EXECUTIVE SUMMARY REPORT

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TEXAS INDOOR RADON MAP 2020 UPDATE

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FOREWORD

This report is the executive summary of a research study to update the indoor radon map of Texas. The project was conducted by an interdisciplinary team of researchers at Texas Tech University for the U.S. Environmental Protection Agency as part of the 2020-2021 Texas State Indoor Radon Grant. This report will be of interest to federal, state, and municipal officials dealing with radon issues, homeowners and members of real estate community, building contractors and inspectors, school boards and school administrators, physicians and healthcare professionals, radon researchers, and other radon stakeholders. The complete research report (Millerick, *et al*. 2022) will be distributed to the U.S. Environmental Protection Agency and available from the EPA National Library Network.

NOTICE

ACKNOWLEDGMENT

This project has been funded wholly or in part by the U.S. Environmental Protection Agency under assistance agreement No. K1-00F94603-1 to Texas Tech University. This publication has not been formally reviewed by EPA. The views expressed in this document are solely those of the authors and do not necessarily reflect those of the Agency. EPA does not endorse any products or commercial services mentioned in this publication.

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ES-1. Overview

This report updates the U.S. Environmental Protection Agency (EPA) Texas radon map from the 1993 *radon zones* to a more contemporary map of Texas *indoor radon levels*. This research study relied on vendor-supplied data and consisted of descriptive analyses of indoor radon levels at the state, county and physiographic subregion levels, statistical comparisons, and predictive correlations to geologic and other variables.

The EPA's 1993 Map of Radon Zones (EPA 1993) identifies "predicted average indoor radon screening levels" for Texas counties into one of three zones: Zone 1 (levels greater than 4 pCi/L), Zone 2 (levels from 2 to 4 pCi/L), and Zone 3 (levels less than 2 pCi/L). Such maps are intended to help governments and other organizations target radon "risk reduction activities and resources" (USGS 1993) and were interpreted from five main types of data: geologic, aerial radiometric, soil characteristics, indoor radon measurements, and building architecture. The 1993 EPA map is the version which, during the past 28 years, has become familiar to all persons interested in radon. For Texas radon stakeholders, it has been the only official radon map of any significance.

The present effort is based on indoor radon measurements obtained by a private testing laboratory, Alpha Energy Laboratories, Inc. (AEL) during the period 2006 through 2020. The Texas dataset received from AEL and screened/ checked for data quality consisted of 27,145 records (all facility types) and a focused subset of 11,504 records (single-family residences). These radon results were from short-term charcoal cannister tests placed at differentiated levels within the structure (Figure 1). In cooperation with Texas Tech University (TTU) and EPA Region 6, AEL entered into an agreement with TTU to share its radon data for this study, and hereafter these are referred to as the "2020 AEL dataset."

Under sponsorship by the EPA and in partial fulfillment of the 2020-2021 State Indoor Radon Grant for Texas, an interdisciplinary team of researchers at TTU analyzed the 2020 AEL dataset to identify indoor radon levels in Texas. The primary goal of this study was to update the EPA radon map of Texas to facilitate improved community outreach for radon awareness in Texas, focusing primarily on areas identified to be potentially high risk.

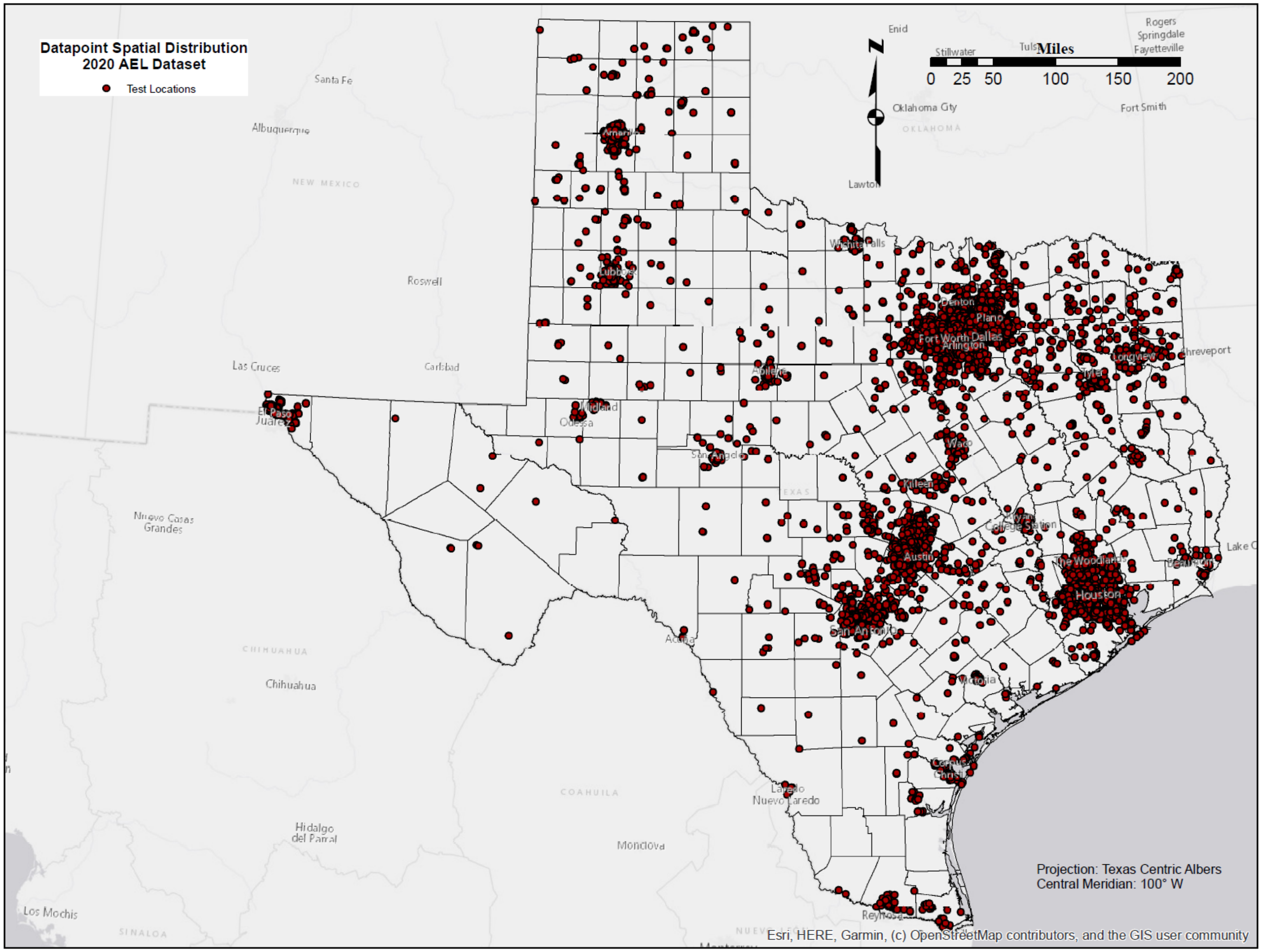

Figure 1. Statewide distribution of Texas indoor radon data, 2020 AEL dataset.

ES-2. Descriptive Results: Texas 2020 Indoor Radon Levels

ES-2.1 Descriptive Analyses

The EPA recommends that indoor radon tests be performed in the "lowest lived-in level of the home" (EPA 2016). Consistent with this guidance, the AEL 2020 dataset differentiates radon test data by the floor on which each radon test was performed, namely, the first floor, basement, and upper floor levels. These radon tests were mostly performed for "personal knowledge" and not as part of a geospatially-defined sample, so the AEL data are not uniformly distributed statewide. For this reason, descriptive analyses of indoor radon data were aggregated at the county level (Figure 2) and by physiographic province (Figure 3).

ES-2.2 First Floor Indoor Radon Levels

Figure 4 presents the Texas *first floor* indoor radon map focusing specifically on radon levels interpreted from radon tests in single-family Texas residences per the 2020 AEL dataset (10,464 records). The map depicts mean radon values at the county level (Figure 2), with results shown only for those counties with five or more measurements. Results are color coded to align with the EPA 1993 map of radon zones. For the updated Texas indoor radon map, results depict measured indoor radon levels (a) greater than 4 pCi/L (brown/dark red), between 2 pCi/L and 4 pCi/L (orange/light orange) and below 2 pCi/L (yellow/light yellow).

Hatching indicates counties where insufficient data precluded determination of statistical metrics, and here the map identifies average radon levels by physiographic province – specifically, by Texas subregion (Figure 3). Because province boundaries do not coincide with political borders (county and state), the map extrapolates from the province level to the county level so that each county was assigned to one zone. Data for all Texas counties and physiographic subregions with a nonzero number of measurements are reported in data tables included in the appendix of the full research report (Millerick, *et al.* 2021).

First floor radon summary observations from the 2020 AEL dataset are:

- The mean (statewide) radon level for first-floor, single-family Texas residences is 1.46 pCi/l, with a median value of 0.78 pCi/L. Levels are *not* uniformly distributed.
- Mean first floor radon levels by physiographic subregion show:
  - $Rn \geq 4$ pCi/ (Zone 1)… Central High Plains
  - $2 \leq Rn < 4$pCi/L (Zone 2)…Southern High Plains, Central Texas Uplift

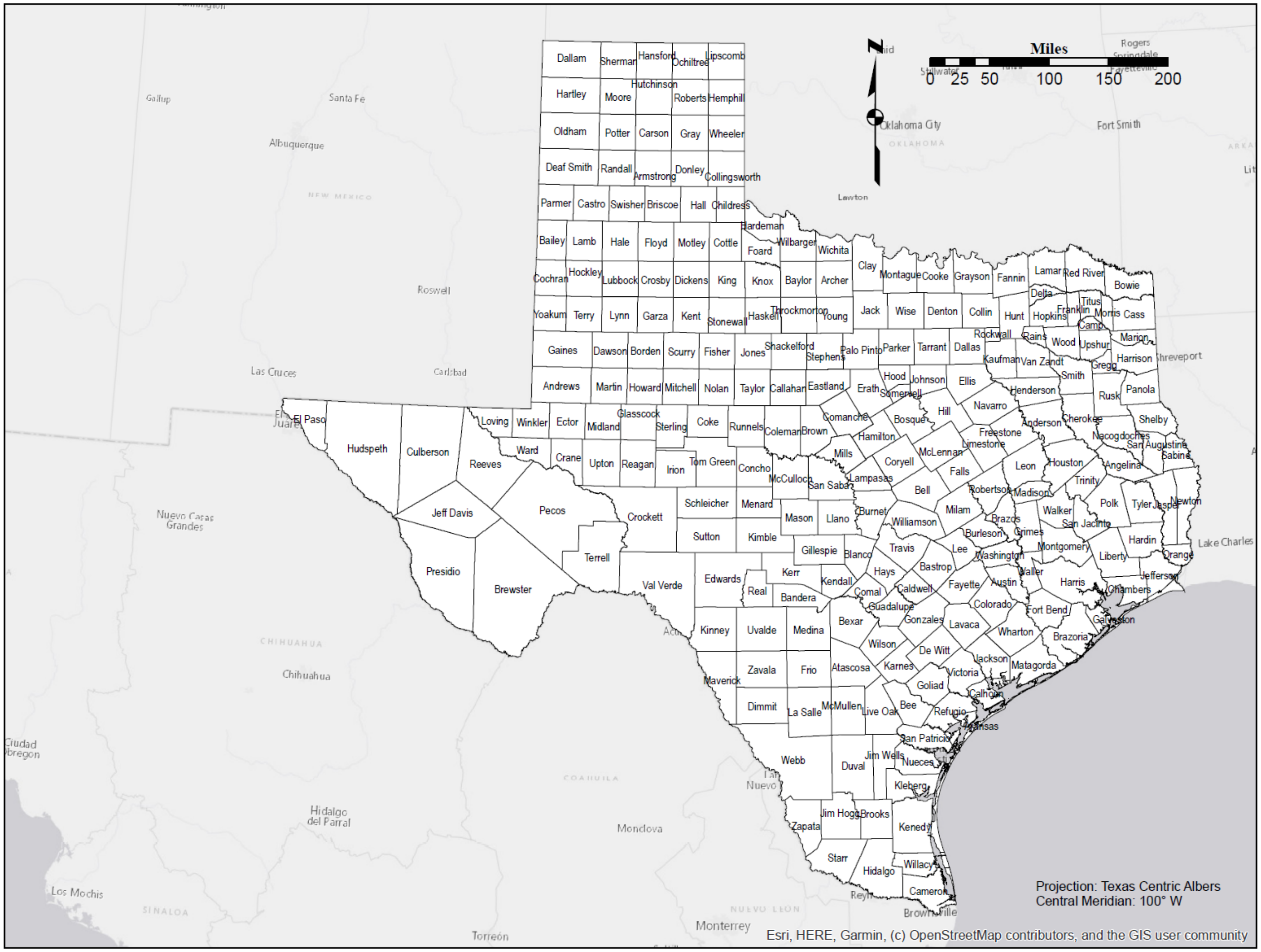

Figure 2. The 254 counties of Texas. Total area- 268,597 square miles. Typical county size- about 1,000 square miles.

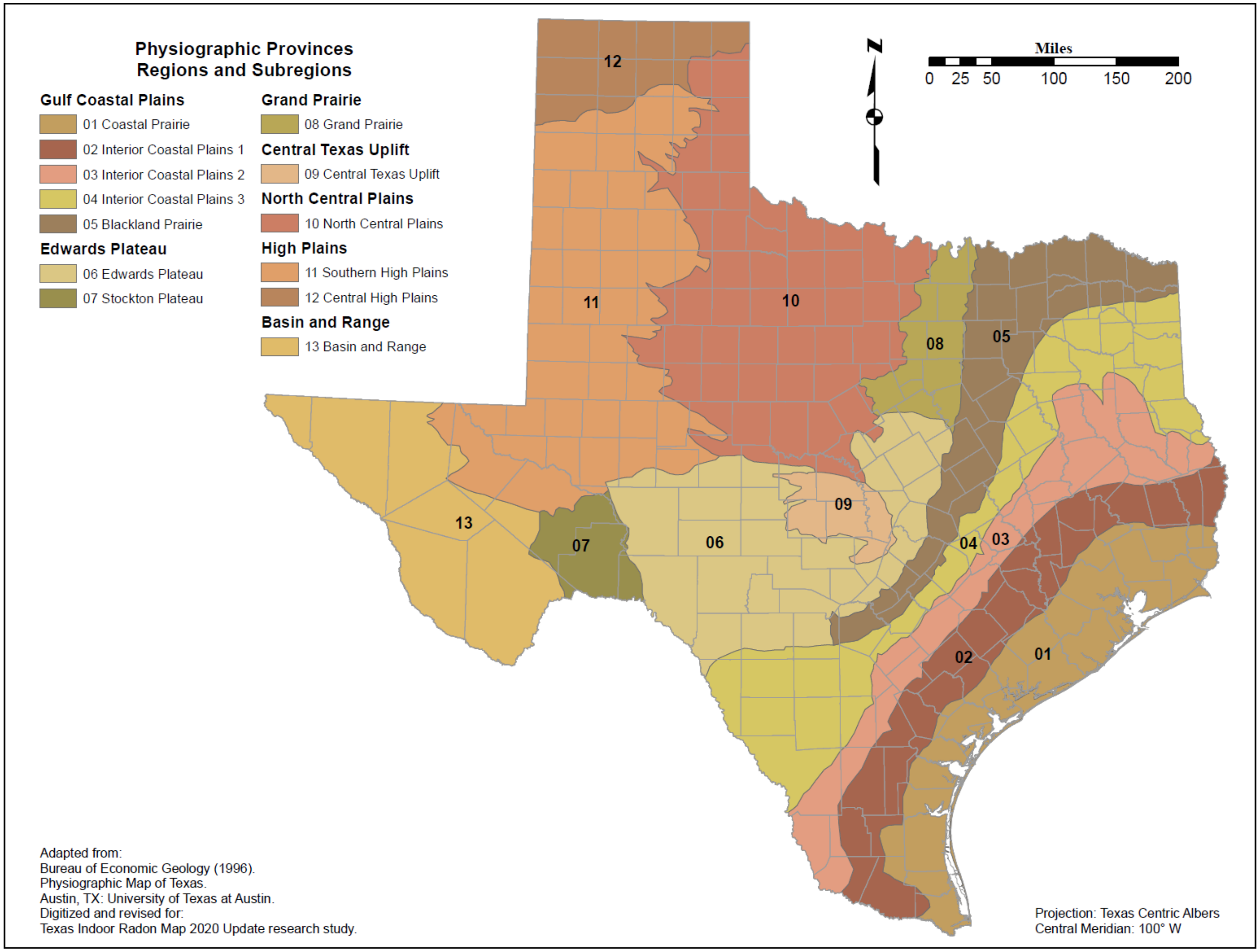

Figure 3. Physiographic provinces (regions and subregions) of Texas, with major subdivisions.

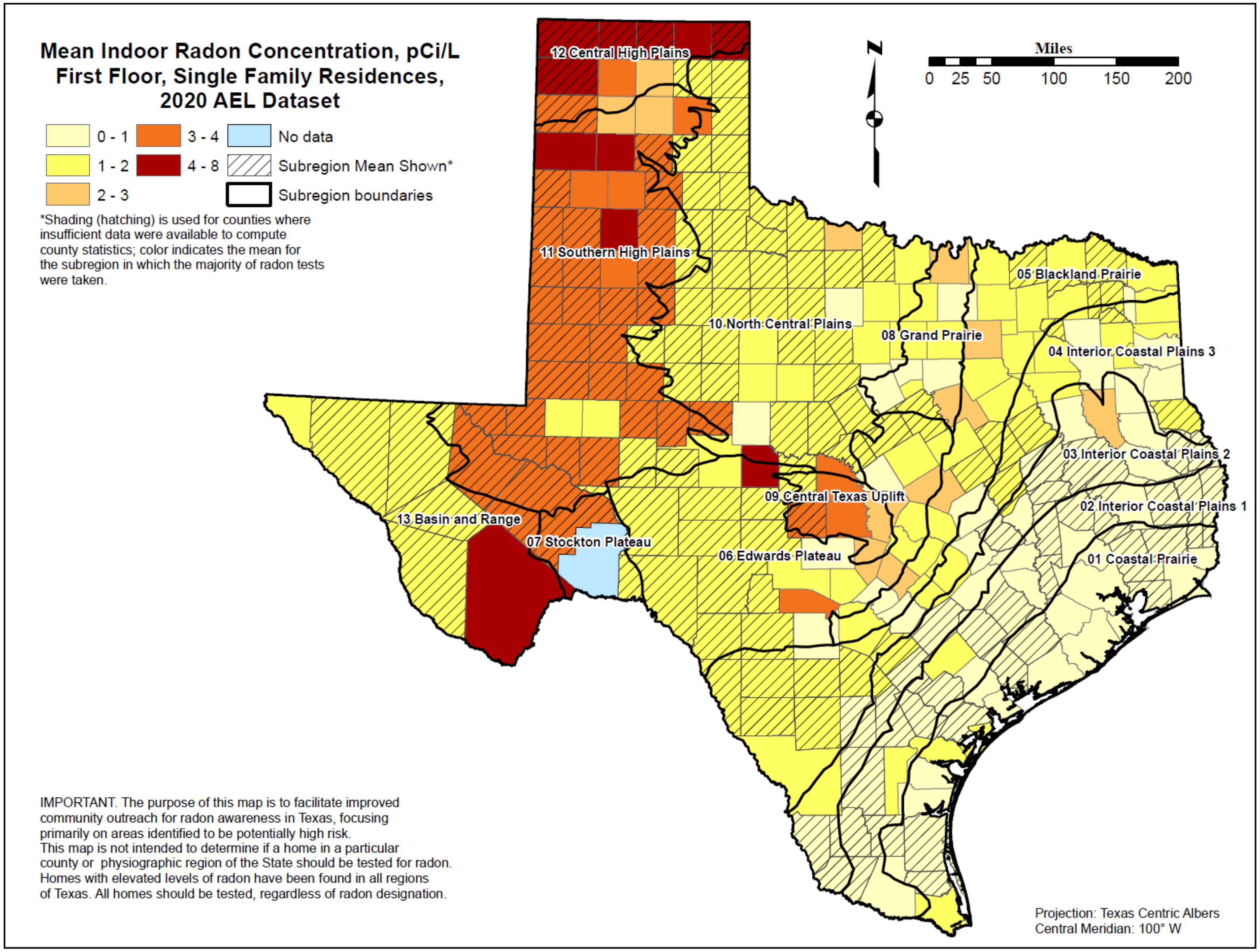

Figure 4. First Floor Radon Map of Texas per the 2020 AEL dataset, mean indoor radon concentration by Texas county, first floor level tests of single family residences, augmented by mean radon values per physiographic subregion.

- Radon < 2 pCi/L (Zone 3)… North Central Plains, Blackland Prairie, Edwards Plateau, Basin and Range, Grand Prairie, Interior Coastal Plains 3, Interior Coastal Plains 2, Interior Coastal Plains 1, Coastal Prairie
- No Data… Stockton Plateau

- The probability of first floor indoor radon values, Rn ≥ 4 pCi/L varies by subregion:
    - $p \geq 0.40$… Central High Plains
    - $0.40 > p \geq 0.10$… Southern High Plains, Central Texas Uplift
    - $p < 0.10$… Blackland Prairie, North Central Plains, Edwards Plateau, Grand Prairie, Interior Coastal Plains 3, Basin and Range, Interior Coastal Plains 2, Interior Coastal Plains 1, Coastal Prairie
  - No Data… Stockton Plateau

The 2020 AEL data indicate heightened radon risk at the first floor level – that is, $p(\text{Rn} \geq 4\ \text{pCi/L})$ is greater than 0.10 – for residences in Texas counties located within the Central High Plains, Southern High Plains, and Central Texas Uplift subregions of the state.

ES-2.3 Basement Indoor Radon Levels

Figure 5 presents the Texas *basement-level* indoor radon map per the 2020 AEL dataset (828 records). The map identifies mean radon values at the county-level, with results shown only for those counties with three or more measurements. Hatching indicates counties where average radon levels were determined by physiographic subregion, and subregions having fewer than 30 measurements are indicated (below) with an asterisk.

Selected basement radon observations are:

- The overall (statewide) mean radon level for basement, single-family Texas residences is 7.85 pCi/l, with a median value of 3.26 pCi/L. These basement radon values are significantly *higher* than the first floor radon levels.
- Basement radon data show *all* physiographic subregions of Texas have average radon levels greater than 2 pCi/L. Mean radon levels are:
    - Rn ≥ 4 pCi/L (Zone 1)… Central Texas Uplift*, Southern High Plains, Central High Plains, Interior Coastal Plains 2*, Coastal Prairie, Interior Coastal Plains 1*, North Central Plains*
    - 2 ≤ Rn < 4pCi/L (Zone 2)… Blackland Prairie, Basin and Range*, Edwards Plateau, Grand Prairie, Interior Coastal Plains 3*
    - Radon < 2 pCi/L (Zone 3)… NONE
    - No Data… Stockton Plateau*

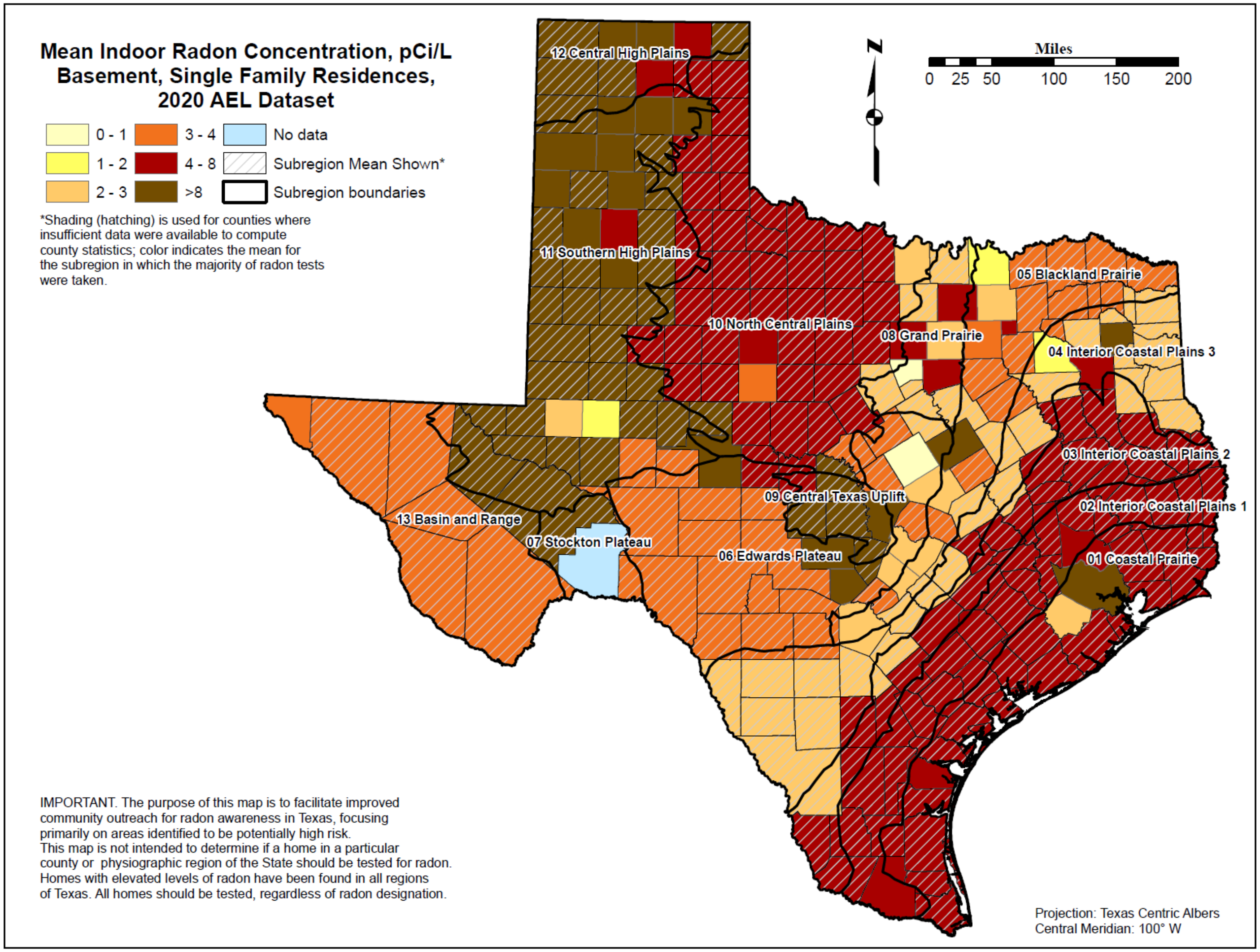

Figure 5. Basement Radon Map of Texas per the 2020 AEL dataset, mean indoor radon concentration by Texas county, basement level tests of single family residences, augmented by mean radon values per physiographic subregion.

- The probability of basement indoor radon values, Rn ≥ 4 pCi/L varies by subregion:
  - $p \geq 0.40$… Southern High Plains, Central Texas Uplift*, Central High Plains, North Central Plains*
  - $0.40 > p \geq 0.10$… Coastal Prairie, Interior Coastal Plains 1*, Interior Coastal Plains 2*, Blackland Prairie, Edwards Plateau, Basin and Range*, Grand Prairie, Interior Coastal Plains 3*
  - $p < 0.10$… NONE
  - No Data… Stockton Plateau*

The 2020 AEL data for Texas residences where the basement is the lowest livable area of the home indicate *heightened radon risk* for Texas counties located within the Southern High Plains, Central High Plains, Central Texas Uplift*, North Central Plains*, Coastal Prairie*, Interior Coastal Plains 2*, and Interior Coastal Plains 1* subregions of the state. Here it must be recognized the statistical sample size for basement readings is limited for many of these subregions. Further, the 2020 AEL data indicate that compared to first-floor radon levels, basement-level radon risk is higher – that is, $p(\text{Rn} \geq 4 \text{ pCi/L})$ is greater than 0.10 – for *all* physiographic subregions of Texas.

ES-2.4 Upper Floor Indoor Radon Levels

Texas *upper floor* indoor radon data per the 2020 AEL dataset are sparse (212 records) and do not support mapping. In fact, nine of 13 subregions of Texas have limited to no upper floor radon data.

Selected upper floor radon observations are:

- The overall (statewide) mean radon level for upper floor, single-family Texas residences is 0.85 pCi/l, with a median value of 0.35 pCi/L, and these upper floor radon values are significantly *lower* than the first floor radon levels.
- Upper floor indoor radon levels are mostly undetermined but low where measured. Mean radon levels by physiographic subregion show:
  - Rn ≥ 4 pCi/L (Zone 1)… UNDETERMINED
  - 2 ≤ Rn < 4pCi/L (Zone 2)… UNDETERMINED
  - Radon < 2 pCi/L (Zone 3)… Coastal Prairie, Blackland Prairie, Edwards Plateau*, Grand Prairie
  - Limited or No Data… Southern High Plains*, Interior Coastal Plains 3*, Interior Coastal Plains 2*, Basin and Range*, Stockton Plateau*, Interior

Coastal Plains 1*, Central Texas Uplift*, North Central Plains*, Central High Plains*

- The probability of upper floor indoor radon values, Rn ≥ 4 pCi/L is mostly undetermined, but low where measured:
  - $p \geq 0.40$… UNDETERMINED
  - $0.40 > p \geq 0.10$… UNDETERMINED
  - $p < 0.10$… Coastal Prairie, Blackland Prairie, Edwards Plateau*, Grand Prairie*
  - Limited or No Data... Southern High Plains*, Interior Coastal Plains 3*, Interior Coastal Plains 2*, Basin and Range*, Stockton Plateau*, Interior Coastal Plains 1*, Central Texas Uplift*, North Central Plains*, Central High Plains*

Upper floor radon data are extremely limited in the AEL 2020 dataset, but the four Texas subregions with upper floor radon data show average radon levels are low (less than 2 pCi/L) and the probability of radon levels greater than 4 pCi/L is also low (less than 10 percent). Further, upper floor average radon values are typically about one-half first floor values and one-fourth basement values. However, for those Texas subregions where first floor and basement radon levels are otherwise highest – *i.e.*, the Central High Plains, Southern High Plains, and Central Texas Uplift subregions of the state – the 2020 AEL dataset lacks sufficient records to meaningfully assess upper floor radon risk in these areas.

ES-3. Comparative Results: 1991 vs 2020 Datasets

It is of interest to compare indoor radon data from the EPA's 1993 Map of Radon Zones to indoor radon levels determined from the 2020 AEL dataset. The 1993 EPA map was based on five types of data, one of which was radon "screening" data. For Texas, this consisted of 2,690 indoor radon tests obtained during the winter of 1990-1991 (USGS 1993). Data were from a random, stratified survey of radon levels measured using 2-7 day charcoal canister radon detectors placed in the lowest livable area of owner-occupied, single-family, detached housing units. Hereafter, these screening data are referred to as the "1991 EPA dataset."

The 1991 EPA dataset and the 2020 AEL dataset are *not* equivalent. One major difference is that the sampling methods differed drastically, the 1991 dataset being a random stratified sample and the 2020 dataset being a self-selected sample. A second major difference is the 1991 dataset identifies average radon levels by county at the lowest livable area (undifferentiated basement and first floor); whereas, the 2020 dataset identifies individual radon measurements differentiated by basement, first floor and upper floor level. Thus the datasets are not amenable to direct, rigorous comparative analyses.

However, to explore trends, basement and first floor data from the 2020 AEL dataset were combined, and the combined data were compared to the 1991 EPA dataset (Figure 6). Comparisons were made for multiple metrics including mean, median, geometric mean, and probability of the radon value exceeding 4 pCi/L. Data were aggregated by physiographic subregion and also for selected counties where both datasets contained more than 50 records.

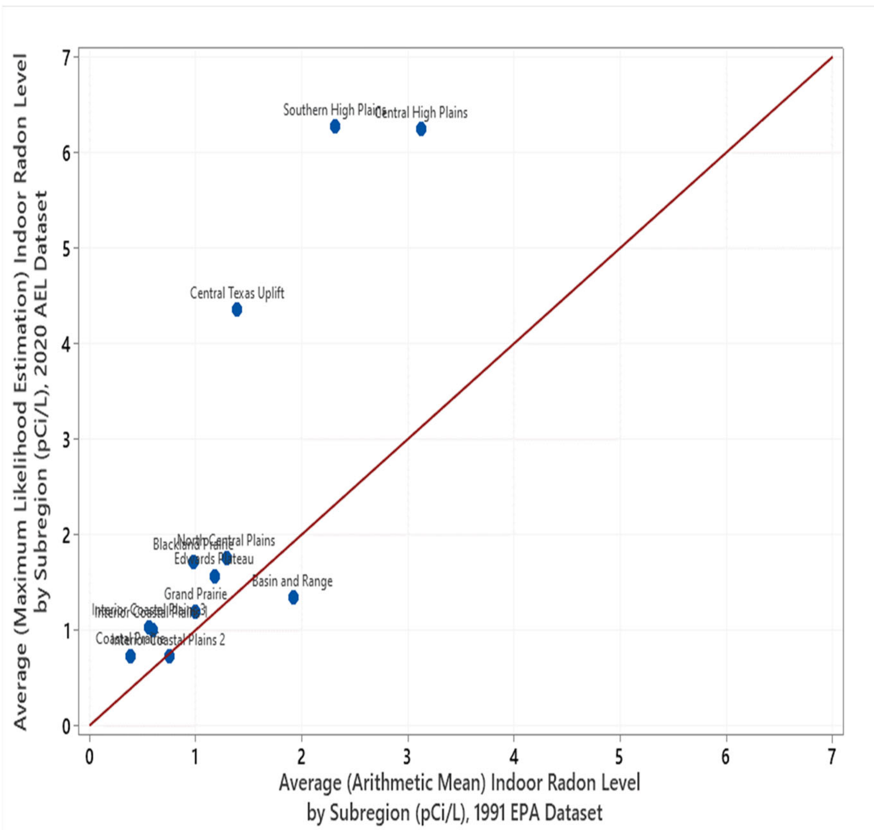

Figure 6. Comparison of mean indoor radon levels by physiographic subregion, 1991 EPA data vs. 2020 AEL data, undifferentiated first floor/ basement radon levels of Texas single family residences.

Qualitatively, when physiographic subregions for both datasets are rank-ordered from high to low by mean indoor radon value, with minor variation the 1991 EPA dataset and the 2020 AEL dataset identify the same subregions (first quartile) as having the *highest* mean indoor radon values/ radon risk: Central Texas Uplift, Southern High Plains and Central High Plains. Further, both datasets identify same subregions (fourth quartile) for the *lowest* mean indoor radon values/ radon risk: Coastal Prairie, Interior Coastal Plains 1, 2, and 3.

Quantitatively, the comparisons indicate the 2020 indoor radon levels for three subregions of Texas – Central Texas Uplift, Southern High Plains and Central High Plains – are roughly two to three times higher than 1991 screening radon levels. For all other physiographic subregions of Texas, the 2020 indoor radon values and 1991 radon screening values are approximately similar. This finding holds for all metrics evaluated.

ES-4. Predictive Results: Correlations with Selected Geogenic Variables

Predictive correlations were explored for 2020 indoor radon levels vs. ten selected geogenic variables commonly associated with radon. Statewide correlations for six variables were identified including soil geochemistry (aluminum, potassium, uranium), clay percent, major aquifer, distance to nearest fault, geology -rock description, and geology- rock type category. Results were mixed with a few selected parameters showing correlations aligned with an expected relationship, that is, the identified trend was consistent with published findings. However, other geogenic variables indicated a relationship contrary to what was expected.

More detailed exploratory analyses were performed for a superficially well-behaved correlation exemplar (uranium) and a poorly behaved correlation exemplar (faulting). These analyses indicated that *statewide* correlations are not supported. In both cases the observed relationships were better explained by intervening variables at the subregion level. In other words, spatial heterogeneity associated with the self-selected AEL 2020 dataset, coupled with sample size limitations, precluded valid inferences for these more geospatially-focused correlations.

Overall, the predictive analyses did not identify specific statewide relationships, but the effort did suggest that real correlations may exist between selected geogenic variables and indoor radon levels for some subregions of Texas. This supports a need for further exploratory research on the issue.

ES-5. Application, Summary, and Limitations

ES-5.1 Application

The intended use of findings from the Texas Indoor Radon Map 2020 Update research study is to help identify areas to target radon program resources, to provide guidance in selecting the most appropriate building code options for areas, and to provide general information on radon and geology for federal, state, and municipal officials dealing with radon issues.

ES-5.2 Summary

Descriptive, comparative and predictive analyses based on the 2020 AEL dataset support the following conclusions:

1. For Texas residences where the lowest livable area is the first floor (*i.e.*, ground surface level), indoor radon values are highest in the Central High Plains subregion of the state. Further, *heightened radon risk* at the first floor level – that is, $p(\text{Rn} \geq 4 \text{ pCi/L})$ greater than 0.10 – exists for residences in Texas counties located within the Central High Plains, Southern High Plains, and Central Texas Uplift subregions of the state.
2. For Texas residences where the lowest livable area is the basement (*i.e.*, below ground surface level), limited data indicate indoor radon values are highest in the Central Texas Uplift, Southern High Plains, Central High Plains, Interior Coastal Plains 2, Coastal Prairie, Interior Coastal Plains 1, and North Central Plains subregions of the state. Further, *heightened radon risk* at the basement level – that is, $p(\text{Rn} \geq 4 \text{ pCi/L})$ is greater than 0.10 – exists statewide in all subregions of Texas.
3. Upper floor radon data are extremely limited in the AEL 2020 dataset. The four Texas physiographic subregions with upper floor radon data show average radon levels are low, and the radon risk is also low. In these areas, upper floor average radon values are typically about one-half first floor values and one-fourth basement values.
4. Comparison of the EPA 1991 screening radon dataset vs. the 2020 AEL basement/ first floor indoor radon data show both sets of data identify the same

subregions of Texas as having the *highest* mean indoor radon values/ radon risk (first quartile) and the *lowest* mean indoor radon values/ radon risk (fourth quartile). Quantitatively, the 2020 indoor radon levels for three subregions of Texas – Central Texas Uplift, Southern High Plains and Central High Plains – are roughly two to three times higher than 1991 screening radon levels, but are roughly comparable for all other physiographic subregions of Texas.

5. Predictive analyses suggest that significant correlations may exist between selected geogenic variables and indoor radon levels for some subregions of Texas. But spatial heterogeneity associated with the self-selected nature of the 2020 AEL dataset precluded definitive inferences, and more data are required to achieve supportable correlations.

ES-5.3 Limitations

The Texas Indoor Radon Map 2020 Update research study relied on a self-selected sample of indoor radon data provided by Alpha Energy Laboratory Laboratories, Inc. Given the span of years represented, the dataset reflected developmental variations in radon test equipment, methods and geocoding approaches. Descriptive parameters for each radon test were self-reported by the person who placed the test (typically the homeowner), and while taken at face value, such data are subject to interpretive and other errors.

Limitations associated with application and use of the updated Texas indoor radon maps presented herein align with those of the EPA 1993 Map of Radon Zones. Because of constraints on the scales of maps presented in this report and because the smallest units used to present the indoor radon data are counties, generalizations were made in order to estimate the radon level of each area. Variations in geology, soil characteristics, climatic factors, homeowner lifestyles, and other factors that influence radon concentrations can be quite large within any particular physiographic subregion, so the maps cannot be used to estimate or predict the indoor radon concentrations of individual homes or housing tracts. Within any region of a given indoor radon concentration, there are likely to be areas where actual radon levels are lower or higher than that assigned to the area as a whole, especially large areas such as the 1,000 square mile county size typical of Texas.

This report offers a generalized assessment of Texas's indoor radon potential and there is no substitute for having a home tested. The conclusions about radon levels and risk presented in this report cannot and should not be used to estimate or predict the indoor radon concentrations of individual homes, building sites, or housing tracts. Indoor radon levels, both high and low, can be quite localized, and any local decisions about radon should not be made without consulting all available local data. EPA recommends that all homes be tested for indoor radon.

ES-6. Works Cited

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ES-7. Contributor Roles Taxonomy (CRediT) Author Statement

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