

Research on Nuclear-Weapon Stockpile Changes, Test Activities, and the Speed of Transition to Nuclear-Weapon Possession Based on TOPSIS

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Abstract. Nuclear-weapon stockpile changes, nuclear-test activities, and national nuclear-policy status jointly record the key process through which nuclear capabilities are formed and evolve. Based on historical country-year data, this study screens countries that have had positive stockpile values in their historical stockpile series and constructs an indicator system for assessing research activity and transition speed. To avoid comparison bias caused by mixing different time periods, the period from 1981 to 1990 is selected as a unified ten-year observation window. Stockpile change, average stockpile growth rate, and the number of nuclear tests are extracted, and the TOPSIS method is used to evaluate the level of nuclear-weapon research activity across countries. In addition, a transition-speed evaluation matrix for nuclear-weapon possession is established from three dimensions: time span, short-term average stockpile growth rate, and short-term stockpile increase. The results show that, within the 1981-1990 window, Russia had relatively high values for both stockpile change and nuclear-test frequency, obtained the highest TOPSIS composite score, and can therefore be regarded as the most active country in nuclear-weapon research during this period. In the evaluation of the transition from "not considering nuclear weapons" to "possessing nuclear weapons", the United States ranked first because of its shortest time span and rapid early stockpile expansion. The study indicates that multi-indicator evaluation can effectively reduce the one-sidedness of relying on a single stockpile or test indicator and provides a reproducible quantitative framework for the structured analysis of historical nuclear-weapon data.

Keywords: nuclear-weapon stockpile, nuclear test, TOPSIS, data preprocessing, transition speed

1. Introduction

Nuclear-weapon stockpiles are an important indicator for observing national strategic capabilities and the international security landscape. SIPRI and the Federation of American Scientists have long tracked changes in global nuclear forces, and their statistics show that nuclear weapons remain concentrated in a small number of countries, with the United States and Russia maintaining dominant positions in global nuclear stockpiles over the long term [1, 2]. Country-level nuclear-

force information compiled by the Arms Control Association and the Bulletin of the Atomic Scientists further provides a basis for cross-national comparison of estimated warhead numbers, deployment status, and modernization dynamics [3, 4]. From a historical perspective, global nuclear stockpiles have gone through stages of Cold War expansion, peak accumulation, post-Cold War reductions, and simultaneous modernization, while the trajectories of different countries vary considerably [5]. Open data platforms such as Our World in Data have also promoted the visualization and reproducible use of historical nuclear-weapon data [6].

Nuclear tests are an important observable variable of nuclear-weapon research, development, and verification activities. The number of nuclear tests reflects not only the intensity of technical verification, but also capability demonstration, strategic deterrence, and policy shifts. Statistics on nuclear testing published by the Arms Control Association indicate that nuclear testing in the middle and late twentieth century had clear stage-based characteristics [7]. The Comprehensive Nuclear-Test-Ban Treaty and its international monitoring system provide institutional constraints and technical supervision for nuclear-test activities [8]. Broader nuclear non-proliferation governance arrangements also work together with restrictions on nuclear testing, including the Treaty on the Non-Proliferation of Nuclear Weapons, International Atomic Energy Agency safeguards, the Treaty on the Prohibition of Nuclear Weapons, United Nations Security Council Resolution 1540, and New START [9-13]. The Nuclear Weapons Ban Monitor supplements governance-related information on nuclear-weapon activities from the perspective of international law and policy compliance [14].

Nuclear-weapon research also has significant humanitarian, environmental, and historical externalities. United Nations historical materials on the prohibition of nuclear tests point out that nuclear testing is not only a military-technical event, but can also have long-term impacts on ecosystems and public health [15]. Pravālie summarized the environmental consequences of nuclear testing from a global perspective, while UNSCEAR reports on the sources and effects of ionizing radiation provide a scientific background for assessing radiation impacts [16, 17]. Historical materials on the Trinity test further show that nuclear explosions have embodied technical verification, strategic demonstration, and risk spillover since their inception [18].

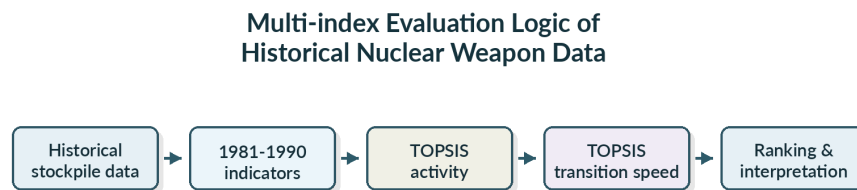


Figure 1. Multi-index evaluation logic of historical nuclear-weapon data

At the methodological level, stockpile change, the number of tests, and growth rate are indicators with different units that nevertheless offer complementary explanations. TOPSIS is based on the core idea of "approaching the positive ideal solution and moving away from the negative ideal solution", and is suitable for multi-attribute evaluation problems with limited sample sizes, few indicators, and a need for interpretable ranking [19]. Compared with ranking based on a single indicator, multi-indicator composite evaluation can simultaneously retain information on absolute expansion, relative growth, and test activities. Once weights are specified, its calculation steps are clear and the results are easy to reproduce [20]. On this basis, this study constructs an analytical

framework consisting of data preprocessing, activity evaluation, and transition-speed evaluation. The research logic is shown in Figure 1.

2. Data preprocessing

This study uses country-year observations as the basic index and organizes stockpile, nuclear-test, and status variables. The data preprocessing does not attempt to provide a full narrative of all historical facts; instead, it retains only the time points and indicators required to support the subsequent TOPSIS model. Specifically, countries that had positive values in the historical stockpile series are first screened. Then, stockpile change, average stockpile growth rate, and the number of nuclear tests are extracted for the 1981-1990 ten-year window to form the original matrix for the activity evaluation in Section 3.

The choice of 1981-1990 as the observation window is based mainly on three considerations. First, this window falls in the late Cold War period, when nuclear-arms competition, nuclear-test activities, and stockpile adjustments were still relatively intensive, allowing it to reflect the intensity of national nuclear-weapon research activities. Second, after 1991, the dissolution of the Soviet Union, post-Cold War arms-control arrangements, and large-scale reductions meant that stockpile changes often reflected political disarmament and strategic restructuring more than research activity. Third, stockpile and test records in this ten-year window are relatively complete, which facilitates comparison across countries under a consistent standard.

2.1. Screening countries that have historically possessed nuclear weapons

In this study, "having possessed nuclear weapons" is defined as follows: a country has at least one year with a positive value in its historical nuclear-weapon stockpile series. According to this rule, 10 countries are screened. Although South Africa no longer maintains a nuclear stockpile, its historical series contains positive stockpile records and it is therefore included in the sample. This study no longer calculates stockpile numbers for each country in 2022, because the subsequent activity and transition-speed evaluations both rely on change indicators within historical windows, and the 2022 cross-sectional stockpile does not constitute a necessary input for the main models of this study. The data organization and preprocessing variables are summarized in Table 1.

Table 1. Countries that have had positive stockpile records in history

No.	Country
1	China
2	France
3	India
4	Israel
5	North Korea
6	Pakistan
7	Russia
8	South Africa
9	United Kingdom

Table 1. (continued)

10	United States
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Note: Country names retain the English spellings used in the data table; screening is based on whether a positive value appears in the historical stockpile series.

2.2. Stockpile change and average stockpile growth rate over the past ten years

The calculated stockpile changes and average growth rates for each country are presented in Table 2. Stockpile change is obtained by subtracting the 1981 stockpile from the 1990 stockpile and is used to describe absolute expansion or contraction in nuclear-weapon stockpiles within the ten-year window. The average stockpile growth rate is used to describe the relative speed of change. For year t , the annual stockpile growth rate is defined as:

$$R_t = \frac{X_t - X_{t-1}}{X_{t-1}} \times 100\% \quad (1)$$

where X_t denotes the number of nuclear weapons in year t , and R_t denotes the stockpile growth rate in year t . The arithmetic mean of the annual growth rates from 1981 to 1990 is then taken to obtain the average stockpile growth rate:

$$\bar{R} = \frac{1}{10} \sum_{t=1981}^{1990} R_t. \quad (2)$$

Table 2. Nuclear-weapon stockpile change and average stockpile growth rate, 1981-1990

Country	Stockpile change	Average stockpile growth rate
China	22	1.247%
France	231	7.807%
India	0	0
Israel	20	5.518%
North Korea	0	0
Pakistan	0	0
Russia	834	0.838%
South Africa	0	7.833%
United Kingdom	-150	-3.219%
United States	-1816	-1.165%

Note: Stockpile change is the difference between the 1990 stockpile and the 1981 stockpile; the average stockpile growth rate is calculated as the mean of annual growth rates.

Table 2 shows that Russia increased its stockpile by 834 weapons during 1981-1990, while France increased by 231. The United States decreased by 1816 weapons, and the United Kingdom decreased by 150. The average stockpile growth rate indicates that France, South Africa, and Israel had relatively high levels of relative growth. Absolute change and relative growth rate describe

different dimensions: the former is more closely related to scale change, whereas the latter focuses more on growth speed. Therefore, both are retained in the subsequent composite evaluation.

2.3. Number of nuclear tests over the past ten years

The number of nuclear tests is used to measure the intensity of nuclear-weapon research, development, and verification activities. Compared with stockpile change, the number of tests corresponds more directly to technical verification and capability demonstration. To maintain a consistent statistical standard for the indicators, this study counts only the number of nuclear tests by country during 1981-1990 and uses it as the second indicator in the composite evaluation in Section 3. The distribution of nuclear tests among countries during the observation period is shown in Figure 2.

The statistical results show that Russia and the United States each conducted 149 tests in this window, France conducted 86, the United Kingdom 10, China 9, Israel 4, and South Africa 2. India, North Korea, and Pakistan had no positive records in this window. Together with stockpile change and average stockpile growth rate, this indicator forms the basis for evaluating research activity.

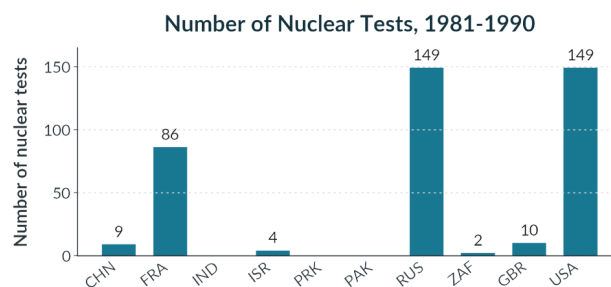


Figure 2. Number of nuclear tests by country, 1981-1990

3. Identifying the most active country in nuclear-weapon research over the past ten years

Nuclear-weapon research activity cannot be determined solely by stockpile size or the number of tests. Stockpile change reflects absolute expansion, the number of tests reflects technical verification activity, and the average stockpile growth rate reflects the speed of relative expansion. These three types of indicators are complementary and can jointly describe the strength of nuclear-weapon research activities across countries during 1981-1990. The activity-evaluation indicator framework used in this study is shown in Figure 3. The detailed indicator matrix used for the TOPSIS evaluation is provided in Table 3.

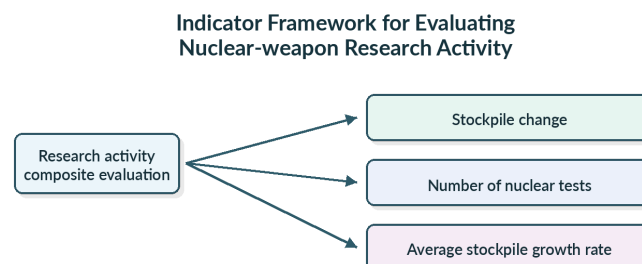


Figure 3. Indicator framework for evaluating nuclear-weapon research activity

Table 3. Indicator matrix for evaluating nuclear-weapon research activity, 1981-1990

Country	Stockpile change	Number of tests	Average stockpile growth rate
China	22	9	1.247%
France	231	86	7.807%
India	0	0	0
Israel	20	4	5.518%
North Korea	0	0	0
Pakistan	0	0	0
Russia	834	149	0.838%
South Africa	0	2	7.833%
United Kingdom	-150	10	-3.219%
United States	-1816	149	-1.165%

Note: This table is the original indicator matrix for the TOPSIS composite evaluation.

This study assigns weights of 0.5, 0.3, and 0.2 to stockpile change, the number of tests, and the average stockpile growth rate, respectively. Stockpile change receives the highest weight because it directly reflects the outcome of nuclear-capability development. The number of tests is used to reflect the intensity of research and verification, while the average stockpile growth rate supplements the evaluation by describing relative growth across countries of different sizes. The indicator weights used in the TOPSIS evaluation are listed in Table 4.

Table 4. Indicator weights for evaluating nuclear-weapon research activity

Indicator	Stockpile change	Number of tests	Average stockpile growth rate
Weight	0.5	0.3	0.2

The TOPSIS calculation process is as follows. Let the original decision matrix be. Vector normalization is used to obtain the normalized decision matrix $B = (b_{ij})$:

$$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}}, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n. \quad (3)$$

Combined with the indicator weight ω_j , the weighted normalized matrix $C = (c_{ij})$ is constructed as follows:

$$c_{ij} = \omega_j b_{ij}. \quad (4)$$

Because stockpile change, the number of tests, and the average stockpile growth rate are all treated as benefit-type indicators, larger values indicate higher activity. The positive ideal solution and negative ideal solution are defined as follows:

$$c_j^* = \max_i c_{ij} \quad (5)$$

$$c_j^0 = \min_i c_{ij}. \quad (6)$$

The Euclidean distances from each sample to the positive ideal solution and the negative ideal solution are:

$$s_i^* = \sqrt{\sum_{j=1}^n (c_{ij} - c_j^*)^2}. \quad (7)$$

$$s_i^0 = \sqrt{\sum_{j=1}^n (c_{ij} - c_j^0)^2} \quad (8)$$

Finally, the composite score index f_i is calculated. A higher score indicates that the country is closer to the ideal active state:

$$f_i = \frac{s_i^0}{s_i^* + s_i^0}. \quad (9)$$

Based on the indicator matrix in Table 3 and the weights in Table 4, the positive ideal solution and negative ideal solution in the activity evaluation are obtained as follows:

$$C^* = [834, 149, 7.833\%]. \quad (10)$$

$$C^0 = [-1816, 0, -3.219\%]. \quad (11)$$

The final TOPSIS ranking results are presented in Table 5 and Figure 4.

Table 5. TOPSIS composite scores for nuclear-weapon research activity by country

Rank	Country	Distance to positive ideal solution	Distance to negative ideal solution	Composite score index
1	Russia	0.15804652	0.48987351	0.75607095
2	France	0.16809888	0.40802282	0.70822331
3	United States	0.38055312	0.36088600	0.48673720
4	South Africa	0.36731421	0.33313419	0.47560133
5	Israel	0.36578763	0.29788802	0.44884579
6	China	0.38070798	0.24583237	0.39236478
7	India	0.41189472	0.23214085	0.36044725
8	North Korea	0.41189472	0.23214085	0.36044725
9	Pakistan	0.41189472	0.23214085	0.36044725
10	United Kingdom	0.43369794	0.20366529	0.31954352

Note: A larger composite score index indicates that the country was more active during the 1981-1990 window.

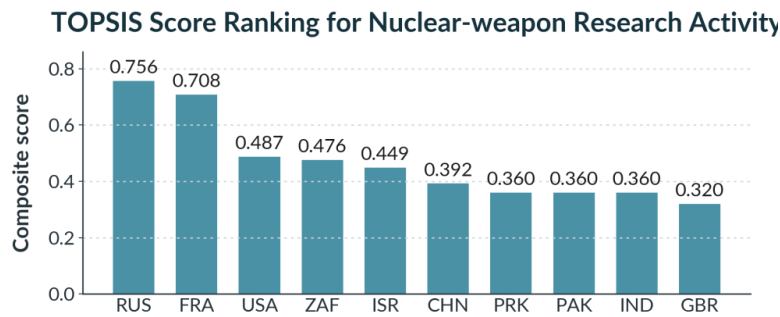


Figure 4. TOPSIS score ranking for nuclear-weapon research activity

Table 5 and Figure 4 show that Russia has a composite score index of 0.75607095 and ranks first, while France ranks second with 0.70822331. Although the United States had the same number of tests as Russia, its stockpile change was negative, resulting in a composite score lower than those of Russia and France. Therefore, within the 1981-1990 window, Russia was the most active country in nuclear-weapon research. This conclusion is based on the combined effects of stockpile change, the number of tests, and the average stockpile growth rate, rather than a mechanical ranking based on a single indicator.

4. The country with the fastest transition from "not considering nuclear weapons" to "possessing nuclear weapons"

A country's transition from a state of "not considering nuclear weapons" to "possessing nuclear weapons" involves both the time span and the speed of initial capability formation after possession. If judged only by time span, the United States entered the possession state in 1945, with a time span of 0, giving it the most obvious advantage. To further evaluate the composite speed of forming an initial nuclear capability after possession, this study introduces three indicators: time span, short-term average stockpile growth rate, and short-term stockpile increase. The framework is shown in Figure 5. The statistical characteristics of transition-speed indicators are summarized in Table 6.

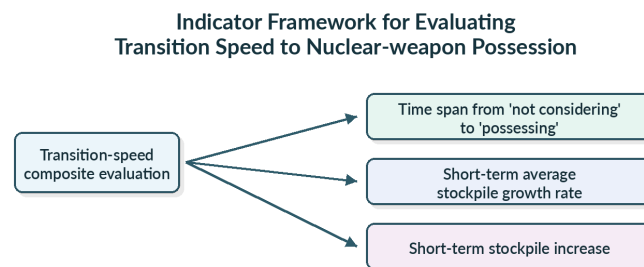


Figure 5. Indicator framework for evaluating transition speed to nuclear-weapon possession

Table 6. Statistics of transition-speed evaluation indicators

Country	Time span	Short-term average stockpile growth rate	Short-term stockpile increase
China	19	94.991%	100

Table 6. (continued)

France	19	88.377%	45
India	53	39.959%	38
Israel	22	30.447%	17
North Korea	70	29.353%	20
Pakistan	53	55.577%	44
Russia	4	131.845%	426
South Africa	37	-2.166%	6
United Kingdom	8	108.914%	105
United States	0	126.034%	841

Note: Time span is a cost-type indicator; short-term average stockpile growth rate and short-term stockpile increase are benefit-type indicators.

In the composite evaluation, a shorter time span indicates a faster status transition and is therefore set as a cost-type indicator. A higher short-term average stockpile growth rate and a larger short-term stockpile increase indicate faster initial capability formation after possession, so both are set as benefit-type indicators. The weights are set as 0.5 for time span, 0.25 for short-term average stockpile growth rate, and 0.25 for short-term stockpile increase. The indicator weights for the transition-speed evaluation are given in Table 7.

Table 7. Indicator weights for the transition-speed TOPSIS evaluation

Indicator	Time span	Short-term average stockpile growth rate	Short-term stockpile increase
Weight	0.5	0.25	0.25

The specific calculation still follows the TOPSIS procedure in Section 3, namely normalization, weighting, determination of ideal solutions, distance calculation, and computation of the composite score. The difference is that time span is treated as a cost-type indicator, meaning that smaller values are closer to the positive ideal solution. Based on Tables 6 and 7, the positive ideal solution and negative ideal solution are respectively:

$$C^* = [0, 131.845\%, 841]. \quad (12)$$

$$C^0 = [70, -2.166\%, 6]. \quad (13)$$

The final transition-speed TOPSIS ranking results are shown in Table 8.

Table 8. TOPSIS composite score ranking for transition speed

Rank	Country	Composite score index
1	United States	0.98226137
2	Russia	0.67554070
3	United Kingdom	0.48061844

Table 8. (continued)

4	China	0.42921307
5	France	0.40334731
6	Israel	0.32646151
7	South Africa	0.22564333
8	Pakistan	0.21060494
9	India	0.17915677
10	North Korea	0.09309587

Note: A higher composite score indicates a faster transition from "not considering nuclear weapons" to possession and initial capability formation.

Table 8 show that the United States has a composite score index of 0.98226137, which is significantly higher than those of other countries. Although Russia performs strongly in terms of short-term average stockpile growth rate and short-term stockpile increase, its time span is not 0, so its composite score is lower than that of the United States. The United Kingdom, China, and France occupy intermediate positions, while North Korea, India, and Pakistan have relatively low composite scores because of their longer time spans. Therefore, whether interpreted narrowly in terms of time span or more comprehensively in terms of capability-formation speed, the United States is the country with the fastest transition speed.

5. Conclusion

This study constructs an interpretable multi-indicator evaluation framework around nuclear-weapon stockpile changes, nuclear-test activities, and transitions in nuclear-weapon possession status. First, based on historical stockpile series, 10 sample countries with positive stockpile records are screened, avoiding the use of current cross-sectional stockpiles as a direct basis for assessing research activity. Second, 1981-1990 is selected as a unified ten-year observation window, and stockpile change, average stockpile growth rate, and the number of nuclear tests are organized to ensure a consistent time standard for the subsequent composite evaluation.

For nuclear-weapon research activity, this study incorporates stockpile change, the number of tests, and the average stockpile growth rate into the TOPSIS model. The results show that Russia has the highest composite score in this window and is the most active country in nuclear-weapon research. France ranks second, while the United States does not obtain the highest ranking solely through its high number of tests because its stockpile change is negative. For the transition speed from "not considering nuclear weapons" to "possessing nuclear weapons", this study evaluates the issue from the perspectives of time span and initial capability-formation speed, and both perspectives indicate that the United States had the fastest transition speed.

It should be noted that TOPSIS results are affected by indicator selection, weight assignment, and the choice of time window. The value of this study lies not in providing a single unchanging historical ranking, but in organizing historical nuclear-weapon data into a consistent country-year analytical standard and forming structured judgments through a reproducible multi-indicator method. Future research may further introduce the entropy weight method, the analytic hierarchy process, or sensitivity analysis to test the stability of ranking results under different weights and time windows.

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