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Soil-to-Plant Transfer of Radiocaesium in Thailand

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ABSTRACT

Soil-to-plant transfer factors (TF) of radiocaesium-137 were estimated by considering soil properties of 51 provinces in Thailand, and by using the model of Absalom. According to our study, the Absalom model could estimate average TF values to be 0.0852 ± 0.0475. Compared with average measured TF values which was 0.1289 ± 0.0529, it was found that calculated TF values decreased with increasing pH, clay contents and exchangeable K^+. The corresponding calculated TF values increased with increasing organic matter contents and NH_4^+ concentrations. Statistical analysis showed that Relative Euclidean Difference (RED) was 0.238, reliability index (k) was 0.661 and geometrically intuitive reliability index (k_g) was 1.97, which confirmed that the Absalom model was reasonably accurate. Calculated TF values by the Absalom model were in good agreement with the measured ones. However, calculated TF values were found to be significantly different from the measured ones for some provinces in Thailand. The parameters used in the Absalom model needed to be modified to suitably match soil properties in Thailand.

Key words: transfer factor, Absalom model, radiocaesium; soil properties

INTRODUCTION

Radionuclides produced by nuclear explosion and nuclear facilities have the potential to be released into the atmosphere. These nuclides are part of the fallout which is deposited on the ground and reach human bodies via food chain (Eisenbud, 1973). Among deposited radionuclides, radiocaesium (^{137}Cs, half life is 30 years) is the dominant fission product which has a high relative mobility in the soil–plant system, long term bioavailability, high radiotoxicity, continuing to cycle through the soil plant-animal system, and is longlived. The plant uptake of deposited ^{137}Cs from soil, commonly expressed as soil to plant transfer factor (TF) is widely used while calculating the radiological humus dose via the ingestion pathway.

Absalom *et al.* (2001) presented a model which predicted the radiocaesium soil to plant transfer factor (TF) on the basis of easily measured soil characteristics (pH, clay content, organic matter content, exchangeable K^+ and NH_4^+ concentration). In the present work, data of soil properties and ^{137}Cs activity concentrations in soil and grass of some selected provinces in Thailand were collected and were used as input parameters to calculate transfer factor (TF) in the Absalom model. Finally, the calculated TF values were compared with the measured TF values to test whether the Absalom model could be applied to the soil characteristics in Thailand.

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MATERIALS AND METHODS

Model descriptions

Absalom *et al.* (1999) presented a semi-mechanistic model, which predicted activity concentrations of ^{137}Cs in plants. The model utilized as input soil characteristic parameters including clay content and exchangeable K^+. In 2001, Absalom *et al.* (2001) developed the model which accounted for the effect of organic matter on ^{137}Cs adsorption by soil and uptake by plants. Therefore, radiocaesium bioavailability is strongly influenced by soil properties such as pH, clay content, organic matter and exchangeable K^+ (Cremers *et al.*, 1988). This model can be applied to mineral and organic soils simultaneously to provide a more generally applicable simulation of ^{137}Cs dynamics. The model of Absalom *et al.* (2001) assumed that ^{137}Cs adsorption occurred exclusively on both clay and humus surfaces, however, fixation only occured on clay, and the radiocaesium adsorbed on the organic fraction was not subject to fixation. The relationship between adsorbed and solution of ^{137}Cs was described by a labile ^{137}Cs distribution coefficient (k_{dl}, $dm^3\ kg^{-1}$) which was estimated as a function of clay content and exchangeable K^+. Plant uptake of radiocaesium was described by a concentration factor (CF, Bq kg^{-1} plant/Bq dm^{-3} soil solution) which was related to solution K^+ concentration ($[m_K]$, moles dm^{-3}).

Data sources

According to input parameters, the data referred to six different regions in Thailand. Samples were collected from several provinces in the north, northeast, east, west, middle and south of Thailand. Each soil sample consisted of subsamples collected from an area of 100 m^2. The samples were taken from 0 to 10 cm upper soil layer. Specific soil parameters in each province were available for comparison with ^{137}Cs concentration in the grass samples.

Five independent soil properties (pH, clay content, organic matter, exchangeable K^+ and NH_4^+ concentration) and initial ^{137}Cs activity in soil were required as the model input parameters in the Absalom model assuming certain days after a deposition of ^{137}Cs in soil for the prediction of TF values in the selected regions. Organic matter (OM) content was calculated as OM = organic carbon $\times$ 1.724 (Nelson and Sommers, 1982). The five values (pH, clay content, organic matter, exchangeable K^+ and NH_4^+ concentration) in Table 1 (LLD, 1988) are used as the input parameters to calculate transfer factor of soil-to-plant (here, it was grass) in the model. The soil and grass were dried and homogenized before being analysed. ^{137}Cs activities in soil and grass, measured by a Hyperpure Germanium gamma-ray detector (HPGe), are also shown in Table 1 (Itthipoonthanakorn).

RESULTS AND DISCUSSION

Since the Absalom model takes into account the time-dependent changes in TF due to radiocaesium fixation, the calculations were performed assuming 365 days after uniform deposition of a certain amount of ^{137}Cs (Bq m^{-2}) in soil. The same parameters as in the model were used in the calculations.

Predicted and observed ^{137}Cs transfer factor (TF) values for grass are given in Table 2 and Figure 1.

Calculated TF values of ^{137}Cs from soil to grass grown in tropical Thailand are shown in Figures 2-6 compared to different functions of soil properties. It can be seen from Figures 2-4 that the calculated TF values decrease with increasing pH, clay content and exchangeable K^+. The corresponding calculated TF values increase with increasing organic matter content and NH_4^+ concentration, as shown in Figures 5-6.

Table 1 Soil properties and ^{137}Cs activities in soil and grass of some selected provinces in Thailand.

Region	Province	pH	Clay content	Organic matter (%)	Ex-K^{+} (cmol$_c$ kg^{-1}) (%)	[NH_4^+] ($\times 10^{-5}$) (mol dm^{-3})	^{137}Cs activity concentration in soil (Bq kg^{-1})[a]	^{137}Cs activity concentration in grass (Bq kg^{-1})[a]
North	1.Chaiang Rai	4.3	8.0	0.914	0.10	2.40	1.669	0.108 ± 0.018
	2.Chaiang Mai	5.3	15.6	1.810	0.20	7.70	0.989 ± 0.235	0.086 ± 0.022
	3.Nakhon Sawan	8.2	30.7	2.879	0.20	34.30	0.813 ± 0.182	0.068 ± 0.021
	4.Phayao	5.7	9.5	1.379	0.10	5.00	1.171 ± 0.269	0.066 ± 0.024
	5.Phichit	4.5	45.0	2.689	0.20	18.50	0.685 ± 0.223	0.118 ± 0.061
	6.Phetchabun	5.9	6.0	1.672	0.10	4.00	0.619 ± 0.140	0.060 ± 0.031
	7.Phrae	5.1	12.0	2.069	0.10	6.00	1.033 ± 0.252	0.081 ± 0.028
	8.Uthai Thani	4.8	13.5	3.448	0.10	5.60	1.150 ± 0.304	0.155 ± 0.024
Central	9.Bangkok	4.2	61.5	0.879	0.60	25.50	1.197 ± 0.480	0.078 ± 0.023
	10.Kanchanaburi	4.7	36.5	0.759	0.10	8.40	0.684 ± 0.158	0.088 ± 0.033
	11.Chai Nat	6.0	19.8	0.345	0.10	6.30	0.676 ± 0.345	0.050 ± 0.009
	12.Nakhon Nayok	5.1	44.9	0.172	0.20	10.60	0.734 ± 0.218	0.097 ± 0.030
	13.Nakhon Pathom	5.0	65.4	4.241	0.50	29.40	0.997 ± 0.327	0.073 ± 0.037
	14.Nonthaburi	7.2	52.3	0.721	0.49	5.31	0.953 ± 0.284	0.141 ± 0.051
	15.Pathum Thani	4.2	46.0	1.569	0.20	20.30	0.898 ± 0.312	0.111
	16.Ratchaburi	4.8	65.1	9.775	0.30	36.50	0.474	0.104 ± 0.019
	17.Lop Buri	7.8	52.0	2.534	0.70	84.00	0.969 ± 0.242	0.172 ± 0.048
	18.Samut Prakan	5.3	74.5	1.827	1.00	28.10	0.519	0.068 ± 0.026
	19.Saraburi	6.6	86.0	1.327	0.30	54.30	0.977 ± 0.244	0.162 ± 0.048
	20.Sing Buri	5.9	44.5	2.155	0.30	27.00	0.630 ± 0.046	0.079 ± 0.043
	21.Ang Thong	5.0	79.6	3.827	0.50	32.20	0.902 ± 0.327	0.127 ± 0.034
	22.Ayuthaya	5.0	65.1	1.207	0.30	25.40	0.955 ± 0.268	0.139 ± 0.064
North-East	23.Kalasin	6.6	10.0	0.034	0.03	0.60	0.834 ± 0.167	0.097 ± 0.027
	24.Khon Kaen	6.0	5.8	1.379	0.10	5.20	1.456 ± 0.113	0.170 ± 0.032
	25.Chaiyaphum	4.7	8.7	0.241	0.03	2.80	0.643 ± 0.157	0.075 ± 0.024
	26.Nakhon Phanom	5.4	6.1	2.862	0.20	5.30	0.963 ± 0.150	0.106 ± 0.033
	27.Maha Sarakham	5.4	2.5	0.931	0.10	2.90	0.791 ± 0.139	0.099 ± 0.024
	28.Mukdahan	5.0	3.6	3.069	0.10	4.80	0.497 ± 0.158	0.101 ± 0.034
	29.Yasothon	5.2	10.8	0.162	0.42	3.58	0.541 ± 0.170	0.082 ± 0.022
	30.Roi Et	5.3	6.6	0.103	0.03	1.00	0.769 ± 0.176	0.132 ± 0.028
	31.Loei	6.1	6.3	0.345	0.07	1.63	0.705 ± 0.133	0.070 ± 0.026
	32.Si Sa Ket	5.0	17.0	0.914	0.03	3.30	0.329	0.098 ± 0.029
	33.Sakon Nakhon	5.9	11.0	8.068	0.40	23.50	0.906 ± 0.243	0.106 ± 0.024
	34.Surin	4.3	10.7	1.862	0.10	7.40	0.762 ± 0.181	0.131 ± 0.029
	35.Nong Bua Lam Phu	4.1	7.9	0.197	0.19	0.92	1.140 ± 0.211	0.127 ± 0.030
	36.Ubon Ratchathani	4.9	2.0	0.414	0.10	1.58	0.681 ± 0.122	0.070 ± 0.016
East	37.Chachoengsao	5.5	2.8	0.793	0.10	1.60	0.731 ± 0.216	0.108 ± 0.041
	38.Chon Buri	5.1	6.6	0.707	0.10	1.60	1.659 ± 0.265	0.105 ± 0.028
	39.Prachin Buri	5.8	4.8	0.707	0.05	1.90	0.646 ± 0.184	0.124 ± 0.029
	40.Sa Kaeo	4.6	7.5	0.271	0.53	5.30	0.5989 ± 0.182	0.095
West	41.Prachuap Khiri Khan	7.3	1.5	1.741	0.10	4.20	0.403	0.109 ± 0.030
	42.Phetchaburi	7.1	4.0	0.155	0.10	1.40	0.994 ± 0.288	0.098 ± 0.026
South	43.Krabi	4.3	8.6	2.327	0.10	3.40	0.876 ± 0.350	0.122 ± 0.025
	44.Trang	6.0	11.0	2.638	0.10	5.40	0.726 ± 0.252	0.058 ± 0.025
	45.Nakhon Si Thammarat	4.7	19.0	2.276	0.10	4.70	0.811 ± 0.230	0.071 ± 0.055
	46.Narathiwat	4.3	14.2	8.448	0.30	34.30	1.341 ± 0.288	0.204 ± 0.027
	47.Pattani	6.3	8.3	0.586	0.10	1.60	0.742 ± 0.083	0.163 ± 0.035
	48.Phangnga	5.9	7.0	1.879	0.10	2.60	1.210 ± 0.164	0.121 ± 0.026
	49.Phuket	4.6	18.5	3.293	0.10	4.50	1.132 ± 0.285	0.151 ± 0.053
South	50.Songkhla	4.6	8.0	1.017	0.10	2.20	1.132 ± 0.262	0.070 ± 0.023
	51.Satun	4.8	14.5	4.207	0.30	6.30	1.076 ± 0.301	0.040 ± 0.018

[a] (average value ± standard error)

Source: Land Development Department or LDD (1988)

Table 2 Measured and calculated TF values of some provinces in Thailand.

Region	Province	Measured TF value	Calculated TF value
North	1.Chaiang Rai	0.0647	0.0677[a]
	2.Chaiang Mai	0.0871	0.0448[b]
	3.Nakhon Sawan	0.0830	0.0790
	4.Phayao	0.0562	0.0738[a]
	5.Phichit	0.1725	0.1124
	6.Phetchabun	0.0975	0.0837
	7.Phrae	0.0783	0.0918[a]
	8.Uthai Thani	0.1347	0.1053
	9.Bangkok	0.0655	0.0350[b]
	10.Kanchanaburi	0.1289	0.1242
central	11.Chai Nat	0.0743	0.0640
	12.Nakhon Nayok	0.1318	0.0550[b]
	13.Nakhon Pathom	0.0735	0.0479
	14.Nonthaburi	0.1482	0.0095[b]
	15.Pathum Thani	0.1237	0.1256[a]
	16.Ratchaburi	0.2195	0.1527[b]
	17.Lop Buri	0.1772	0.0329[b]
	18.Samut Prakan	0.1320	0.0160[b]
	19.Saraburi	0.1663	0.1173
	20.Sing Buri	0.1248	0.0613[b]
	21.Ang Thong	0.1410	0.0543[b]
	22.Ayuthaya	0.1459	0.0787[b]
North-East	23.Kalasin	0.1159	0.0792
	24.Khon Kean	0.1166	0.0856
	25.Chaiyaphum	0.1161	0.1876[a]
	26.Nakhon Phanom	0.1101	0.0635[b]
	27.Maha Sarakham	0.1253	0.1093
	28.Mukdahan	0.2032	0.1683
	29.Yasothon	0.1513	0.0185[b]
North-East	30.Roi Et	0.1713	0.1174
	31.Loei	0.0989	0.0661
	32.Si Sa Ket	0.2979	0.2344
	33.Sakon Nakhon	0.1168	0.0772
	34.Surin	0.1713	0.1139
	35.Nong Bua Lam Phu	0.1114	0.0358[b]
	36.Ubon Ratchathani	0.1027	0.1001
East	37.Chachoengsao	0.1476	0.0915
	38.Chon Buri	0.0633	0.0601
	39.Prachin Buri	0.1927	0.1096[b]
East	40.Sa Kaeo	0.1587	0.0199[b]
West	41.Prachuap Khiri Khan	0.2697	0.2134
	42.Phetchaburi	0.0981	0.0525[b]

Table 2 (continued).

Region	Province	Measured TF value	Calculated TF value
South	43.Krabi	0.1398	0.0876
	44.Trang	0.0806	0.0856[a]
	45.Nakhon Si Thammarat	0.0871	0.0830
	46.Narathiwat	0.1523	0.1506
	47.Pattani	0.2202	0.0473[b]
	48.Phangnga	0.0998	0.0721
	49.Phuket	0.1331	0.0894
	50.Songkhla	0.0611	0.0651[a]
	51.Satun	0.0370	0.0370

[a] The calculated TF values were found to be overestimating compared to the measured TF values for most provinces in Thailand.

[b] The calculated TF values were found to be significantly different from the measured TF values for several provinces in Thailand.

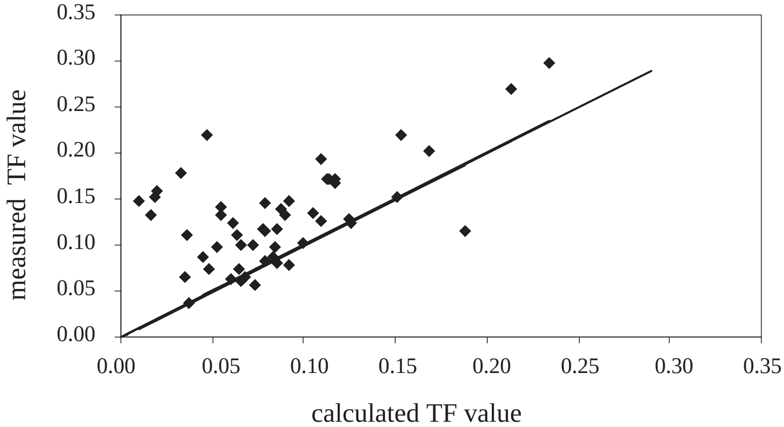

Figure 1 Measured and calculated TF values of ^{137}Cs for grass in Thailand. The solid line indicates 1:1 relationship for measured and calculated values.

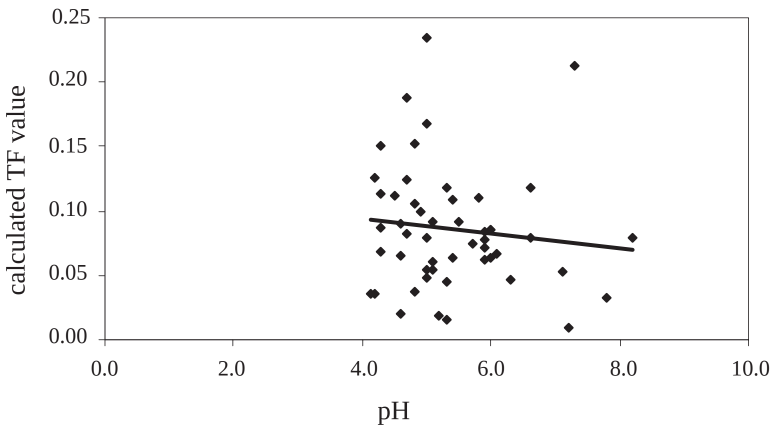

Figure 2 Calculated TF values are shown as a function of pH. The solid line is a curve fitted to the data in the graph.

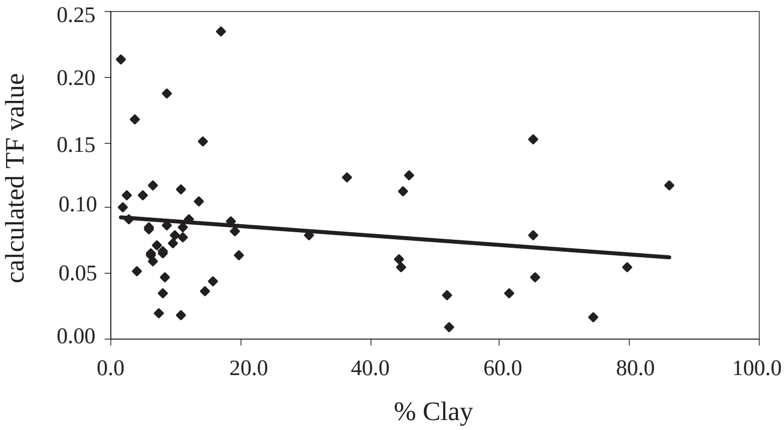

Figure 3 Calculated TF values are shown as a function of clay content. The solid line is a curve fitted to the data in the graph.

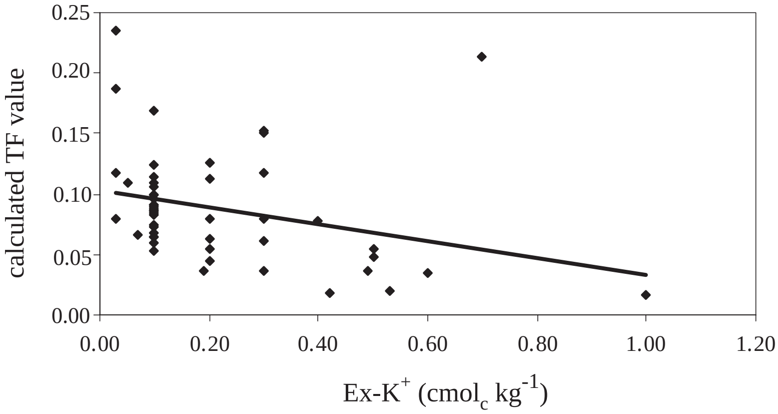

Figure 4 Calculated TF values are shown as a function of exchangeable K^+. The solid line is a curve fitted to the data in the graph.

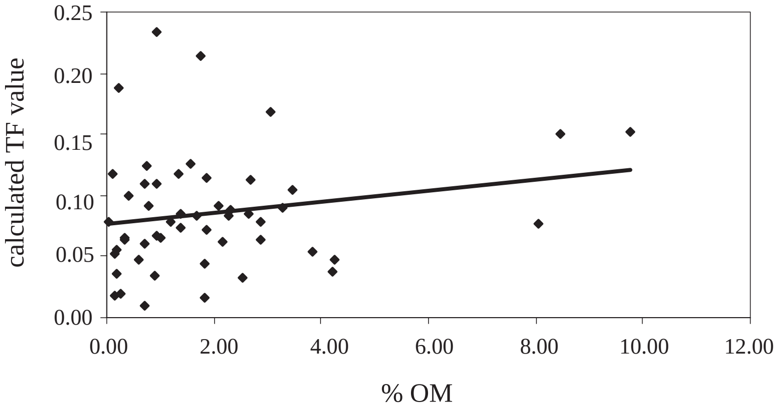

Figure 5 Calculated TF values are shown as a function of organic matter (OM) content. The solid line is a curve fitted to the data in the graph.

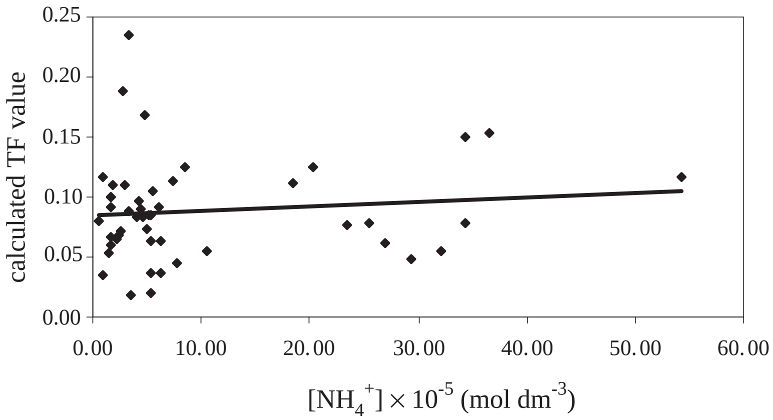

Figure 6 Calculated TF values are shown as a function of NH_4^+ concentration. The solid line is a curve fitted to the data in the graph.

Measured TF values of ^{137}Cs for grass were observed to be 0.037 - 0.298 in the north, northeast, east, west, middle and south, with an average of 0.129 ± 0.053. These values were relatively high compared to the corresponding values (0.010 - 0.234 in the north, northeast, east, west, middle and south, with an average of 0.085 ± 0.048) predicted by the Absalom model.

These calculated values differed significantly from the measured values. This is due to the differences in soil, the types of grass and the environmental conditions. In addition, soil management such as plough, cultivation method and fertilization, microbial process, root density, soil moisture and ^{137}Cs uptake may decrease with increasing ^{137}Cs-soil contact time after the deposition on soil (Bell *et al.*, 1988; Kirk and Staunton, 1989; Noordijk *et al.*, 1992; Ehlken and Kirchner, 2002; Rahman and Voigt, 2004).

Simple statistical analysis (Williams and Leggett, 1984) showed that the agreement between model and measured values (Relative Euclidean Difference, RED) was 0.238, the value of the reliability index (k) was 0.661 and the geometrically intuitive reliability index (k_g) was 1.97, which confirmed that the Absalom model was reasonably accurate. Calculated TF values by the Absalom model were in good agreement with the measured ones. However, calculated TF values were found to be significantly different from the measured ones for some provinces. As a result, the parameters used in the Absalom model needed to be suitably modified to the characteristics of soils in Thailand.

CONCLUSION

In this work, the uptake of deposited ^{137}Cs has been predicted based on the soil properties, such as pH, clay content, organic matter content, exchangeable K^+ and NH_4^+ concentration valid for the tropical environment in Thailand, and using the Absalom model. It has been found that the calculated TF values differ significantly from the measured values for some provinces in Thailand, which implies that the soil properties in these provinces differ from those used in the Absalom model and they need to be measured practically in order to validate the model. Furthermore the parameters (k_3, k_4, k_5, k_6, k_{fast}, k_{slow}, P_{slow} and CEC_{clay}) could be re-evaluated for the tropical environment of Thailand.

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