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The radiological assessment, hazard evaluation, and spatial distribution for a hypothetical nuclear power plant accident at Baiji potential site

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Abstract

Background: The safety assessment in site selection for a new nuclear power plant is an essential issue for human health. It could be improved by predicting the consequences for a hypothetical accident. This paper is contextual with the nuclear safety regarding the risk upon human health from the hazard constituted by the emission of radio-active material due to a hypothetical nuclear power plant accident. HYSPLIT model used and configured based on terrestrial and meteorological conditions for this purpose.

Results: It presents an analysis of the time-series and spatial distribution for dispersed radioactive contaminants from a hypothetical accident at Baiji potential site. This is based on the geological and meteorological specifications of the potential site. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model configured to simulate the atmospheric dispersion of fission emissions, then assesses the public health consequences of a hypothetical nuclear accident. Results indicate that the total individual dose intake by the population living around the potential site from the hypothetical accident exceeded 1 Sv, greater than the allowed dose limits by International Commission on Radio-logical Protection (ICRP). The probability of cancer incidence at regions on directions of southeast to northeast along 30 km from the potential site was high (0.0378 to 0.00131) risk/person. However, the areas that laid on the west and south-west of the site recorded higher levels of influence compared to regions on other directions. Also, the reduction of exposure dose with the distance from the site presented. The north-direction regions from the Baiji site recorded a rapid reduction of exposure dose to become zero at 40 km distance.

Conclusions: Finally, to minimize the radiological impacts on population, emergency procedures are required at the regions that laid on the west and south-west of the site. These countermeasure remedy actions should include evacu-ation, sheltering, ban the sale of local agriculture productions, and long-range resettlement of the population. Since the plume of radioactive contaminants did not arrive at the regions on east and northeast, 40 km away from Baiji site, these areas could be categorized as a support zone.

Keywords: Nuclear safety, Radiological assessment, HYSPLIT, Atmospheric dispersion modeling, Iraq, Baiji potential site

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Background

Accident management is an important factor that ensures an effective defense in depth implementations. According to defense in depth principles, each safety design level should be individually protected and to be independent

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of other levels [1–3]. This consideration ensures the availability of accident management provisions for any case and to be well defined, even if the provisions within the design components are sufficient [4, 5]. Deciding on an emergency planning zone (EPZ) is an implementation of defense in depth concepts, especially for the fifth safety level [6–8]. It is also an essential procedure in nuclear safety management. Emergency planning zones are off-site areas around the nuclear facilities, including new nuclear power plants. These are prepared in advance for any effective and protective actions that are required during any undesired accident to ensure the protection of public health, the environment, and properties [5, 8].

The pre-evaluations of radiological impact for normal operation of a new nuclear power plant at Baiji potential site were conducted for two different types of nu- clear reactors; VVER 440 and AP100 reactors [9, 10]. The assessment showed that normal operation of a nuclear power plant at Baiji potential site is safe and poses no significant biological effect upon population living around, but no investigation has been conducted previously to study the radiological impact of any hypothetical accident at Baiji potential site [9, 10]. Therefore, this work aspires to fill this gap in the safety assessment procedures for this potential site [9–11]. Baiji site with other three sites were nominated by Iraqi Atomic Council for new installation of a new nuclear power plant in Iraq [11, 12]. Iraq showed early desire to employ nuclear technologies in scientific researches and energy production [10, 11, 13]. The Iraqi government returned back this desire to handle the chronic shortage in electricity provision. Also, to reduce the significant increase in greenhouse-gas levels in Iraq, which primarily resulted from consumption of fossil fuel [14, 15]. Safety is the basis in nuclear reactor's design so that the occurrence of failures is very low, and if that happened, the effects are on not to afford any risks to public health [16, 17]. Each nuclear reactor, whether used for research purposes or in electricity generation, produces a considerable amount of radioactive substances, which might be a source of risk to the human life and the surrounding environment [16, 18, 19]. So it requires a precautionary procedure to prevent this risk. Nuclear safety is a set of technical and regulatory provisions that could be applied in the design, site selection, construction, and operation procedures for each nuclear facility to control and reduce the probability of undesired accidents or to reduce the subsequence effects of an accident [20, 21]. The defense in depth concept is an important key element to ensure the nuclear safety. This concept intended containment of the radioactive materials by protecting an integration of physical barriers against internal or external events. This approach intends to impede any radiological incidents fully or to limit and reduce any consequences if prevention has failed. As well as, it is to avoid any increase in the successive impacts that should lead to more serious conditions [21, 22].

Nuclear accident scenario selection

Any accident sequence initiates by an event which should occur by an external factor such as earthquake, flood, tsunami. Moreover, the internal factors such as loss of off-site power, loss of coolant, or human-made failures could be considered as initiator events [6–8]. The nuclear reactor control and safety system might be affected by any initiating events. Furthermore, the steady state of operation for the nuclear reactor should be perturbed. Consequently, these will lead to a failure in operation, which probably causes a damage to the reactor core. As a result, a high level of radioactive fission products will emit to the environment [23].

The nuclear power plant comprises a diverse range of safety and control systems [23]. The possibility of different accident sequences is featured according to the initial events, the defect of equipment and the kind of involved operator actions. Event-fault tree analysis could be used as a logic model to develop the accident sequences [24]. Then, the identification of possible accident sequences will be more systematic. Probabilistic risk assessment (PRA) concept follows this mechanism to enhance the nuclear safety by preventing probable accidents for the event tree pathways, whether from internal or external events [23, 25].
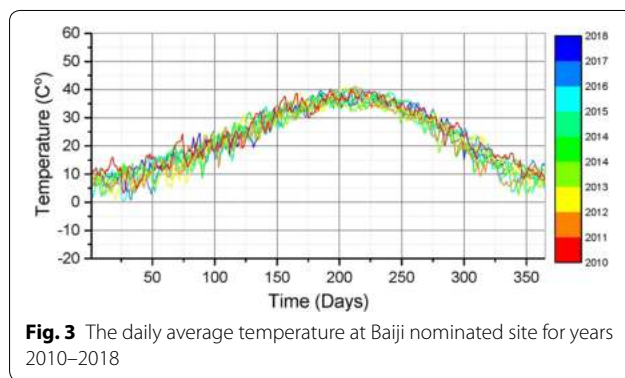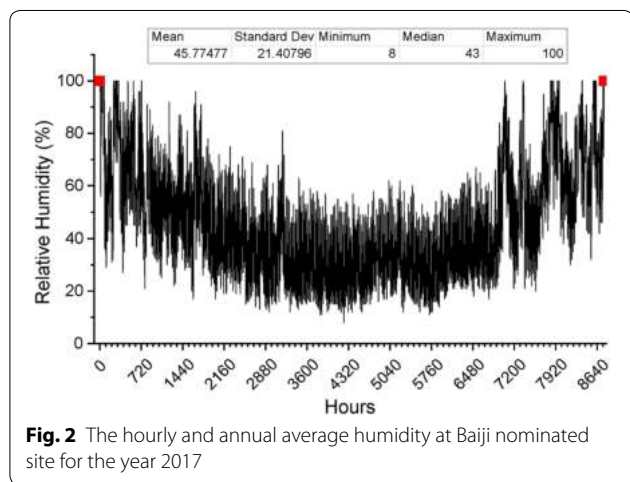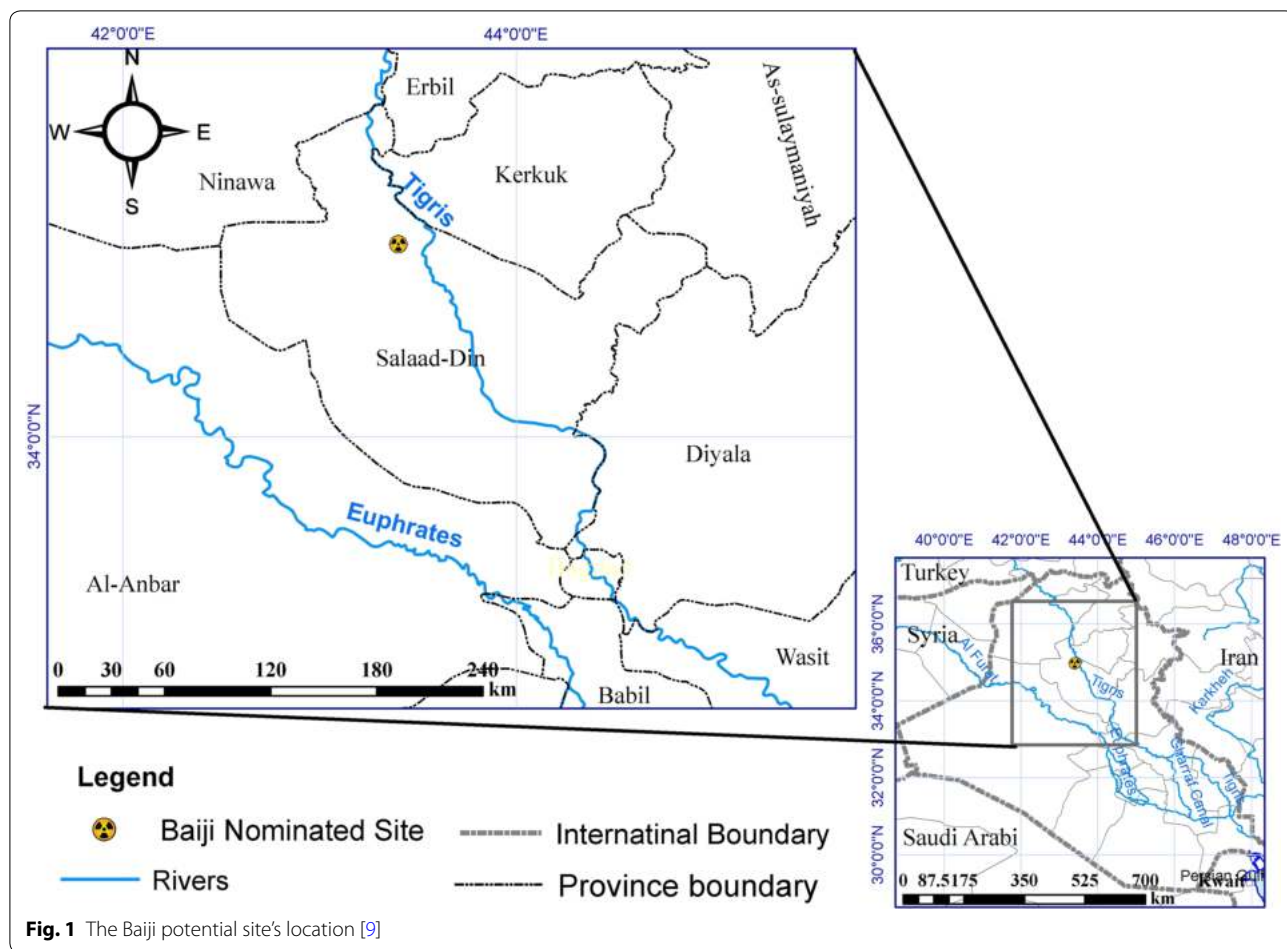
Methods

The study area

With cooperation of JSC Atomstroyexport company [26], Iraqi Atomic Energy Council IAEC nominated four potential sites; Abu Daalaf, Abbasiyah, Baiji and Mahzam [27, 28]. The study of radiological impact of a new nuclear power plant conducted for Baiji nominated site among other nominated sites, is shown in Fig. 1.

Iraq has a climate zone of continental and subtropical type, as it is located in the south-western side of Asian continent. Thus, it is under the influence of any change occurred at neighboring regions such as Mediterranean Sea and Indian desert [29]. This explains why the winter season is always cool to cold with an average temperature between 2 and 15 °C and a moderate humidity per day, ranging between 8% in summer to 100% in winter season, as shown in Fig. 2. Summer is well-known by dry and extreme hot weather, as the temperature exceeds 40 °C during July and August day-time.

The Baiji nominated site (34.98°N, 43.40°E) is influenced by the same weather conditions. The temperature varies between 0 and ≤ 40 °C along four seasons, as shown in Fig. 3. Baiji city is located through a piedmont

Fig. 1 The Baiji potential site's location [9]

Fig. 2 The hourly and annual average humidity at Baiji nominated site for the year 2017

Fig. 3 The daily average temperature at Baiji nominated site for years 2010–2018

zone that extends from north to the south with lowlands and semi-plains [26, 28]. This region's elevation varies between 200 and 500 m above sea level [30]. Moreover, the Makhoul-Hamrin ridge lies at the southernmost of the zone [26, 27, 30].

Another meteorological parameter that influences the particle dispersion at the potential site is the wind speed and direction. The wind conditions were considered as a critical factor in Baiji potential site, as they decide the dispersion profile of any emitted pollution in the atmosphere medium. Figure 4 shows the wind-roses of Baiji potential sites at recent 4 years 2015–2018. It
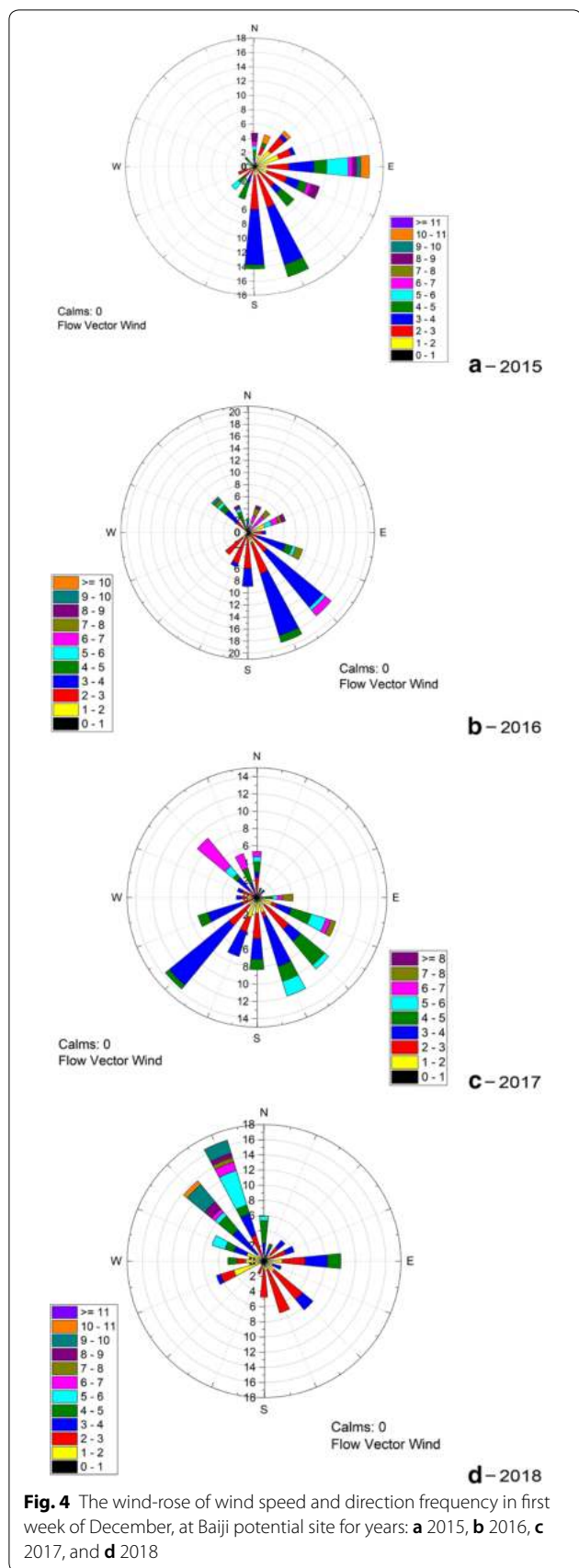
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Fig. 4 The wind-rose of wind speed and direction frequency in first week of December, at Baiji potential site for years: **a** 2015, **b** 2016, **c** 2017, and **d** 2018

Table 1 Highly populated cities around nominated sites for potential NPP with location and distance

City	Latitude	Longitude	Distance from Baiji site (km)	Population 103 person
Baghdad	33.32	44.36	215	6000
Mosul	36.35	43.15	150	1800
Erbil	36.19	44.01	143	935
Kirkuk	35.46	44.38	100	610
Samarra	34.19	43.89	100	158.5
Ramadi	33.43	43.29	175	275
Fallujah	33.35	43.78	185	191
Baqubah	33.744	44.61	177	153
Tikrit	34.59	43.67	50	42.5
Balad	34.01	44.14	128	42
Baiji	34.93	43.49	12	36.5
Shirqat	35.50	43.23	60	25

represents a comparison of wind speed and direction at first week of December for the mentioned 4 years.

Spatial distribution time-series

In order of evaluation the time-series of the spatial distribution for the radioactive plume over the cities around Baiji potential site, 12 cities were chosen according to their population density and their distance to the Baiji nominated site, as shown in Table 1. The direction and the location of these cities were considered from the nominated site. However, the west regions from the Baiji nominated site had very low population densities. Moreover, population density is different for these cities according to their geographical location.

HYSPLIT model configuration

HYSPLIT model configured according to radionuclide properties and available data on the release rate of radionuclides to the atmosphere during assumed accidents. The simulation was conducted for the atmospheric dispersion of radioactive emissions. Both puff and particle dispersion equations in HYSPLIT are expressed in terms of turbulent velocity components (U,W) [31–33]. The new position of particles or puffs has computed by adding the turbulent component to the mean position (X), as expressed in Eq. 1 [32, 33]:

$$X_{\text{final}}(t + \Delta t) = X_{\text{mean}}(t + \Delta t) + U^t(t + \Delta t)\Delta tG. \tag{1}$$

For the new position towards (Z) direction, the computation is according to the Eq. 2. This is due to the mean advection in the wind [32, 33].

$$Z_{\text{final}}(t + \Delta t) = Z_{\text{mean}}(t + \Delta t) + W^t(t + \Delta t)\Delta t Z_{\text{top}}^{-1}, \quad (2)$$

where the positions (horizontal (X) and vertical (Z)) are given in grid and sigma units, respectively, while the components of turbulent velocity are in ms^{-1}. G and Z_{top} are conversion factors. The concentration distribution by each puff of mass m to a grid point increase according to Eq. 3:

$$\Delta C = m\left(\pi r^2 \Delta z\right), \quad (3)$$

where C is air concentration, m is the pollutant mass, r is the distance from the source and $r = 1.54$ σh, where σz and σh are the dispersion coefficient in crosswind direction and vertical direction the vertical extent, and $\Delta z = 3.08$ σz.

The total dose intakes through inhalation and external exposure pathways were

calculated using Eq. 4:

$$\text{Dose}_{\text{total}} = \sum_{t_1}^{t_2} CD_{\text{cf}} \quad (4)$$

where C is the air concentration of the pollutant or ground deposition, D_{cf} is the dose conversion factor of each radionuclide for each pathway and $(t2 - t1)$ is the duration of the exposure to the pollutant [32, 33]. ICRP 60 and 103 regulatory standards were adopted in all estimation processes, for more precision, including dose conversion factors and dose limits [34, 35].

The calculation of cancer risks due to the exposure to a certain measure of annual effective dose equivalent performed by using the general formula that is authorized by ICRP organization according to dose-to-risk coefficients [35]. Equation 5 explains the major formula to calculate the cancer fatality risk:

$$\text{Risk}_{\text{Cancerfatality}} = 0.05 \text{ Sv}^{-1} * E(t), \quad (5)$$

where, $E(t)$ is the total dose and 0.05 Sv^{-1} is dose-to-risk coefficient for cancer fatality risk in the population.

Accident scenario selection

The International Atomic Energy Agency (IAEA) as the organization which is responsible for the regulations and guidances for the nuclear facilities, is involved intensively in the study of the nuclear accidents and its consequences upon environment and humans. Furthermore, it provides the appropriate suggestions and recommendations to new nuclear enterprises to avoid repeating these accidents [7]. Consequently, many study and regulation series have been published such as Safety Standards Series Nos NS-R-1, NS-R-2, Safety Standards Series No. NS-G-1.2,

INSAG Reports, Technical Reports and TECDOCs and others to enlighten future vision about new generations of nuclear power reactors and the new nuclear power plant constructions [6, 36]. International Nuclear and Radiological Event Scale (INES), cosponsored by the IAEA and OECD/NEA, classified nuclear accident into seven classes according to the event initiator and their consequences. The classification of all nuclear accidents up until today is illustrated in Fig. 5 [6, 36].

United States Nuclear Regularity Commission (U.S.NRC) announced a project entitled State-of-the-Art Reactor Consequence Analyses (SOARCA), to develop a knowledge body about the pragmatic results of selecting any severe nuclear reactor accident [6]. As a result of the research group focus, all previous severe accidents in nuclear power plants have been analyzed in detailed integration, and more realistically than ever before [23]. Based on SOARCA outputs and considering the most frequent initiated events in severe nuclear accidents, five scenarios have been chosen by NRC organization [23].

All severe accidents release scenarios; source term (ST), together with the fifth scenario ST5 based on reference information of releases for pressurized water reactors (PWR) [23]. The SOARCA project classified the scenarios into two main categories, station blackouts (SBOs) and early failure (or bypass) of containment. The latter category is supposed to be higher in both consequence and risk. The SOARCA project has considered external events, seismic event, as initiators for three source term scenarios; (ST1), (ST2) and (ST3) [23, 37]. For the fourth
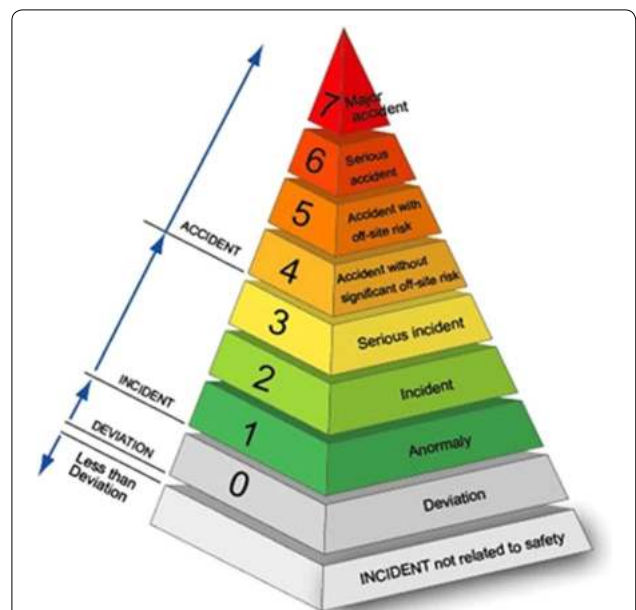

Fig. 5 INES classification for accident level [6, 36]

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scenario (ST4), the initiator event is an internal event. The fourth scenario (ST4) assumes a severe failure in the nuclear power plant such as a core melt without any defect in its safety filtering system. The fifth assumption of accident scenario (ST5) was one where the nuclear power plant suffered a severe failure (core melt), but its safety filtration systems were assumed to remain intact [23].

Considering the geological, seismic and tectonic parameters at study area, the probability of external events is very low, as there are no records for any severe accident in the industrial sector during last 50 years initiated by an external event in Iraq [38]. Hence Iraq is safe for high-magnitude earthquakes, especially the study area (nominated sites). Otherwise, earthquake should be excluded as an external event initiator. However, the release scenarios are still the best estimation that is available as a severe accident in PWR reactors that could result from an external event [30, 38].

Accidental release rate

The annual release has been adopted from official institutions such as IAEA and NRC-USA for ST4 scenario [23, 39]. The input data of meteorological, location, sources (radioactive pollutants) and the dispersion specifications were selected similar to the normal operation. The release rates of radionuclides were chosen based on the accident scenario. The half-life, release rate, type of emitted radiation and risk group were considered for selected radionuclides in the study. The simulation was run for radionuclides that was included in Table 2 for both ST1 and ST4 scenarios.

Results and discussion

The simulations were carried out to study the dispersion profile of radioactive pollution that is released from Baiji nominated site during the hypothetical accident ST4. The accident was assumed to occur for 3 days on the first week of December, 2015, 2016, 2017 and 2018. These dates were selected based on the facts that the probability of the rain is high due to the high rate of precipitation, Also, the temperature reaches below 0 °C, and the difference between the maximum and minimum temperature is significantly large between daytime and nighttime. Therefore, these events could be considered as the most likely external natural events to initiate any hypothetical accident. Moreover, this is to evaluate the consequent health impacts in terms of annual effective dose equivalent and cancer risk.

Table 2 Accidental releases for source term scenarios ST1 and ST4 according to the accident scenarios

Radionuclide	Half-life	ST1 release (GBq)	ST4 release (GBq)
Kr-85	10.7 years	3E+07	5E+07
Kr-85 m	4.48 h	6E+08	1E+09
Kr-87	76.3 min	1E+09	2E+09
Kr-88	2.48 h	2E+09	3E+09
Rb-86	18.63 days	0E+00	2E+05
Mo-99	66.02 h	0E+00	2E+07
Te-127	9.35 h	2E+06	5E+0
Te-127 m	109 days	3E+05	8E+06
Te-129	69.6 min	8E+06	2E+08
Te-129 m	33.6 days	1E+06	3E+07
Te-131 m	30 h	4E+06	9E+07
Te-132	78.2 h	4E+07	8E+08
Sb-127	3.89 days	2E+06	5E+07
Sb-129	4.31 h	8E+06	2E+08
I-131	8.04 days	1E+07	6E+08
I-132	2.30 h	2E+07	9E+08
I-133	20.8 h	3E+07	E+09
I-134	52.6 min	3E+07	1E+09
I-135	6.61 h	2E+07	1E+09
Xe-133	5.25 days	4E+09	8E+09
Xe-135	9.09 h	1E+09	2E+09
Cs-134	2.06 years	0E+00	2E+07
Cs-136	13.2 days	0E+00	4E+06
Cs-137	30 years	0E+00	1E+07

Atmospheric dispersion profile during the hypothetical nuclear accident

The atmospheric dispersion of radioactive discharges simulated for a hypothetical severe accident at Baiji nominated site. The nuclear accident is of the type (ST4) which is initiated by an internal event such as loss of coolant. Figure 6 illustrates the atmospheric dispersion contours and magnitudes for an accidental release. This is due to a hypothetical accident (ST4) for 72 h at second week of December. The simulation repeated for four sequent years (2015–2018), as the study area is characterized by continental weather. The air concentration at the center of the site records high values of 323×10^3 Bq m^{-3} at 2018 to 894×10^3 Bq m^{-3} at 2015.

The radioactive plume of ^{131}I radionuclide was dispersed mostly around Baiji toward those areas that were west, south-west of the site during years of 2015, 2017 and 2018. These areas are called the West-Jazeera desert, where the population density is significantly below 50 people per km^2. Also, it was dispersed throughout the south and south-east of Baiji nominated site during the year of 2016. Baiji city was the only area that was highly influenced area during all dates of simulation. Otherwise,
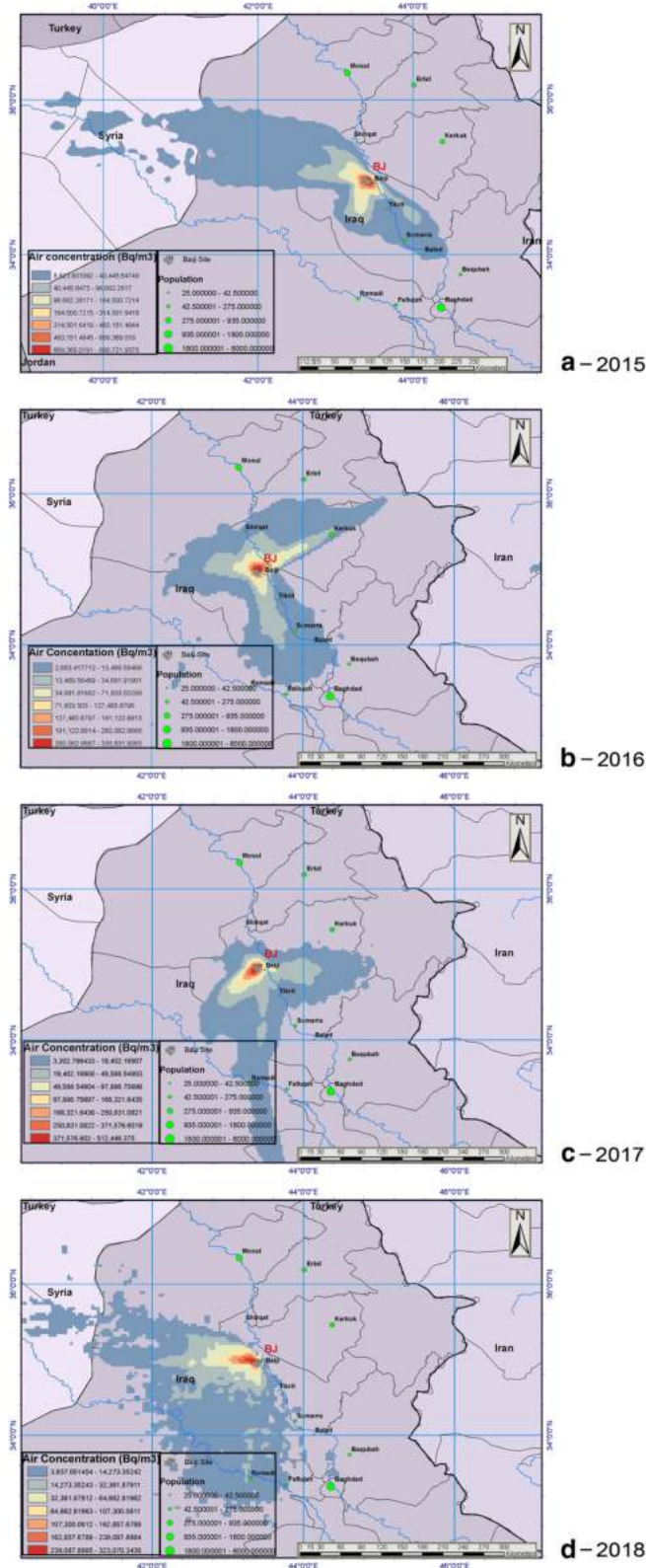
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Fig. 6 Atmospheric dispersion of ^{131}I radionuclide for a hypothetical accident release scenario (ST4) at Baiji nominated site for years; **a** 2015, **b** 2016, **c** 2017, and **d** 2018

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the plume did not arrive at highly populated cities such as Baghdad, Mosul, or Erbil during the first 3 days of the accidental release. The radioactive plume reached Samarra city, one of the cities with high population density. However, it takes more than 1 day from the accident day to rich cities such as Samarra. Furthermore, the radioactive plume became less concentrated while it arrived at Samarra, Balad, Shirqat, or Baqubah Cities. For instance, in 2015, the air concentration of the ^{131}I radionuclide decreased from 2.1×10^6 Bq m^{-3} at the Baiji city to 4.9×10^4 Bq m^{-3} at Samarra city, as the plume needs 30 h to arrive Samarra city. This fact should be helpful in any preparedness of emergency plans for any undesired accident.

Based on the weather conditions such as humidity, precipitation rate, wind velocity and its direction, the deposition of fission products occurs once they dispersed around the nuclear power plant site. However, the deposition of radioactive releases appeared to be zero at the area of 20 km radius around the potential site, as shown in Fig. 7. For instant, the dispersed particles of ^{137}Cs
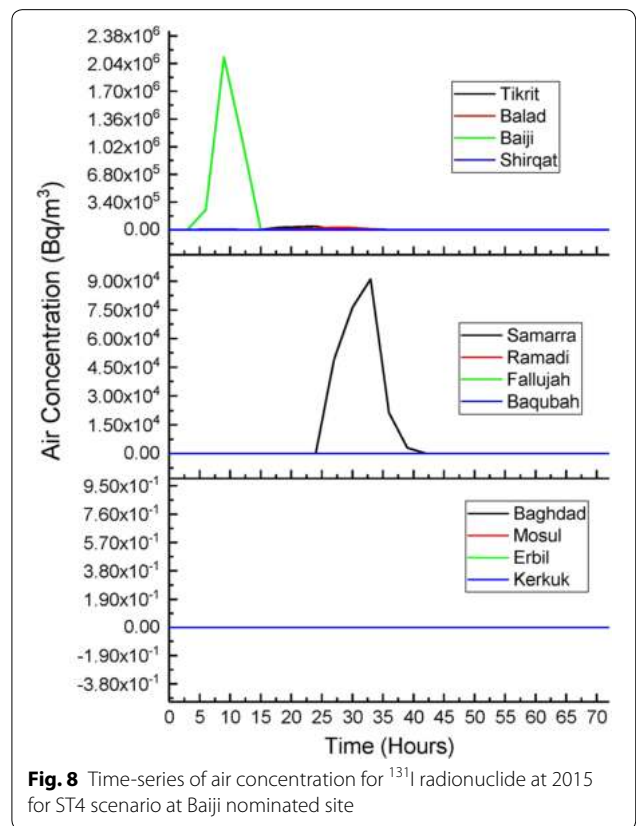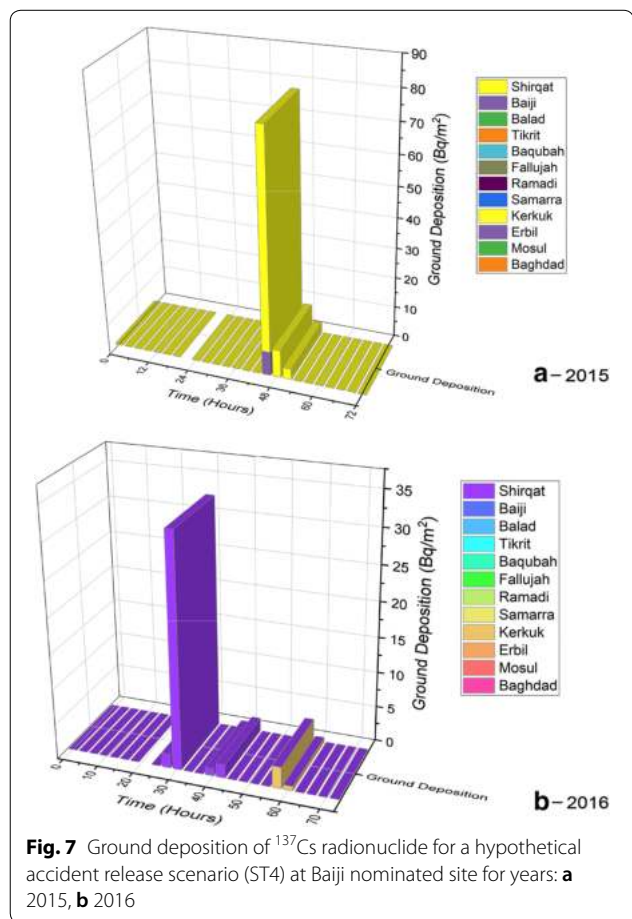
arrived Shirqat city after 40 h during 2015, and it took 28 h to arrive at Samarra city during 2016.

In addition, the health risk that resulted from ground deposition of radioactive gaseous and particulates is not instantaneous, but it is long-term one [40], while the ground soils or aquatic surfaces that are contaminated by the deposition of radioactive pollution is susceptible for turning into another source of radiation and contributed as an external exposure pathway [40, 41]. Otherwise, the contribution of ground deposition to radiation exposure is dominated by the future human activities at the contaminated areas, which could be replaced by alternative resources of food, drink or other human needs [40, 41].

The time-series of ^{131}I radionuclide air concentration in Baiji nominated site during ST4 scenario

Figures 8 and 9 show the dispersed plume of ^{131}I radionuclide emissions from Baiji nominated site during the ST4 scenario at same date and duration for years 2015 and 2016.

The dispersion profile of the radioactive plume seems clearly different, and it covers divergent areas around Baiji potential site. Whereas the radioactive plume of ^{131}I radionuclide air concentration reaches Erbil, Ramadi,
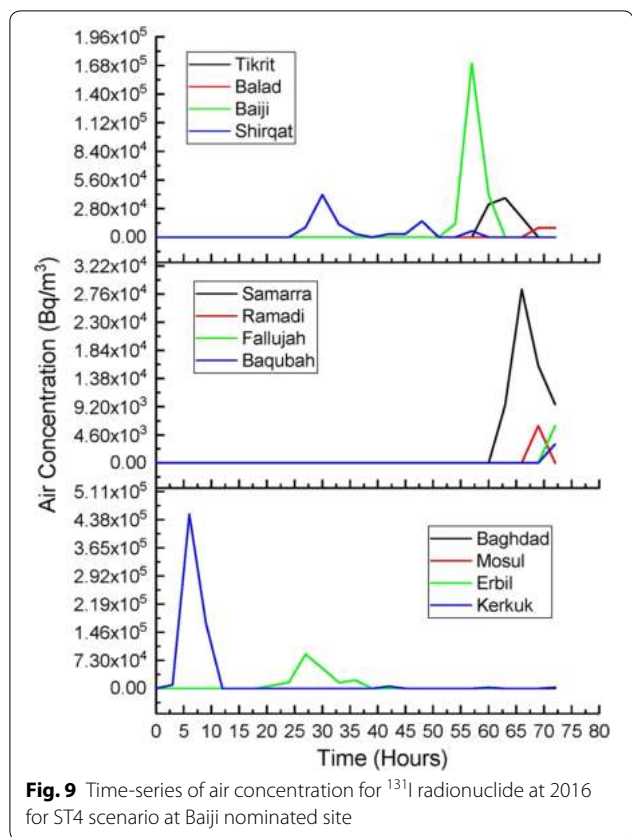

Fig. 7 Ground deposition of ^{137}Cs radionuclide for a hypothetical accident release scenario (ST4) at Baiji nominated site for years: **a** 2015, **b** 2016

Fig. 8 Time-series of air concentration for ^{131}I radionuclide at 2015 for ST4 scenario at Baiji nominated site

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Fig. 9 Time-series of air concentration for ^{131}I radionuclide at 2016 for ST4 scenario at Baiji nominated site

and Fallujah cities in 2016, however they are located at distances of (140–190 km) as shown in Table 1. Furthermore, for all years of simulation, the plume of radioactive pollution covers cities of Baiji (12 km), Tikrit (50 km), Samarra (100 km), and Balad (128 km). This means that the regions around the Baiji potential site at the range of (10–130 km) should be accounted as contaminated area after any undesired accident.

Assessment of radiological impacts and risks of accidental releases from Baiji nominated site for ST4 scenario

The assessments were conducted to assess the total health impact of the hypothetical accident scenario ST4 from Baiji nominated site. The evaluations were in terms of total effective dose equivalent (TEDE) and cancer risk.

The variation of total effective dose equivalent (TEDE) for ST4 scenario in Baiji nominated site
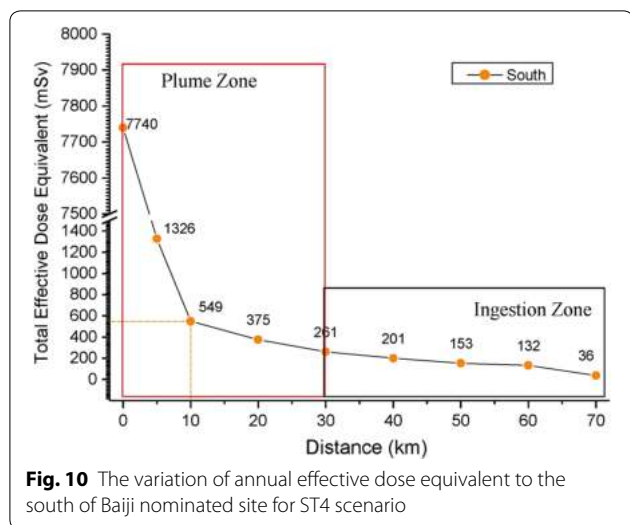
The total effective dose equivalent (TEDE) at any point around the nominative site is dependent on the weather conditions around the NPP such as wind speed and direction, temperature, and humidity. Therefore, the TEDE changes according to distance and direction to the nominated site.

Table 3 shows the total effective dose equivalent at different locations and directions from the Baiji nominated site for the ST4 accident scenario. The TEDE at areas close to the NPP were considerably high, with a value of 7.74×10^3 mSv at the center of the site. However, along the distance this value decreased to the range of 0–81 mSv at 70 km from the NPP. Exposure dose proportionally decreased with distance from the NPP for a certain direction.

At 5 km from the NPP, the TEDE reached its highest value of 3.43×10^3 mSv in the southeast of the NPP, while the lowest level was 6 mSv at northeast of the NPP. At 10 km from the NPP, the highest TEDE was received by receptors from the west of the NPP of 1.44×10^3 mSv, while the lowest was 0 mSv at the east of the NPP. At 20 km, populations living at the west regions of the Baiji nominated site received the highest TEDE of 678 mSv, while regions on the north to east received the lowest TEDE of (0–12) mSv. At 30 km from the NPP, the TEDE decreased significantly. The highest TEDE was 261 mSv at the west and southeast of the NPP, while at the north and east of the NPP the values ranged between 0 and

Table 3 Total effective dose for different locations and directions from the NPP at Baiji nominated site for ST4

Total effective dose (mSv)

Direction	Distance (km)								
	0	5	10	20	30	40	50	60	70
North	7740	45	36	12	3	0	0	0	0
Northeast	7740	6	3	0	0	0	0	0	0
East	7740	507	0	0	0	0	0	0	0
Southeast	7740	3430	545	369	186	72	30	21	6
South	7740	1326	549	375	261	201	153	132	36
Southwest	7740	2560	523	138	117	18	15	9	6
West	7740	3150	1440	678	261	135	123	126	81
Northwest	7740	693	323	204	147	51	72	42	30

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Fig. 10 The variation of annual effective dose equivalent to the south of Baiji nominated site for ST4 scenario

3 mSv. At 40 km from the NPP, the TEDE decreased. The population at 40 km south from the NPP received the highest annual effective dose of 201 mSv, while on the north and east sides, they did not receive any exposure dose.

Figure 10 shows the variation in TEDE on the south, along 70 km from Baiji nominated site. The results show that the TEDE at the south regions decreased significantly. However, it was still high compared to other directions even at far locations from the NPP. Thus, these areas should be considered as the most influenced regions around Baiji nominated site during accidents.

Most regions located on the south from the Baiji nominated site within a radius of 50 km should be considered as extreme exposure areas. This is due to the high level of radiation exposure along the plume travel direction during accidents.
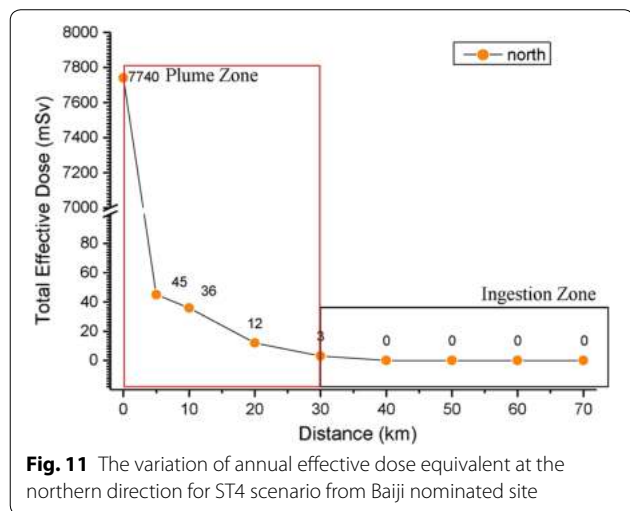
Figure 11 shows the variation in TEDE along 70 km, north of Baiji nominated site. The results show that the TEDE decreased rapidly from 7740 to 12 mSv at 20 km from the NPP, with consideration for plume zone. The TEDE declined to 3 mSv at 30 km from the NPP outside the plume zone.
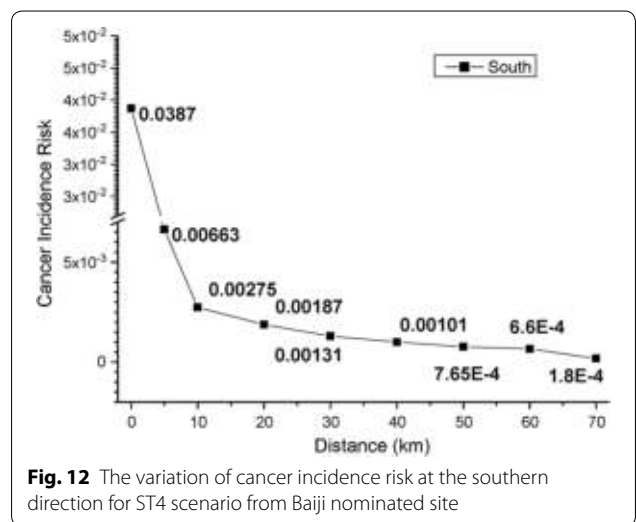
This should help in the decision about the selection of evacuation areas around the NPP, as the north and north-eastern regions are mostly safe and free of radiation at 40 km from the NPP during the release time of the accident scenarios.

As a result, the TEDE level was significantly high inside the plume zone in all directions. Nevertheless, it starts to decrease for most of the directions except for the direction of the wind inside the ingestion zone as shown in Figs. 10 and 11.

The risk probability of cancer incidence was high with value of 0.0387 risk/people at the center of Baiji potential site. However, its value was different at areas around the potential site as same of the total dose intake. Figure 12 shows the decrement of the cancer incidence probability along the south direction from the potential site.

Conclusions

The assessment of health impact consequences for a nuclear accident at Baiji potential site was based on simulation of atmospheric dispersion for emitted radionuclides over Baiji nominated site and surrounded areas during ST1 and ST4 accidental release scenarios. Based on the time-series analysis, Baiji city received more than 100 mSv of TEDE and categorized as a plume zone. The instant protective actions, such as immediate evacuation, sheltering and medication are required. For the city of Tikrit categorized as ingestion zone, continuous monitoring of the radioactive

Fig. 11 The variation of annual effective dose equivalent at the northern direction for ST4 scenario from Baiji nominated site

Fig. 12 The variation of cancer incidence risk at the southern direction for ST4 scenario from Baiji nominated site

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contaminants is required to avoid the intake of these contaminants. However, other cities were less influenced by the accident compared to Baiji and Tikrit, but still monitoring and medication processes are required. The areas that are outside the 30-km radius in the direction of North and Northeast from Baiji site is categorized as support area zone due to the absence of radioactive contaminants during the accident scenarios. The results of the current work provide preliminary expectations about environmental and radiological impacts as well as exposure limits received by the populations. In order to ensure an adequate mitigation of the nuclear accident consequences for the environment and surrounding populations, these assessments could help in deciding the emergency plans.

Abbreviations
NPP: nuclear power plant; HYSPLIT: Hybrid Single-Particle Lagrangian Integrated Trajectory; ICRP: International Commission on Radiological Protection; VVER-440: the water–water energetic reactor; AP1000: advanced pressurized water reactor; PRA: probabilistic risk assessment; IAEC: Iraqi Atomic Energy Council; INES: International Nuclear and Radiological Event Scale; U.S.NRC: United States Nuclear Regularity Commission; SOARCA: State-of-the-Art Reactor Consequence Analyses; ST: source term; SBOs: station blackouts; TEDE: total effective dose equivalent.

Authors' contributions
IMMS supported data analysis, assessments, and drafted the manuscript; MAMS is the project supervisor; SH is the project supervisor; YMSH interpreted and evaluated the data and drafted the manuscript; KH is the project supervisor; SHA contributed by supporting the writing of the manuscript. All authors read and approved the final manuscript.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Not applicable.

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Competing interests
The authors declare that they have no competing interests.

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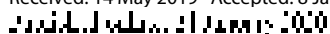
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