V. CASE STUDIES

"To develop a complete understanding of the costs of a military attack against Iran, it is imperative to understand the topography, history, infrastructure, and population density of the areas surrounding the potential targets. With this local picture in mind, we have developed case studies for the cities of Isfahan, Natanz, Arak, and Bushehr."

To develop a complete understanding of the costs of a military attack against Iran, it is imperative to understand the history, background, infrastructure, and makeup of the areas surrounding the potential targets. With this local picture in mind, we have developed case studies for the cities of Isfahan, Natanz, Arak, and Bushehr. These cities and their surrounding area would be those most likely to suffer from a military strike and its aftermath. We have not included a case study on the impact of an attack on Qom's Fordow enrichment facility, which deserves its own study after an escalation in activity in late 2011 and early 2012.

CASE 1: ISFAHAN

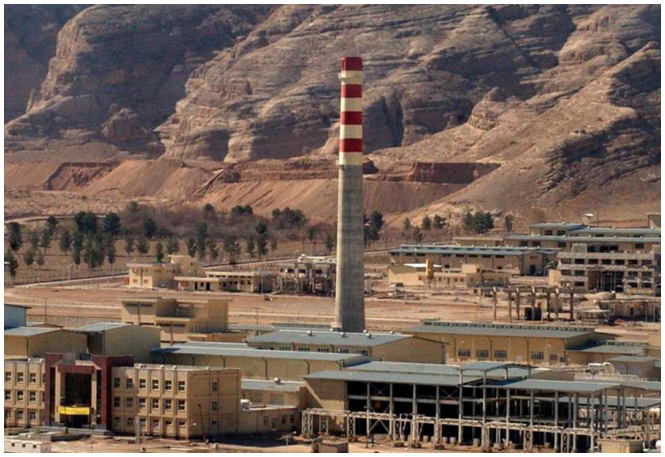

Figure 21: Isfahan Nuclear Facility (Photo: Associated Press)

Few cities would pay as high a price for the Islamic Republic's nuclear gamble as Isfahan. There is nothing abstract about targeting the Uranium Conversion Facility at Isfahan (Figure 21). As the main site for the production of uranium hexafluoride (UF6), as well as fuel manufacturing and fuel plate fabrication, the facility at Isfahan contains UF6 as well as other corrosive, toxic fluorine compounds. According to the IAEA, from 2004 to 2010, the Isfahan Uranium Conversion Facility (UCF) has produced in excess of 371 metric tons (409 US):

"The total amount of uranium produced at UCF since March 2004 remains 371 tonnes in the form of UF6"[95]

These compounds are classed as acidic poisons that form hydrofluoric acid when they come in contact with bodily fluids. In lethal concentrations, they attack the lungs, eyes, skin, and tissue. Thus, should a substantial stock of this material still be stored at Isfahan, a successful attack on such facilities, as with attacks on any industrial chemical plant where vast amounts of toxic chemical are stored, can be viewed as a lethal chemical attack—a form of chemical warfare that would lead to the release of highly toxic plumes close to a major population center. With the city center of Isfahan less than 10 miles from the Uranium Conversion Facility, and prevailing wind directions blowing in a westerly direction at average speeds of 9-13 miles per hour, a toxic plume would reach the suburbs of Isfahan in less than an hour (Figure 23).

Given the population densities of the districts along the path of the toxic plume, tens and quite possibly hundreds of thousands of people could be exposed to dangerous concentrations of highly reactive fluorine compounds. Even the most developed of countries with advanced early warning and civil defense capabilities, let alone the Islamic Republic of Iran, would be overwhelmed by military strikes on a nuclear plant this close to a major population center.

A military strike on the Isfahan facility could be compared to the 1984 Bhopal industrial accident at the Union Carbide plant in India (Figure 22). In that accident, the release of 42 metric tons (47 U.S. tons) of methyl isocyanate turned the city of Bhopal into a gas chamber. Estimates of deaths have ranged from 3,800 to 15,000. The casualties went well beyond the fatalities: More than 500,000 victims received compensation for exposure to fumes.

95 "Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions," IAEA Report to the Board of Governors, 18 February 2010: 6.

Figure 22: Victims of the Bhopal disaster (Photo: www.wsws.org)

Human Casualty Estimates at Site

According to Dr. Ghannadi-Maragheh, 800 to 1,000 experts are employed at Iran's Uranium Conversion Facility.[96] If we assume an expert-to-worker ratio of 1 to 1, then we can assume that in addition to the scientists and engineers at the site, a large percentage of the 2,000 workers, soldiers, and support staff would be killed immediately as a result of a military attack on the site. They would be exposed to overpressure of 5 PSI at the blast point which would almost certainly destroy all the buildings and kill virtually all the people at the site. The number of the dead could vary depending on the timing of the attack, but if the goal of an attack on the site is to damage and delay Iran's nuclear program, then it is likely that it would be timed to inflict the highest possible damage, not only to the site, but to the skilled scientists, technicians, and workers needed to operate the site. We have assumed that a strike on the plant would kill the entire shift working at the plant at the time of the strikes, approximately 800 to 1,000 people.

Figure 23: City limits of Isfahan—Distance to City: 9.3 miles (15 km) (Source: Google)

Additional Casualties: The Isfahan Toxic Plume

Estimating the additional casualties from military strikes against Isfahan is more complex. While there is no question about the fact that thousands of people living in close proximity to the strikes would be at risk, casualty figures will depend on the length of exposure to lethal concentrations of chemicals released from the plant.

We have discussed our key assumptions about the properties, inventory, storage, location, release, vaporization, reactivity, lethality, and dispersal of the highly toxic chemicals stored and processed at the Isfahan facility (please see section on Metholodology and Assumptions). These assumptions are critical to any calculation about the nature of the chemical and radiological threat facing the people of Isfahan and, one might add, Natanz.

To arrive at specific estimates of casualties at Isfahan, we have factored in variables related to climate, geography and demography such as topography, wind direction and speeds, and population densities.

A third component for quantifying the impact of military strikes on Isfahan is assessing the Islamic Republic's civil defense capabilities, such as early warning systems, evacuation and crisis management plans, medical infrastructure and public education.

Isfahan Toxic Plume Profile

To understand the transport profile of the gases, one must recognize that the force of the blast would disperse these agents, along with other debris and dust into the atmosphere, allowing it to be carried by the prevailing winds. The Isfahan Meteorological Bureau reports prevailing winds from the UFC in a westerly direction, toward Isfahan city eight months out of the year (Table 3). With average winds ranging from 9.4 to 13 mph, these gases could easily reach the residential suburbs of Isfahan in less than a half-hour, and the densely populated city center and beyond within an hour.

Month	Prevailing Wind Direction	Average Prevailing Wind Speed (meters/second)	Average Prevailing Wind Speed (miles/hour)
January	West	4.5	10.07
February	West	5.2	11.63
March	West	5.7	12.75
April	West	5.8	12.97
May	West	5.6	12.52
June	West	4.9	10.96
July	East	5.3	11.85
August	East	5.1	11.41
September	East	4.3	9.62
October	West	4.6	10.29
November	South-West	4.7	10.51
December	West	4.2	9.4

Table 3: Isfahan's Prevailing Winds (Source: Isfahan Meteorological Office)

96 M. Ghannadi-Maragheh, "Iranian Nuclear Fuel Cycle Experience," presented at the World Nuclear Association Annual Symposium, 3-5 September 2003.

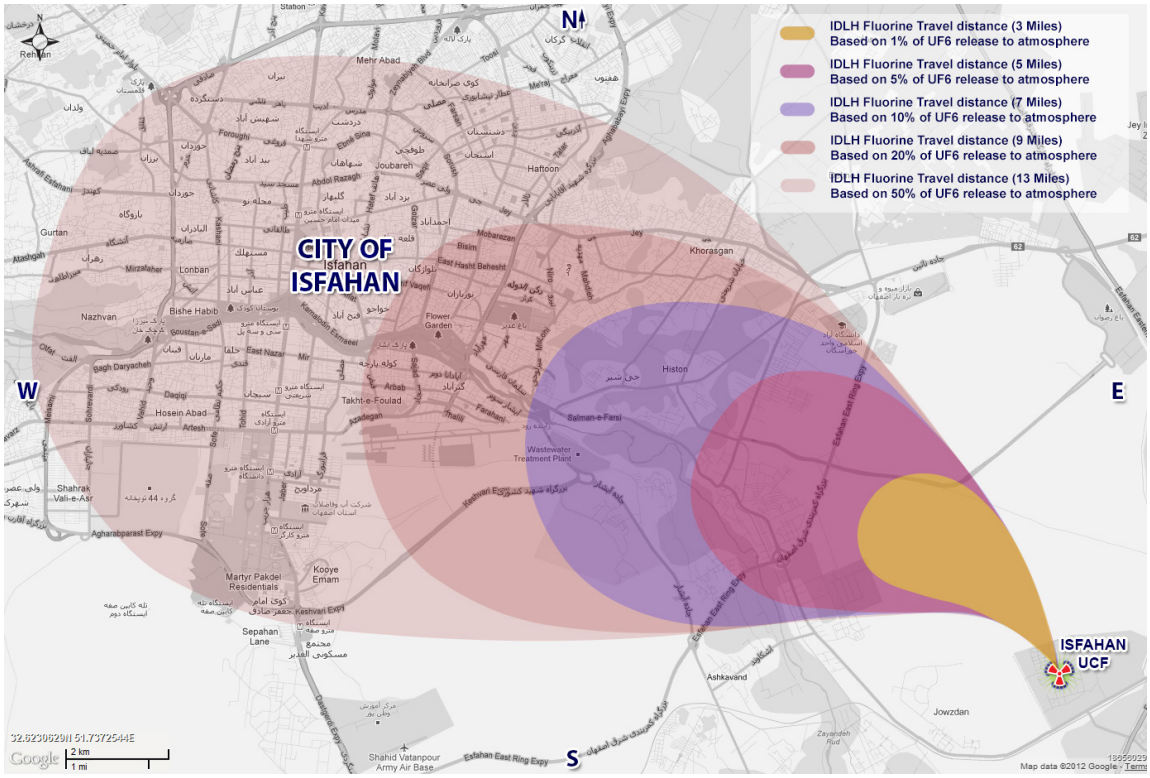

Figure 24: Possible Plume Travel Scenarios Towards Isfahan

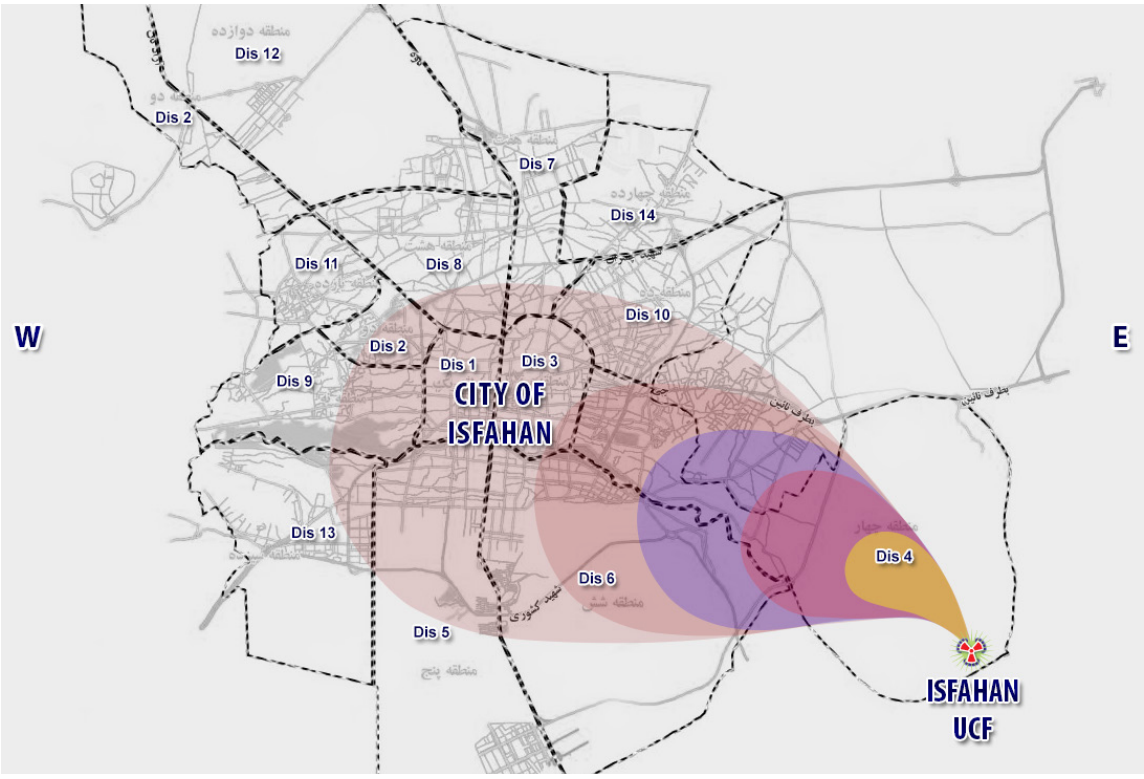

Figure 25: Isfahan Municipality's Districts

The Isfahan plume map (Figures 24 & 25) demonstrates the travel pattern of the IDLH (Immediately Dangerous to Life or Health) plume at 1%, 5%, 10%, 20% and 50% of UF6 releases. Based on our calculations, if there is only a 1% release of UF6 to the atmosphere, this plume will travel approximately 3 miles, covering a surface area of 5 square miles. The resulting poisonous gases may expose some, if not a majority of the 132,000 residents in district 4 to deadly or harmful levels of an IDLH of 25 parts per million (Table 4). If only 5% of the uranium hexafluoride stockpile at the Isfahan facility becomes airborne, the toxic plumes could travel 5 miles with the IDLH level of 25 ppm covering a surface area of 13 square miles. With prevailing wind moving in a westerly direction towards the city for most of the year, this plume could expose some of the 239,000 residents of the Isfahan municipality's eastern districts, particularly districts 4 and 6. At a 20% release, the IDLH plume will travel 9 miles covering 41 square miles and could expose some of the 352,000 residents in districts 3, 4 and 6, including residents in the region north of district 4, where population figures are unavailable (Table 4). If we assume a 5-20% casualty rate among these populations at a 1%-20% release, we can expect casualties in the range of 5,000-70,000.

District	2006 Population	2011 Estimated Population
1	73,926	74,153
2	56,028	59,834
3	111,816	111,950
4	119,455	132,725
5	144,963	165,272
6	107,871	107,956
7	135,854	166,568
8	205,437	248,782
9	69,321	71,943
10	189,976	215,836
11	56,246	65,230
12	105,312	148,786
13	109,101	125,705
14	139,532	166,670
TOTAL	**1,624,838**	**1,861,410**

Table 4: Isfahan District Population (Source: Statistical Center of Iran, Population and Housing Census of 2006)

Radiological

Another consequence of the release of uranium compounds to the environment would be the radiological contamination of soil and water followed by radiation exposures to people. Radiation from these uranium compounds would produce external exposure from alpha rays and internal exposure from inhaled and ingested materials. A RESRAD[97] analysis shows that 8.4 grams of uranium deposited per square meter of land surface area poses a radiation exposure of about 1 milliSievert/year (or 100 millirem/year) from all pathways for human radiation exposure. This level is generally considered the maximum allowable increase in dose to the public from surface-deposited uranium materials. The land area that could be contaminated at this level from the release to the environment of 371 tons of UF6 is approximately 11.6 square miles (30 square km) around the facility. This area would be permanently contaminated by uranium and uranium compounds deposited in the soil because of the very long radioactive lifetime for decay of uranium. Furthermore, soluble uranium compounds could permeate into surface and ground water and be dispersed into plants and drinking water. Human exposure to radiation from these uranium compounds will result in increased cancer and birth defects over time. Estimate of total human casualties for such long-term chronic risks is not possible because of the uncertainty in location of surface contamination and future land use.

Military Defense Capabilities

The city of Isfahan lacks the appropriate air defense systems to protect the inhabitants against a sophisticated U.S. or Israeli air assault. Russia's decision to cancel its deal to supply S-300 ground-to-air missiles to Iran leaves Isfahan largely exposed to U.S. or Israeli military strikes. According to Cordesman, Iran's Air Defense System "has become largely obsolescent" and Iran "lacks the modern weapons systems, integration and C41 Battle Management"[98] to reduce the potential destructive effectiveness of any offensive interdiction missions.[99]

Isfahan's air defense system consists of no more than five F-E and SU-24.[100] There are two HAWK sites and one HQ-2 site in the vicinity of Isfahan. One of the HAWK sites and the S-200 site are located on the grounds of the Isfahan AB, with the HAWK site likely situated to provide point defense of the airbase. The HQ-2 site and the remaining HAWK site are located south of Isfahan proper.[101]

What this means in practice is that the Islamic Republic has very limited air defense capabilities to shield Isfahan's nuclear facility.

97 RESRAD is a computer code developed by the U.S. Department of Energy to evaluate human health and ecological risks resulting from residual radioactive and chemical contamination. The RESRAD code has been widely used in the United States and abroad for assessing environmental radiation risks.

98 Note: C41 command, control, computing, communications and intelligence systems are crucial to protection of Iran's nuclear facilities:
Anthony Cordesman and Abdullah Toukan, "Study on a Possible Israeli Strike on Iran's Nuclear Development Facilities," Center for Strategic and International Studies Report, 14 March 2009, <http://csis.org/publication/study-possible-israeli-strike-irans-nuclear-development-facilities>.

99 Arleigh A. Burke and Anthony Cordesman, "Israeli and US Strikes on Iran: A Speculative Analysis," a Center for Strategic and International Studies study working draft as of 5 March 2007, <http://csis.org/files/media/csis/pubs/070305_iran_Israelius.pdf>.

100 Cordesman and Abdullah Toukan, "Study on a Possible Israeli Strike on Iran's Nuclear Development Facilities," Center for Strategic and International Studies, 14 March 2009: 77.

101 Sean O'Connor, "Strategic Sam Deployment in Iran," 2009, http://www.ausairpower.net/APA-Iran-SAMDeployment.html; AND "Iran Military Guide," <http://www.globalsecurity.org/military/world/iran/index.html>.

The Iranian air force cannot defend or repel an air strike. The U.S. and Israeli air force can elude Iran's limited early warning systems and, thus, there will not be sufficient time to evacuate the workers, scientists, and engineers at the sites.

Civil Defense and Emergency Response Capabilities

Civil defense and emergency response capabilities are crucial to mitigating casualties in the immediate prelude and aftermath of military attacks. Preparedness, whether in the form of early warning systems, rapid evacuation, timely medical intervention, and basic protective measures can reduce the risks of exposure to toxic plumes and radiation.

Isfahan's civil defense capabilities are among the best in Iran. Isfahan province has been designated as the province that would handle the city of Tehran in the aftermath of a major earthquake. Isfahan Province Crisis Management Council (IPCNC) has the provincial and military logistics, infrastructure, funding and human resources, and thus a higher capacity than most other provinces to respond to emergencies.

Nevertheless, Isfahan lacks the specialized capability needed to cope with the consequences of a military attack on nuclear sites. The total crisis management budget of Isfahan province is around $20 million.[102] The city of Isfahan's budget for emergency response is $6 million.[103] Neither the city nor the province has the experience, resources, logistics, infrastructure, budget, or even emergency response plans, procedures and equipment necessary for detecting or responding to nuclear accidents, let alone to military strikes against nuclear facilities.

Responding to attacks on nuclear facilities requires a high level of planning, coordination, and communication. Securing the sites requires an established command and control structure capable of coordinating military, medical, logistics, and communications aspects of operations. Without that training and preparation, it is highly likely that the first response teams themselves would be exposed to concentrated and dangerous levels of poisonous gases that would be fatal. Yet, there is no evidence that the Iranian government has provided the military, Revolutionary Guards, and local officials with adequate information, funding, equipment, training, and medical resources necessary for detection, evacuation, and treatment of exposed populations and areas surrounding Iran's nuclear facilities.

Medical Capabilities

Strikes would also trigger an immediate and massive medical emergency with casualties in the tens of thousands. Based on the best available information, there are 26 hospitals in Isfahan with about 5,200 hospital beds,[104] many of which are already occupied. These hospitals would in all likelihood be overwhelmed with tens of thousands of casualties in the immediate aftermath of an attack. They would also be flooded with non-injured people worried about being contaminated by radiation, as was the case after the Goiânia Incident in Brazil when a medical radioactive source containing Cs-137 was opened.[105] There is no evidence that the government at the national or local level has taken the necessary precautions to train, treat, and supply these medical hubs for the specific medical problems of mass exposure to toxic clouds.

Public Awareness

Educating the public about the dangers of radiation and contamination can reduce the risks of exposure in the event of strikes against Iran's nuclear facilities. Although in certain instances, such as Bushehr, the government has sought to relocate local inhabitants or limit development around sites, much more needs to be done to educate the public, particularly those living by the nuclear sites, about defensive measures they can take to protect themselves and their families. These steps include establishing active programs for communicating and protecting civilians: preventing people from swarming around the sites after the strikes, and providing people with timely information about contamination zones, evacuation plans, and safe food and water and building trust in the instructions issued by the government in an emergency.

Remediation Capabilities

Iran's nuclear program is young, and, consequently, there is limited experience with remediation. No technical data is currently available to assess such capability, especially in the case of Isfahan.

Environmental Consequences

Beyond human casualties, the Ayatollah's gamble would degrade the environment and severely damage Isfahan's economy, agriculture, industry and culture. With the high likelihood of soluble uranium compounds permeating into the groundwater, strikes would wreak havoc on Isfahan's environmental resources and agriculture. The Markazi water basin, one of six main catchment areas, which covers half the country (52%), provides slightly less than one-third of Iran's total renewable water (29%) (Figure 26). According to the Food and Agriculture Organization (FAO), the groundwater discharge in the basin from approximately 155,000 wells, 22,000 channels and 13,500 springs is the primary water source for agricultural and residential uses.[106] It is almost certain that the contamination of groundwater as a result of strikes would damage this important fresh-water source.

102 Isfahan budgetary and fiscal information available at <http://www.hoshdaresf.ir/?id=8445>(Persian).

103 Ibid.

104 <http://mihanfa.com/culture-art/introduction-of-hospital/>, <http://www.tebyan.net/newindex.aspx?pid=21821>.

105 Lisa W. Foderaro, "Columbia Scientists Prepare for a Threat: A Dirty Bomb," New York Times, 8 July 2010.

106 "Iran water report," Food and Agriculture Organization of the United Nations (report 34), 2009, <http://www.fao.org/nr/water/aquastat/countries/iran/tables.pdf#tab2>.

Figure 26: Major basins in Iran (Source: United Nations Food and Agriculture Organization)

Given that Isfahan's nuclear facilities are only 5 km (3.1 miles) away from many existing water wells along the Zayandeh Rud river basin, this uranium could spread quite extensively across miles of urban and industrial hubs as well as arable land along Zayandeh Rud and Isfahan's eastern districts. The introduction of contaminants would have profound ramifications not only for the security and safety of Isfahan's water supply but also for the water and food supply of the entire region, including the rural and agricultural backbone of the province.

Isfahan, like much of the Iranian plateau, is arid and semi-arid, with low precipitation ranging from 0 to 19.6 millimeters per month. Management of its water resources is vital to its economy, agriculture, and urban geography. According to Dr. Habib Borjian, of the 10.7 million hectares of surface area of the province, only 600,000 hectares are arable. In 2002, 535,000 hectares were under cultivation, of which 263,000 hectares were under cultivation for irrigated annual crops, with orchards accounting for 56,000 hectares.[107]

Should agricultural products be contaminated, or even be perceived as contaminated though they are safe, as was the case with produce from Fukushima, Japan and Goiânia, Brazil, the region's fruit and vegetable markets would be devastated for years to come.[108] In addition to the major loss from the contamination of agricultural crops, there would also be an impact on orchards and farms, and thus the apples, pears, apricots, and peaches, as well as the quinces and melons that give Isfahan its flavor. Should the river remain dry, as it has been in recent years, then the contamination of the river bed is highly likely, with problems exacerbated once the water flow resumes.

To gain some sense of the scale of the economic damage, it is important to recognize the district of Isfahan proper ranks as the second most important industrialized region in Iran, after Tehran.[109] The distribution of economic and industrial activity in the province of Isfahan is focused around an 80-km (49.7 miles) radius of the city of Isfahan, where the bulk of the province's industrial agglomerations are located. Tourism would also suffer immensely. In 2010, the total number of domestic tourists to Isfahan was more than 300,000 with more than 50,000 foreign tourists from European, Scandinavian, and Asian countries.[110] Once Isfahan is perceived as a contaminated city, and a potential health hazard to visitors, the city would cease attracting tourists. Hundreds of millions of dollars of revenue from tourism would be lost in the wake of strikes.

Cultural and Historic Consequences

Figure 27: Isfahan: Masjid-i Shah (Photo: esential-architecture.com)

Isfahan is one of Iran's cultural and historic jewels. Indeed, the center of the city, built by the Safavid King Shah Abbas, has been designated as a world heritage site by UNESCO.[111] Justifying the decision to protect Isfahan as a World Heritage site (Figure 27), UNESCO cited the site's authenticity and integrity:

"Monuments, buildings and spaces that constitute this complex might individually be losers in a competition with unique world heritage properties, but are unrivaled in the world as an ensemble! Thus it requires to be included as a World Heritage site in order to make rehabilitation policies and programs realized."[112]

In addition to the architectural splendor of its city center, there are more than 20,000 historical and cultural sites in Isfahan. An attack on Iran's nuclear facilities would destroy a city and a tradition that have been integral to Iran's history and heritage for centuries. The city would be covered under a toxic and radioactive shroud that would render it unlivable. The price of such a loss amounts to the stripping away of the Iranian people's historic, religious, and cultural identity.

Instead of opening up Iran to the world so that millions could benefit from the cultural and artistic flowering of Iranian civilization, the Ayatollah's nuclear gamble threatens to transform Isfahan, one of the marvels of human civilization, into a nuclear and chemical wasteland.

107 Habib Borjian, "Isfahan, Modern Economy and Industries," Encyclopedia Iranica, Vol. 14, 2007, <http://www.iranicaonline.org/articles/isfahan-xiv-modern-economy-and-industries>.

108 L. David Roper & Marco Antônio Sperb Leite, "The Goiânia Radiation Incident: A Failure of Science and Society," Veneer Magazine, No. 01/18
See also: John S. Petterson, Ph.D., "From Perception to Reality: The Goiânia Socio-economic Impact Model," Waste Management Symposia Papers, 1988: 3

109 Ibid.

110 "Isfahan,tourist figures" available at <http://www.isfahancht.ir/Fa.aspx?p=5&aiuid=95091157-5479-4geO-bd51-e7b6d57eOOed>(Persian).

111 "Historic-Natural Axis of Isfahan City," UNESCO, 2007, http://whc.unesco.org/en/tentativelists/5176/.

112 Ibid.