium concentrations, such as granites. Conversely, low Rn concentrations might be expected from rocks such as basalts or limestones which typically have lower uranium and thorium concentrations. However, in the course of making indoor Rn measurements in Ireland, homes that had been built on limestone having thin soil cover were found with elevated Rn concentrations. Although this might seem enigmatic, a detailed study of the Rn distribution in a limestone terrain in Ireland indicates that there are very sound geologic reasons, such as dissolution enhanced permeability, that explain the findings (O'Conner and others, 1993). In a moist climate as this, volume-loss concentration of Ra in the formation of residual soils could also be a major factor.

A comprehensive technique for estimating radon potential has been recently developed and reported by Schumann (1993). That approach utilized input parameters of 5 different data sources: 1) Aeroradiometric data; 2) soil classification; 3) lithological data; 4) indoor radon screening measurements (less than 90 day duration); and 5) general house construction techniques, that is, whether the house had a basement, crawlspace, or was constructed on a ground-contact slab. Soil-gas radon concentrations were not considered as a primary factor because extensive data bases are not available. However, the analyses are relatively inexpensive compared to geologic mapping and airborne radiation mapping at the similar scales.

Soil-gas Sampling and Analytical Techniques

Soil-gas samples were collected using a method described in detail by Reimer (1990). In order to collect a soil-gas sample, a hollow steel probe was hammered into the ground by use of a slide hammer fitted over the shaft of the probe. The probe is then fitted with a septum device that makes an air tight seal around the upper opening of the hollow probe. The tip of the probe was set at a depth of 1 meter and, after purging air from the probe, a sample of soil gas was collected with a hypodermic syringe. The gas sample was transferred from the syringe into a phosphor-coated scintillation cell for the radon analysis and another sample from the syringe was transferred to a stainless steel container for subsequent helium analysis. Radon concentrations were calculated at the field site based upon previous primary calibration of the alpha scintillometer and individual scintillation cells.

Study Area

Soil-gas Radon and helium measurements were conducted in the vicinity of Claremorris, County Mayo, Ireland. In this part of western Ireland, the only geologic information available was bedrock information, surficial morphology, and structural jointing analysis (O'Conner and others, 1993). The 110 km² study area is underlain by a single limestone formation. The only topographic coverage is from a map published in 1916 by the Geological Survey of Ireland. No soil descriptions or gamma-ray measurements are available. As reported by Madden and others (in press), the study area is underlain by a well-bedded crystalline Lower Carboniferous limestone. Bedding

thicknesses average 0.6 m and dip 3° to 5° to the SW. Extensive vertical joint systems trend in directions of 27° and 117° (tension) and 47° and 157° (shear) with spacings ranging from 0.1 to 1 m. Ground water dissolution occurs on the bedding planes and karstification is very advanced on the shallower limestone beds. Soil thickness averages 1 to 2 m and peat occurs in landscape depressions. Topographic relief in the study area averages less than 100 meters. Glacially-derived till occurs in the drainages of the study area and is mostly composed of limestone cobbles, but the drainages were not sampled; terminal and lateral moraines occur several km north of the study area.

The soil-gas surveys were conducted in May of 1993 and May of 1994. The overall study area is rectangular in shape and approximately 11 km by 10 km (Figure 1). The sample spacing was 200 to 300 meters for the reconnaissance survey and 216 samples were collected.

The sampling was not random because the samples were primarily collected near pathways and roads (within the right of way but away from the disturbance of road construction). Within that constraint, and the limits imposed by the occurrence of local bogs, the sampling density was about one sample per 0.5 km². Within the overall study area, three localized surveys were conducted with a sample spacing of 25 to 50 meters. These areas are shown in Figure 1.

Discussion

Reconnaissance soil-gas radon concentrations in the study area averaged about 70,000 Bq m⁻³ (Ort and others, in press). By comparison, the average soil-gas concentration range world wide is 20,000 to 60,000 Bq m⁻³. Radon soil-gas concentrations greater than 70,000 Bq m⁻³ can be considered anomalous, because they have the greatest potential of causing elevated indoor radon concentrations (Gundersen and others, 1988). The current threshold of indoor radon adopted by the European Community is 250 Bq m⁻³ (Becker, 1994), above which simple mitigation techniques, such as sealing foundation cracks and other obvious entry points, are recommended. For indoor concentrations above 600 Bq m⁻³, more stronger mitigation procedures, such as sub-foundation suction are recommended (Becker, 1994).

Two contour intervals are plotted on Figure 1. One demarcates the upper half of radon distribution (Figure 2), which corresponds to those samples with greater than 70,000 Bq m⁻³. This contour was chosen because it represents the soil-gas radon concentrations above which the soil-gas radon is likely to contribute to indoor concentrations that exceed the lower indoor radon threshold adopted by the European Community (250 Bq m⁻³). World-wide measurements of soil-gas radon This selection is equivalent to the 60,000 Bq m⁻³ threshold earlier described (Gundersen and others, 1988) as having a high probability, that is, involving more than half the homes in an area, of contributing to indoor concentrations that exceed the lower indoor radon threshold adopted by the U.S. Environmental Protection Agency (148 Bq m⁻³). The second contour interval on Figure 1 identifies concentrations in the upper quintile of the distribution, that is, those above 100,000 Bq m⁻³. This is a common demarcation interval used in Europe and indicates a high probability that the indoor radon concentration will exceed the upper threshold limit (600 Bq m⁻³) adopted by the European Community.

Figure 1 should not be regarded as a radon potential map. Rather, it is a display of an estimated distribution of soil-gas radon concentrations derived solely from the soil-gas radon measurements. It is used to determine the utility of soil-gas radon measurements in defining radon potential areas at this scale of sample collection.

The ultimate comparison is to determine if a derived estimation of radon potential has a significant correlation with measured indoor concentrations. Two general methods are employed to use the soil-gas radon concentrations for this evaluation. The first evaluation approach used the mapped distribution of radon and compared them with indoor radon concentrations. The second evaluation approach used the proportion of samples with concentrations exceeding the high radon probability threshold. In this second case, some concern should be reserved because neither the indoor measurements or the soil-gas samples were randomly distributed.

In the study area, 160 homes had indoor radon concentrations measured by long-term alpha-track detectors (1-year duration). Only 26 of 160 measured homes exceeded 250 Bq m^{-3} and 9 exceeded 600 Bq m^{-3} . That is, only about 16 percent exceeded the lower limit threshold. Of this total of 26, 11 were in an area that would be classified as low-radon potential by the reconnaissance contour distribution, and 15 were in areas that would be classified as having high radon potential. The difference is not significant because of the small sample size. In addition, it must be noted that home construction and lifestyle have a large part in controlling the indoor radon concentrations. It should also be observed that soil-gas radon concentrations vary daily and seasonally and are influenced greatly by meteorologic conditions. The radon concentrations for this study were corrected for daily variations (Ort and others, in press), but no seasonal correction was employed.

For the first evaluation, using the mapped distribution of all soil-gas samples collected in the reconnaissance study (Figure 1), about 50 percent of the area has soil-gas radon concentrations above $70,000 \text{ Bq m}^{-3}$. This is not an artifact of sample spacing as can be seen by the distribution of sample points in Figure 1. In the second approach, using the total sample population, only 1 in 3 samples have radon concentrations that exceed $70,000 \text{ Bq m}^{-3}$.

The difference between house-measured radon and soil-gas mapped radon distribution is striking. The reconnaissance survey indicates a classification of high-radon potential would be applied to about half the mapped area, a factor of 3 greater than suggested by the actual home measurements (16 percent). Comparison to the number of soil-gas samples with concentrations indicative of high radon potential ($>70,000 \text{ Bq m}^{-3}$) indicates a factor of 2 greater estimation.

These comparisons indicate that the reconnaissance soil-gas survey tends to overestimate by up to 100 or 200 percent, depending which comparison is used, the area that might be classified as having high radon potential. This compares with observations for the entire United States where a radon potential map developed using 5 input parameters for classification, described earlier (Schumann, 1993), estimated that about 30 percent of the land has the potential for exceeding the threshold level. However, a random survey in the U.S. using alpha-track detectors (U.S. EPA, 1992) provided an estimate that only 6

percent of the homes exceeded the threshold for high radon classification (148 Bq m^{-3}). In addition, the study in Ireland indicates that by itself, a soil-gas survey at this low-density scale of sampling (a sample every 200-300 meters) is not adequate to accurately define specific geographic boundaries of radon potential zones.

The question of sampling scale will be addressed in a later study. Briefly, in smaller test areas, high density soil-gas sampling (25-50 m scale) indicated that of 9 of 10 houses in the measured areas were correctly classified as to radon potential. Although the numbers are few, the study suggests that a higher density sampling has a better chance of more precisely identifying radon potential for specific zones. This is also reflected in a study in the United States where high density soil-gas sampling and analysis for radon was shown to correctly identify the radon potential of individual home sites (Reimer and Gundersen, 1989).

Conclusion

This study demonstrates the utility of soil-gas radon mapping and defines both the capabilities and the limitations of such a single method technique for developing radon potential estimations for an area. Soil-gas radon mapping provides a crude but helpful estimate of the radon potential of an area. Low-density sampling cannot define specific geographic areas of radon potential but can help estimate the magnitude of the classification for the entire studied area. The estimate of high-radon potential areas is generally higher than that confirmed by measured indoor concentrations, perhaps being several hundred percent higher. But in the absence of complementary data, the relatively inexpensive radon survey can help local officials determine the extent of the problem, and plan resources, priorities, information distribution, and building codes accordingly.

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FIGURE CAPTIONS

Figure 1. Map showing distribution of sampling sites, radon soil-gas concentrations, and indoor radon concentrations near Claremorris, Ireland.

Figure 2. Histogram of the soil-gas radon concentrations found in soil-gas samples collected in May 1992 and May 1993 near Claremorris, Ireland.

Figure 2. Histogram of the soil-gas radon concentrations found in soil-gas samples collected in May 1992 and May 1993 near Claremorris, Ireland.

LEGEND

AREA CLAREMORRIS (IRELAND)

Regional Distribution of Radon in
Soil Air (corrected for
low density sampling)

Soil Air
Radon concentration
70000 Bq/m³
Radon concentration
70000 - 100000 Bq/m³
Radon concentration
100000 Bq/m³

Radon indoor concentration
200 Bq/m³
250 - 500 Bq/m³
500 Bq/m³

Radon indoor concentration
200 Bq/m³
250 - 500 Bq/m³
500 Bq/m³

Renewal Budget

Estimated Budget for July 1, 1995 through June 30, 1996

Salaries and Wages

Name	Title	Grade/Step	Pay Periods	Salary (Thousands of \$)
Reimer, G.M.	Geologist	14/7	13	41.2
Been, J.M.	PST	11/4	6	10.2
Szarzi, S.L.	PST	9/7	7	11.5
<u>Total Salaries</u>				<u>62,900</u>

Equipment

Steel for probes	1.0
Consumables for radon and helium detectors	3.0

<u>Domestic Travel</u>	Field work and Meetings	9.0
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<u>Foreign Travel</u>	EC Final Report and Meeting	4.0
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Other Direct Costs

<u>Materials and Supplies</u>	2.0
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<u>Publication Costs/Page Charges</u>	2.0
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<u>Consultant Services</u>	0.0
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<u>Computer (ADPE) Services and Equipment</u>	4.0
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<u>Subcontracts</u>	1.0
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<u>Total Direct Costs Excluding Salaries</u>	<u>26,000</u>
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Indirect Costs

<u>Administrative costs are 58% of the total direct costs and salaries.</u>	<u>51,000</u>
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<u>Project Total</u>	<u>139,900</u>
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